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The use of soybean milk in soft cheese making

II. Organoleptic and chemical properties of Domiati cheese made from a mixture of soybean milk and whole milk

N. H. METWALLI, S. I. SHALABI, A. S. ZAHRAN
AND O. EL-DEMERDASH

Summary

A method for making Domiati cheese (soft cheese) from a mixture of soybean milk and whole milk has been reconstructed. The results obtained showed some important differences in cheese characteristics as the result of using soybean milk, particularly in the higher moisture, soluble nitrogen and acidity contents. The main organoleptic property affected by the soymilk was the flavour. This improved on ripening.

A number of changes were observed during ripening. The presence of soymilk resulted in (1) less loss of cheese moisture and consequently cheese weight, (2) increase in the development of titratable acidity and (3) increase in protein breakdown.

It is suggested that the soybean milk activates the lactic acid, producing bacteria and the proteolytic enzymes present in cheese.

Introduction

The composition and properties of cheese depend on the method of making, composition of milk and previous treatments of milk (Price, 1927; Carbone, 1953; Sharara, 1961; Davis, 1965).

In our previous paper (Metwalli *et al.*, 1982) we demonstrated that soybean milk can be used for cheese making if mixed with milk to a ratio of 1 : 4 and if calcium chloride is added and the pH is lowered to 5.5. In this study an attempt has been made to make Domiati cheese from a mixture of soybean milk and

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whole milk. The cheese is a simple type of soft cheese and easy to pepare on a pilot plant scale. The cheese can be ready for consumption after preparation (fresh) or after ripening (pickling) in brine solution or salted whey, which is a relatively simple type of ripening. The results could provide a simple example of the influence of soybean milk on cheese characteristics before, and during, ripening.

In Egypt, like most underdeveloped countries, cheese is an important contribution to diet, as a source of protein, calories, minerals and some vitamins. Milk is therefore much in demand, so any attempt to replace part of the milk with soybean milk in cheese making would be of great economical interest.

Materials and methods

Milk supply

Soybean milk was prepared from soaked beans (soymilk I) or from soyflour (soymilk II) as previously described by us (Metwalli *et al.*, 1982). The milk samples were a mixture of equal parts of cow's and buffalo's milk, mixed with soymilk to a ratio of 4 : 1. The chemical composition of the mixture used for cheese making is shown in Table 1, which demonstrates that addition of soymilk had little effect on milk composition except to increase the titratable acidity.

Table 1. Chemical composition of milk and soymilk mixture

Product	Titratable acidity (%)	pH	Fat (%)	Total protein (%)	Casein (%)	Total solids (%)
Milk	0.17	6.48	5.58	3.69	2.95	13.87
Milk + soymilk I	0.18	6.20	4.93	3.59	2.16	12.85
Milk + soymilk II	0.19	6.17	4.93	3.29	2.10	12.78

Cheese manufacturing

Domiati cheese is simply manufactured by addition of rennet to salted or unsalted milk to produce a curd. Preliminary trials showed that the presence of soybean milk resulted in a poor curd syneresis. The following steps were found to be essential to enhance whey drainage.

The soybean milk (soymilk I or II) was first autoclaved at 120°C for 15 min, cooled and mixed with milk in a double-jacketed cheese vat at a ratio of 1 : 4 to make 30 litres. Calcium chloride (0·02%) was added and the pH of the mixture adjusted to 5.5 using 10% HC. The mixture was warmed to 37°C, then 45 ml of calf rennet was added to it, and it was left standing for 1 hr to complete clotting. The curd was then cut into small cubes with American knives. The temperature

was raised to 40°C and the curd cubes were gently hand-stirred for 20 min. They were then ladled into 40 cm^3 wooden moulds lined with cheese-cloth. The curd was allowed to drain for 30 min, after which it was wrapped in the cheese-cloth and covered with a board. A weight of about 50% of the curd weight was placed on it and left for 1 hr. The curd was then cut into cubes, weighed and stored at 5°C for analysis. Cheeses were made in triplicate and, as the results showed no trends, they were averaged.

Pickling (ripening)

Pickling was conducted by canning about 450 g of cheese in cans of 900 g capacity, filled with 500 ml of 15 or 20% brine solution. The cans were sealed by hand-seaming and stored at 25°C. Samples were taken after 1, 2, 3 and 4 months for analysis.

Analytical methods

The methods used for the estimation of moisture, titratable acidity, fat, protein and NaCl contents were as described by Ling (1956). Amino acid analysis was made by paper chromatography.

Organoleptic test

In addition to the chemical analysis an organoleptic examination was made. The panel consisted of fifty people to give a representative sample of consumers. A total of 100 points was awarded (5 for appearance, 10 for colour, 35 for body and texture and 50 for flavour).

Results and discussion

Compositional quality of fresh cheese

The data in Table 2 represent the cheese yields, acidity, moisture content, fat content and nitrogen content of Domiati cheese, made either from whole milk (control cheese) or from a mixture with soymilk I or II. The results show that the yield of the cheese made from whole milk and soymilk I (from soaked beans)

Table 2. Chemical composition of fresh unsalted Domiati cheese with and without soymilk

Cheese made from	Yield (%)	Titratable acidity (%)	Moisture (%)	Fat (D.M.)	Total nitrogen (D.M.)	Soluble nitrogen (D.M.)
Whole milk (control)	18.36	0.30	53.45	59.27	5.74	0.70
Milk + soymilk I	18.17	0.42	57.71	53.36	5.73	0.88
Milk + soymilk II	16.78	0.41	57.33	56.05	5.70	0.94

mixture was slightly less than that made from whole milk. With soybean II (from soyflour), the cheese yields were considerably less, compared with those of the control cheese or those of soymilk I. This suggests that the method of preparing soymilk may affect the property of the extracted soybean proteins and so, the cheese yield.

The chemical composition showed that acidity and moisture contents of cheeses made from soymilk and whole milk mixture were higher than in the control cheese (from whole milk). The data for fat content on a dry matter basis showed a higher percentage in whole-milk cheese than that of soymilk, apparently due to the dilution effect of soymilk (Table 1). On the other hand the total nitrogen content of the three cheeses were almost the same. The soluble nitrogen content was higher in cheeses containing soymilk than that of whole-milk cheese, with a higher percentage in soymilk II cheese. This was expected as the majority of soymilk proteins are soluble in water (Wolf, 1972).

From the amino acid analysis (Table 3) a small difference was apparent between the three cheeses in their amino acid composition. Such differences are mainly caused by the difference in the amino acid composition of the milks (Metwalli *et al.*, 1982). Cheeses with soymilk have less lysine, asparagine, proline, tyrosine, methionine and leucine. However, the essential/total amino acid ratio was almost the same in the three cheeses.

Table 3. Amino acid composition of fresh cheeses

Amino acid	Control cheese (g/100 g protein)	Cheese from soymilk I (g/100 g protein)	Cheese from soymilk II (g/100 g protein)
Cystine + cysteine	0.03	0.04	0.03
Lysine	8.40	7.40	7.00
Histidine	2.50	2.10	2.05
Arginine	3.10	3.00	2.90
Asparagine	7.10	3.60	3.70
Serine	5.92	5.91	5.01
Glutamic acid	20.11	20.08	17.96
Threonine	3.20	3.11	3.24
Alanine	3.90	3.27	2.25
Proline	9.00	6.40	4.09
Tyrosine	5.80	4.70	4.80
Methionine	2.70	1.20	1.98
Valine	5.40	4.30	5.06
Phenylalanine	3.90	3.80	3.30
Leucine and isoleucine	16.70	14.03	12.70
Total	97.76	82.94	76.07
Essential	45.90	38.94	38.23
Essential/total	0.47	0.47	0.50

Organoleptic test revealed that although the cheeses were similar in appearance and texture, cheeses with soymilk failed to get the acceptance of the panel because of the clearly observed nutty flavour and a slight-brownish colour. Obviously there is a need to devise a method for producing soymilk without this flavour. Most of the methods described in the literature for the improvement of soymilk flavour involve the use of additives (Kiykoman Syoyuco Ltd, 1973; Ferrerira & Shirose, 1975), which have limited application for soymilk.

Changes during ripening (pickling)

Results in Fig. 1a demonstrate that the cheeses show a considerable weight loss during ripening. The weight loss was at the maximum during the first month and subsequently increased gradually. This loss was less with cheeses containing soymilk. The weight loss has been attributed mainly to the loss of moisture (Fahmi & Sharara, 1950; Davis, 1965; Noomen, 1977). The uptake of salt and the increase in cheese acidity, which affect the loss of moisture, are the

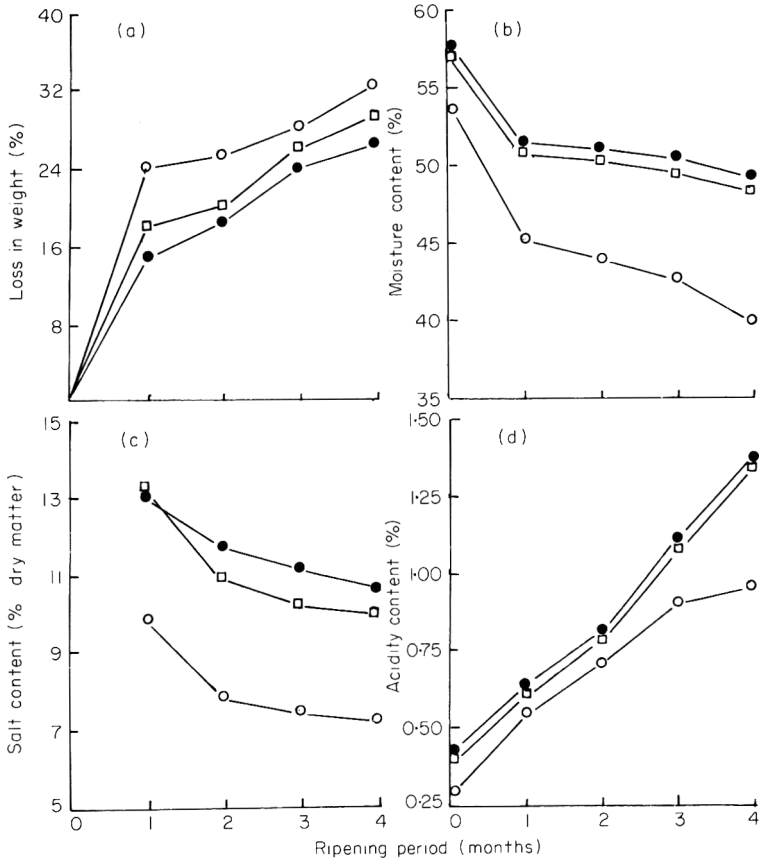

Figure 1. Changes in (a) cheese weight, (b) moisture content, (c) salt content, (d) acidity content during ripening.
(O) cheese control, (●) cheese with soymilk I, (□) cheese with soymilk II.

additional factors responsible for the decrease in weight as the ripening proceeds (Noomen, 1977).

Figure 1b shows that a pronounced loss of moisture content occurred during the first month of ripening. This loss is caused mainly by the salting of cheese. There is a relation between the inward migration of salt into the cheese and the accompanying transport of water to the outside of the cheese (Geurts, Walstra & Mulder, 1974). A further decrease, but at slower rate, occurred up to the end of the ripening period. On the other hand, cheeses with soymilk showed less moisture loss, possibly due to the differences in moisture tendency between milk and soymilk proteins. As soymilk proteins are more hydrophilic (Noyes, 1969), it would be expected that their presence in cheese curd would increase the water-holding capacity.

The changes of salt content on a dry matter basis at different months of ripening are shown in Fig. 1c. The salt content percentage after 1 month was 9.96, 13.01 and 13.09 for the control and soymilk I and II cheeses respectively. It seems that soymilk cheeses absorb a higher proportion of salt, probably because of the higher moisture content. Cheeses during ripening in brine conform with the 'Donnan equilibrium' which controls the partition of ions between the curd and the brine (Mansour & Alais, 1972). This would explain the observed decreases in salt content after 1 month.

The rate of development of cheese acidity (titratable acidity) during ripening is shown in Fig. 1d. The results demonstrate a gradual increase in cheese acidity up to the end of the ripening period, and is more observed with cheeses containing soymilk. The development of acidity is caused by the production of lactic acid, free fatty acids and amino acids as a result of the breakdown of carbohydrates, fat and proteins. The production of lactic acid plays a major part in the acidity increase of soft cheese (Sharara, 1959; Noomen, 1977). However, El-Safty, Korshid & Ismail (1979) demonstrated that adding soymilk to buffalo's milk increases the lipase activity in Ras cheese. In this laboratory we have observed that mixing soymilk with raw milk reduces the keeping quality of raw milk even under cold storage. The milk clotted after 48 hr due to the drop in the pH to 4.6. So, it seems probable that the presence of soymilk in cheese curd activates the lactic acid producing bacteria.

The changes in fat and nitrogen content on a dry matter basis during ripening are shown in Table 4. The data show a noticeable drop in fat content during the first month followed by a gradual increase. This change could be attributed in part to the uptake of salt, as well as breakdown of fat and the continuous loss of the degraded components of cheese into the brine.

A gradual decrease was observed in the total nitrogen content (TN) up to the end of the ripening period, but the soluble-nitrogen content (SN) showed a considerable increase throughout. On calculating the percentage SN/TN it can be seen that cheeses with soymilk have the higher values. The percentage decrease in micellar nitrogen (TN–SN) is higher with cheese containing soymilk. In both cases the values after 2 months of ripening were higher with soymilk cheeses than that from whole milk cheese by the end of ripening period. The

Table 4. Fat content and nitrogen content of Domiati cheese with and without soymilk ripened in 15% brine

Cheese Sample	Age of cheese (months)	Fat (%)	TN (%)	SN (%)	MN* (%)	SN/TN (%)	Decrease in MN (%)
Whole milk (control)	0	59.27	5.74	0.70	5.04	12.19	0
	1	56.65	4.84	0.94	3.90	19.42	22.61
	2	58.49	4.61	1.23	3.38	26.68	32.93
	3	60.89	4.47	1.38	3.09	30.87	38.69
	4	61.84	4.42	1.42	3.00	31.69	40.04
With soymilk I	0	56.39	5.73	0.88	4.85	15.35	0
	1	55.30	4.85	1.40	3.45	28.86	28.86
	2	56.03	4.84	1.51	2.97	33.70	38.76
	3	57.23	4.42	1.65	2.77	37.33	42.88
	4	58.06	4.34	1.68	2.66	38.70	45.15
With soymilk II	0	56.06	5.76	0.94	4.82	16.31	0
	1	53.43	4.75	1.57	3.18	33.05	34.02
	2	58.81	4.63	1.69	2.94	36.50	39.00
	3	56.34	4.48	1.81	2.67	40.40	44.60
	4	57.43	4.38	1.85	2.53	42.23	47.51

*Micellar nitrogen (total nitrogen–soluble nitrogen)

increase in the percentage SN/TN and the decrease in the percentage of micellar nitrogen is due to the degradation of protein (Noomen, 1977). The results demonstrate that the presence of soymilk enhances cheese ripening. The protein proteolysis is mainly due to the action of rennet (Mabbitt, Chapman & Berridge, 1955; Reiter *et al.*, 1966). As soymilk does not coagulate by rennet action (De Man, Tanaka & Stanley, 1975), it seems likely that the presence of soymilk activates the other proteolytic enzymes present in cheese.

Organoleptic properties during ripening

Results from fresh cheeses have indicated that soymilk cheeses were not acceptable to the tasters due to their nutty flavour. However, the cheese flavour

Table 5. Average score of organoleptic properties of Domiati cheese with and without soymilk ripened in 15% brine

Property (points scale)	1 month			4 months		
	Control cheese	Soymilk I cheese	Soymilk II cheese	Control cheese	Soymilk I cheese	Soymilk II cheese
Appearance (5)	4	4	4	4	4	4
Colour (10)	9	7	8	9	8	8
Body and texture (35)	29	28	27	30	31	30
Flavour (50)	39	37	39	40	38	39
Total (100)	81	76	78	83	81	81

was greatly improved with ripening. In fact the cheese was ready for consumption after 1 month of ripening and was accepted by most of the taste panel. The average scores after 1 month and at the end of ripening period are shown in Table 5. The results show no differences between the cheeses except in colour, which was slightly brown with soymilk cheeses.

The results given were with cheese matured in 15% brine. The results with 20% brine were about the same, so that either concentration is suitable for pickling.

Conclusion

The main aspect of this study is the possibility of replacing some of the milk with soymilk in cheese making to overcome milk shortages in underdeveloped countries.

Soymilk proteins are hydrophilic, which result in poor curd syneresis. The manufacture of satisfactory cheese became possible when additional steps were employed to enhance whey drainage. The method described produced cheeses with satisfactory properties and could possibly be applied to other types of cheese.

The comparison of the chemical composition of cheeses containing soymilk with that of whole milk cheese has demonstrated that the method of preparing soymilk was of critical importance. The most significant effect of the method of preparing soymilk was on cheese yield, as a mixture of soybean milk from soyflour (soymilk II) and whole milk gave the lowest cheese yield. Moisture and soluble nitrogen were the constituents most influenced by the use of soymilk. The moisture and soluble-nitrogen contents were higher in soymilk cheese than in the control cheese.

Organoleptic examination emphasized the importance of developing a method which would yield soymilk with a blank flavour, as fresh cheeses from soymilk failed to get the acceptance of the panel because of the nutty flavour. However, the flavour was greatly improved on ripening, so that cheese pickling is highly recommended.

The most important findings are that the presence of soybean milk reduces the loss in moisture and weight, increases the development of acidity and enhances protein breakdown. It is concluded that the presence of soymilk may activate the lactic acid producing bacteria and the proteolytic enzymes present in the cheese. Further study is needed to clarify this aspect.

Little difference was found between the cheeses in their amino acid content. Thus the use of soybean milk for cheese making has little influence on the nutritive value of the cheese.

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Factors controlling the growth of *Clostridium botulinum* types A and B in pasteurized, cured meats

III. The effect of potassium sorbate

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Summary

The growth of *Clostridium botulinum* types A and B spores, at 10^1 or 10^3 per container, was studied in a pork slurry system containing nitrite (40 μg/g), sodium chloride (2.5, 3.5, 4.5% w/v) sodium isoascorbate (550 μg/g) at varying pH levels, with or without potassium sorbate (0.26% w/v), without heating and after two heat treatments (80°C for 7 min, and 80°C for 7 min + 70°C for 1 hr) followed by storage at 15, 17.5, 20 or 35°C for up to 6 months. At a given spore inoculum, potassium sorbate significantly decreased toxin production, as did increasing NaCl, decreasing pH or decreasing storage temperature. Heat treatment did not significantly affect spoilage or toxin production overall, but interacted significantly with some factors. The effect of sorbate was greater at 3.5% NaCl than at 2.5%, at pH values below 6.0, and at low storage temperature.

Introduction

Sorbic acid and potassium sorbate are firmly established as permitted preservatives of a wide range of manufactured or processed foods (Anon, 1979). Both are listed as 'generally recognized as safe' (GRAS) food additives by the Food and Drug Administration of the U.S.A. (Pierson, Smoot & Stern, 1979; Sofos, Busta & Allen, 1979b) although GRAS status for the use of potassium sorbate in bacon was recently refused (Anon, 1980). The overall safety of potassium sorbate and sorbic acid as food additives is also recognized by WHO at an acceptable daily intake of 0.25 mg/kg body weight (Anon, 1974).

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Sorbic acid is one of a group of organic acids and esters which inhibit yeasts and moulds (Gooding, 1945) and is widely used to inhibit them in fermented foods and pickles (Phillips & Mundt, 1950; Costilow, Ferguson & Ray, 1955; Costilow *et al.*, 1957; Sheneman & Costilow, 1955; Costilow, 1957) and as a preservative in cheese (Smith & Rollin, 1954a, b; Melnick & Luckmann, 1954a, b; Melnick, Luckmann & Gooding, 1954a, b). Sorbic acid has also been added to ice water to retard bacterial growth on live crawfish and freshly killed, dressed chickens (Kaloyereas, Crown & McClasky, 1961). A potassium sorbate dip significantly reduced the growth of bacteria on poultry pieces (Robach & Ivey, 1978), and potassium sorbate also delayed growth of *Vibrio parahaemolyticus* in laboratory media and crab meat and flounder homogenate (Robach & Hickey, 1978).

Early work (Emard & Vaughn, 1952; York & Vaughn, 1954; 1955) showed that clostridia, in particular *Clostridium botulinum,* grew in laboratory medium in the presence of sorbic acid and its use as a preservative in meat products has consequently been very restricted. The possible use of sorbates to inhibit mould spoilage of meats prompted Tompkin *et al.* (1974) to study the effect of potassium sorbate on the growth of food-borne pathogens in cooked sausage where 0.1% delayed growth of the normal spoilage flora for 1 day. Growth of salmonellae (five species) was markedly retarded as was growth and toxin production of *Cl. botulinum.* The decline of *Cl. perfringens* to undetectable levels was unrelated to the presence of potassium sorbate. This partial inhibition of *Cl. botulinum* by potassium sorbate/sorbic acid in a meat product prompted further experiments in the U.S.A. (Ivey *et al.*, 1978; Ivey & Robach, 1978; Sofos *et al.*, 1979b, d) to determine its effect on *Cl. botulinum* in cured meat with a view to replacing some, or all of the added nitrite with potassium sorbate. A reduction in the amount of nitrite ingested was deemed desirable to reduce further the possibility of nitrosamine formation from reaction between nitrite and secondary or tertiary amines, which may be present in the stomach.

The overall conclusions were that combinations of 'low' nitrite (40μg/g) plus sorbate/sorbic acid controlled the growth of *Cl. botulinum* as effectively as the level of nitrite (156 μg/g) presently used in the U.S.A. The low level of nitrite (40 μg/g) had no significant effect on the growth of *Cl. botulinum,* but was included to ensure acceptable cured colour and flavour. These experiments were thoroughly reviewed by Sofos, Busta and Allen (1979a) and further work has subsequently been published (Sofos, Busta & Allen, 1979c, 1980a; Sofos *et al.*, 1980b; Shaver, 1979; Robach *et al.*, 1980).

In the U.S.A. curing brines commonly contain isoascorbic (erythorbic) acid (Tompkin, Christiansen & Shaparis, 1978). In the U.K. ascorbic acid (or its sodium or calcium salt) is permitted only as an antioxidant (Antioxidant in Food Regulations, 1978) but is quite commonly included in pasteurized hams to accelerate and stabilize cure colour. The use of isoascorbic acid as an antioxidant was reviewed in 1964 (Food Standards Committee, 1964) but as ascorbic acid was already permitted its use was not recommended.

Following the above claims we have attempted to test, over a wider range of conditions than the U.S. workers, whether potassium sorbate in combination with 40 μg/g nitrite was an effective inhibitor of growth of *Cl. botulinum* in a pork slurry system used previously (Roberts, Gibson & Robinson; 1981a, b, c). Although isoascorbate is not a permitted food additive in the U.K. it was selected to facilitate comparison with U.S. work, since there is no evidence that isoascorbate differs from ascorbate with respect to its effect on the growth of *Cl. botulinum.*

Materials and methods

Details of the meat slurry system, spore inocula, heat treatment, toxin tests and chemical analyses were described by Roberts *et al.*, (1981a, b).

Experimental plan

The factors studied were:

NaCl (% w/v on water)	2.5, 3.5, 4.5
$NaNO_2$ (μg/g slurry)	40
Sodium isoascorbate (μg/g slurry)	550
Potassium sorbate (% w/v slurry)	0, 0.26
Inoculum (spores per bottle)	10, 1000
Heat treatment	0, 80°C/7 min (LOW), 80°C/7 min +70°C/1 hr (HIGH)
Storage temperature (°C)	15, 17.5, 20, 35
Initial pH of meat (approx.)	5.8, 6.4

Table 1. List of slurries prepared including chemical analysis immediately after preparation

Slurry No.	pH value	NaCl (% w/v water) Added	NaCl (% w/v water) Detected	Nitrite (μg/g) Added	Nitrite (μg/g) Detected	Isoascorbate (μg/g) (Added)	Sorbate (% w/v) (Added)	Fat (%)	H_2O (%)
	HIGH								
165	6.56	2.5	2.05	40	29	550	0	0.70	90.22
166	6.49	2.5	1.95	40	28	550	0.26	0.61	89.28
167	6.40	3.5	3.67	40	34	550	0	0.85	86.83
168	6.45	3.5	2.97	40	28	550	0.26	0.73	88.22
175	6.46	4.5	4.19	40	24	550	0	0.74	86.00
174	6.49	4.5	3.65	40	7	550	0.26	0.56	88.77
	LOW								
169	5.76	2.5	2.42	40	12	550	0	1.14	87.30
170	5.82	2.5	2.23	40	3	550	0.26	1.12	87.27
171	5.80	3.5	3.13	40	35	550	0	0.97	86.94
172	5.85	3.5	3.15	40	34	550	0.26	1.01	86.44
178	5.80	4.5	3.62	40	26	550	0	1.02	86.40
177	5.70	4.5	3.10	40	26	550	0.26	1.10	85.83

A complete list of slurries prepared is shown in Table 1. Bottles were examined during storage for spoilage indicative of growth of *Cl. botulinum*, spoilage being assessed on a scale of 1–5 (Roberts *et al.*, 1981a). Toxin tests were carried out on samples reaching a score of 5 and on all bottles remaining after 6 months storage, irrespective of the extent of spoilage.

Data collecting and processing

Spoilage data were reduced into a form suitable for analysis of variance on the 'area under the mean step function' (Roberts *et al.*, 1981a).

Logistic regression

The proportion of samples containing toxin (p) within each treatment combination was calculated for use in a logistic regression. A logistic model was used to describe the relationship between the probability of toxin production and the level of factors/variables present (e.g. salt, temperature, sorbate etc.). The probability of a proportion of samples containing toxin at a given treatment combination of factors/variables is modelled by the following equation:

$$p = \frac{1}{(1+e^{-\mu})},$$

where $\mu = (\text{constant} + \beta_{\text{salt}} \times [\text{salt level}] + \beta_{\text{sorbate}} \times [\text{sorbate}] + \ldots)$ (Roberts *et al.*, 1981c).

In this equation μ is termed the linear predictor and may include interactions between factors. The βs are obtained by maximum likelihood, i.e. since the probability of obtaining the data is a function of the data itself and the βs in the linear predictor, the values of β are chosen to make this probability as great as possible.

Analysis of deviance

The process of model fitting was initiated by including the constant term only in the above equation and progressed by including one extra term at a time, each of which was retained only if the reduction in unexplained variation (residual deviance) of the data was significant, e.g. try a linear term in salt first, and fit the model:

$$p\ (\text{toxin production}) = \frac{1}{1+e^{-(C+\beta_{\text{salt}} \times [\text{salt level}])}}.$$

Since the inclusion of the term for salt resulted in a significant reduction of the unexplained variation, the term was retained and a second term (e.g. sorbate) was fitted:

$$p\ (\text{toxin production}) = \frac{1}{1+e^{-(C+\beta_{\text{salt}} \times [\text{salt level}] + \beta_{\text{sorbate}} [\text{sorbate}])}}.$$

This process was continued until no further reduction in unexplained variation occurred.

Results

Examples of the spoilage and toxin data accumulated after 6 months' storage are presented in Tables 2 and 3 (Full data are stored on magnetic tape, prepared using an ICL System 4 computer. Copies will be made available, on request, at cost of tape+handling).

Spoilage data

Analysis of variance revealed that the most significant main effects were storage temperature and pH, with inoculum level, salt concentration and potassium sorbate also statistically significant, but smaller. Heat treatment was not a significant factor controlling spoilage. There were several significant two- and three-factor interactions. The factors and interactions significantly affecting spoilage are summarized in Table 4 and discussed below.

Single factors controlling spoilage: (Table 5) Decreasing storage temperature, or initial pH, or inoculum level or adding potassium sorbate (0.26%) all significantly decreased spoilage. Increasing salt from a calculated 2.5–3.5% also decreased spoilage but increasing salt to 4.5% did not reduce spoilage further (NB: The levels of salt used in the analysis of variance [2.5, 3.5, 4.5%] were values calculated from the amount of salt and water added to the meat. Chemical analysis of slurries after preparation (see Table 1) revealed that the target salt level of 4.5% was not achieved, an in most cases those salt concentrations were nearer 3.5%. The salt levels referred to in this paper are nominal levels [i.e. 2.5, 3.5, 4.5%] unless otherwise stated). Since increasing heat treatment from 0 to LOW or to HIGH did not significantly affect spoilage, these results seem relevant to unheated as well as pasteurized cured meats.

Two-factor interactions: (Table 6) Storage temperature was a highly significant factor and at high storage temperatures there was significantly more spoilage at high inoculum levels and with 'high' initial pH.

Although heat treatment was not significant overall, it interacted with sorbate and, in the presence of sorbate, heating (either LOW or HIGH) significantly increased spoilage. At 'high' initial pH, adding sorbate did not significantly reduce spoilage.

Many interactions involving salt were significant because spoilage at 4.5% salt was not significantly less than at 3.5%, possibly the result of discrepancies between the nominal and analysed salt levels. The interation between salt and pH was significant because at 'low' initial pH increasing salt from 3.5 to 4.5% significantly increased spoilage. At high storage temperatures (35°C) increasing salt from 3.5 to 4.5% significantly increased spoilage.

Three-factor interactions: These were small compared with the single main effects. Many involved salt and were significant because the 4.5% salt level did not always result in significantly less spoilage than 3.5% salt.

Table 2. Example of spoilage data accumulated after 6 months' storage. Five replicates per treatment combination, unheated slurry

Slurry No.	NaCl (% on water)	$NaNO_2$ (μg/g)	Sodium isoascorbate (μg/g)	Potassium sorbate (% w/v)	*15										17.5										20										35									
					†10^1					10^3					10^1					10^3					10^1					10^3					10^1					10^3				
					‡1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
		HIGH pH																																										
165	2.5	40	550	0			§5					§5					§1		4					§5				§5							§5				§5				§5
166	2.5	40	550	0.26		5						5					4	1						5				5					1	1	3							5
167	3.5	40	550	0		5					5						5					5					4	1			2		3					5				5
168	3.5	40	550	0.26		5					5					4	1					1	2	1	1				5			3		2					5				5
175	4.5	40	550	0		5					5					5						5					3	2					3	2					5				5
174	4.5	40	550	0.26		5					5					4	1					4	1			3	2					5							5				5
		LOW pH																																									
169	2.5	40	550	0		5					5						4	1						4	1			4	1			1		4				2		3			5
170	2.5	40	550	0.26		3	2				5					2	3					5				2		3			2	3					5				5
171	3.5	40	550	0			5			5						5							5				4	1					5				4	1				5
172	3.5	40	550	0.26	3	2					5					5						4	1			5				3			2				5			5		
178	4.5	40	550	0	5					5					5					5						4	1				5				5						5	
177	4.5	40	550	0.26		5				4	1					5					5						5				5				5					5		

*Storage temperature (°C)
†Inoculum (spores per bottle)
‡Spoilage score
§Number of replicates at each spoilage score

Table 3. Example of toxin data accumulated after 6 months' storage. Five replicates per treatment combination, unheated slurry

Slurry No.	NaCl (% on water)	$NaNO_2$ ($\mu g/g$)	Sodium isoascorbate ($\mu g/g$)	Potassium sorbate (% w/v)	*15										17.5										20										35									
					†10^1					10^3					10^1					10^3					10^1					10^3					10^1					10^3				
					‡1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
		HIGH pH																																										
165	2.5	40	550	0			§5					§5					§1		4					§5				§5							§5							§5	
166	2.5	40	550	0.26		0						5					4	1						5				5						1	0	3					5	
167	3.5	40	550	0		1					5						5					5					4	1		2		3			5					5	
168	3.5	40	550	0.26		0					0				0	1					1	2	1	1				5			3		2			5					5	
175	4.5	40	550	0		1					1				1						5					3	2				3	2			5					5	
174	4.5	40	550	0.26		0					0				0	0					0	1			0	1				5					5					5	
		LOW pH																																									
169	2.5	40	550	0		0					1					0	1						4	1			4	1			1		4		0		3				5	
170	2.5	40	550	0.26		0	1				1				0	1					0					0		2			1	3		0						5	
171	3.5	40	550	0			2					5			1							1				0	1					4		0	1						2	
172	3.5	40	550	0.26	0	1					0				0						0	1			0				0			2		0				0				
178	4.5	40	550	0	0					0					0					0					1	1				5					5					5	
177	4.5	40	550	0.26		0				0	0				0					0							0			0				0					5		

*Storage temperature (°C)
†Inoculum (spores/bottle)
‡Spoilage score
§Number of replicates containing toxin at each spoilage score

Table. 4. Summary of factors and interactions significantly affecting spoilage and toxin production in slurries containing sorbate

Spoilage data(analysis of variance)	Toxin data (logistic regression analysis)
inoculum level	inoculum level
initial pH	initial pH
salt	salt
potassium sorbate	potassium sorbate
storage temperature	storage temperature
—	salt×salt (i.e. S^2)
—	temperature×temperature (i.e. T^2)
pH×salt	—
heat×sorbate	heat×sorbate
pH×sorbate	—
pH×storage temperature	pH×storage temperature
salt×storage temperature	salt×storage temperature
—	inoculum×sorbate
—	inoculum×storage temperature
—	pH×heat
heat×pH×salt	—
pH×salt×sorbate	—
inoculum×pH×storage temperature	—
heat×salt×storage temperature	—
pH×salt×storage temperature	—
pH×sorbate×storage temperature	—

Toxin data

The probability of toxin production as modelled by logistic regression analysis is an increasing function of the linear predictor, μ, so that the influence on toxin production of a single factor may be visualized by plotting the linear predictor against that factor.

There was evidence of non-linearity with storage temperature and nominal salt concentration (Figs. 1 & 2). The linear predictor increased steeply with increasing storage temperature from 15°C to 20°C (Fig. 1) but did not increase further at 35°C. In Fig. 2 the linear predictor decreased with increasing (nominal) salt from 2.5 to 3.5%, with little or no further decrease when salt was raised to 4.5%. Since the concentration at nominally 4.5% salt was considerably lower than anticipated, the full logistic regression analysis was repeated using the analytical values for salt concentration in each of the slurries. When this second linear predictor was plotted against salt (Fig. 3) the non-linearity was more pronounced. Comparing the two logistic regression analyses, more of the variation was accounted for with the model using the nominal salt levels. The plot of linear predictor against temperature was also repeated to include a second order term for temperature (temperature^2).

Table 5. Analysis of variance on spoilage data. Effects of individual factors: figures given are the mean of the 'area under the step function' i.e. the smaller the number the less spoilage. (Roberts *et al.* 1981a).

Treatment	Level tested				Number of replicates	Least significant difference (LSD)	
						$P = <0.05$	$P = <0.01$
Sodium chloride	2.5	3.5	4.5				
(% w/v on water)	456.8	367.6	382.6		96	19.42	25.70
Potassium sorbate	0	0.26					
(% w/v)	411.9	392.8			144	15.86	20.98
Inoculum	10	1000					
	383.4	421.3			144	15.86	20.98
Heat treatment	*UH	†LOW	‡HIGH				
	395.7	410.4	401.0		96	19.42	25.70
pH values	§'low'	**'high'					
	344.6	460.1			144	15.86	20.98
Storage temperature	15	17.5	20	35			
	269.0	310.5	393.5	636.5	72	22.66	30.14

*Unheated
†80°C for 7 min
‡80°C for 7 min + 70°C 1 hr
§5.70–5.85
**6.40–6.56
Treatment levels are significantly different when their means differ by more than the LSD.

Table 6. Analysis of variance on spoilage data. Effects of two-factor interactions: figures given are the mean of the 'area under the step function' i.e. the smaller the number the less the spoilage (Roberts *et al.* 1981a)

Treatment	Level tested			Number of replicates	Least significant difference (LSD)	
					$P = <0.05$	$P = <0.01$
Inoculum × heat		10	1000			
	UH	383.7	404.1	48	28.04	37.48
	LOW	392.3	428.5			
	HIGH	370.7	431.2			
Inoculum × pH		10	1000			
	'low'	324.4	364.8	72	22.66	30.14
	'high'	442.4	477.8			
pH × heat		'low'	'high'			
	UH	340.8	450.6	48	28.04	37.48
	LOW	347.5	473.4			
	HIGH	345.6	456.3			

Table 6 *continued*

Treatment	Level tested					Number of replicates	Least significant difference(LSD) $P = <0.05$	Least significant difference(LSD) $P = <0.01$
Sorbate × inoculum		0	0.26					
	10	387.1	379.7			72	22.66	30.14
	1000	436.7	405.9					
Sorbate × pH		0	0.26					
	'low'	365.5	323.7			72	22.66	30.14
	'high'	458.3	461.9					
Sorbate × salt		0	0.26					
	2.5	461.4	452.2			48	28.04	37.48
	3.5	390.5	344.7					
	4.5	383.8	381.5					
Sorbate × heat		0	0.26					
	UH	427.5	363.9			48	28.04	37.48
	LOW	418.4	402.4					
	HIGH	389.8	412.1					
Salt × inoculum		2.5	3.5	4.5				
	10	438.7	343.7	367.9		48	28.04	37.48
	1000	475.0	391.5	397.4				
Salt × pH		2.5	3.5	4.5				
	'low'	389.7	292.3	351.9		48	28.04	37.48
	'high'	524.0	442.9	413.4				
salt × heat treatment		2.5	3.5	4.5				
	UH	444.1	372.7	370.3		32	34.68	46.75
	LOW	462.0	373.8	395.4				
	HIGH	464.4	356.2	382.2				
Storage temperature		15	17.5	20	35			
× inoculum	10	270.5	298.2	372.7	592.2	36	32.36	43.25
	1000	267.4	322.8	414.3	680.7			
Storage temperature		15	17.5	20	35			
× pH	'low'	249.7	275.8	333.6	519.6	36	32.36	43.25
	'high'	288.2	345.5	453.4	753.3			
Storage temperature		15	17.5	20	35			
× sorbate	0	283.4	317.5	399.7	646.9	36	32.36	43.25
	0.26	254.5	303.5	387.3	626.0			
Storage temperature		15	17.5	20	35			
× heat	UH	265.7	284.5	393.9	638.6	24	40.44	59.96
	LOW	268.7	328.9	390.0	654.0			
	HIGH	272.5	318.1	396.6	616.7			
Storage temperature		15	17.5	20	35			
× salt	2.5	282.6	366.7	455.6	722.4	24	40.44	59.96
	3.5	264.2	274.8	382.4	549.0			
	4.5	260.0	290.1	342.5	638.0			

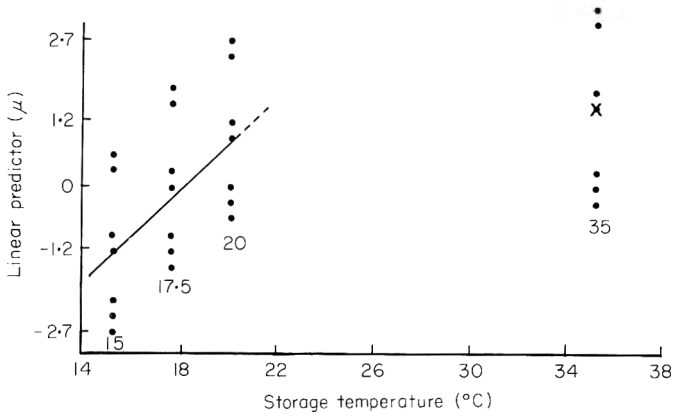

Figure 1. The effect of storage temperature on the linear predictor (μ). **X,** Median point.

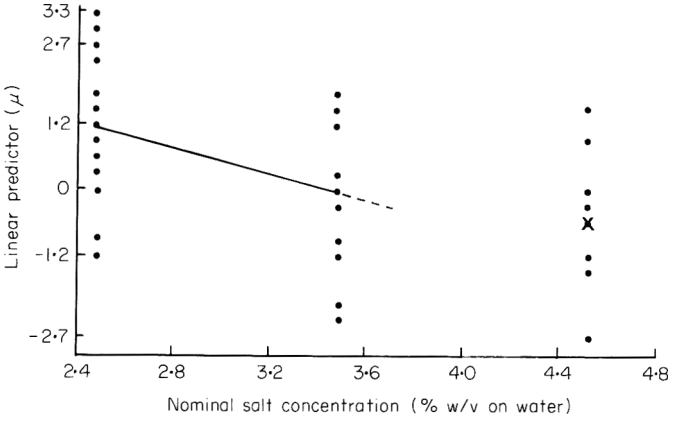

Figure 2. The effect of salt (nominal concentration on the linear predictor (μ). X, Median point.

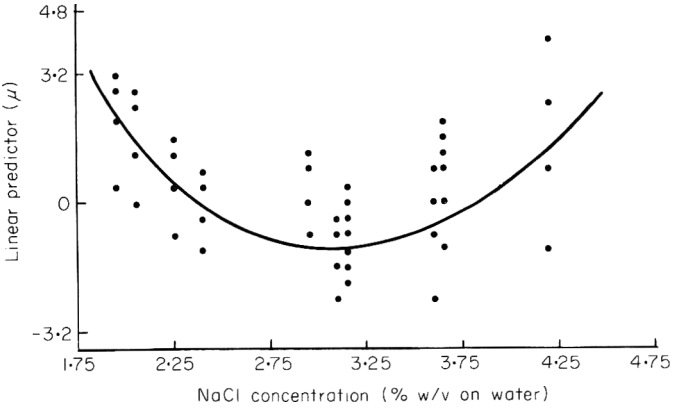

Figure 3. The effect of salt (analysed concentration) on linear predictor (μ).

Although heat treatment was not significant overall, it was included in the model because there were significant higher order interactions involving heat treatment. The final model contained all the main effects including a term for $(\text{salt})^2$ and $(\text{temperature})^2$, plus six of the most significant interactions, and took the form:

$\mu = -11.67$	
$-(6.099 \times S)$	where S = NaCl (% w/v on the water)
$+13.04$	if heat treatment LOW
$+16.69$	if heat treatment HIGH
$+(0.2920 \times T)$	where T = storage temperature (°C)
$+(0.5415)$	if inoculum 10^3
$-(1.783)$	if sorbate (0.26%) present
$+(1.578 \times pH)$	
$-(0.02382 \times T^2)$	
$+(0.5790 \times S^2)$	
$+0.05071 \times S \times T)$	
$+(0.1427 \times pH \times T)$	
$+(0.06272 \times T)$	if inoculum 10^3
$+(0.03758)$	if sorbate present *and* heat treatment LOW
$+(1.091)$	if sorbate present *and* heat treatment HIGH
$-(0.8638)$	if sorbate present *and* inoculum 10^3
$-(2.122 \times pH)$	if heat treatment LOW
$-(2.898 \times pH)$	if heat treatment HIGH

Probabilities of toxin production for all combinations of additives and treatments tested were calculated (Tables 7–12) according to the formula:

$$p = \frac{1}{(1+e^{-\mu})}.$$

In this analysis, pH was treated as a variable and probabilities have been calculated over the pH range 5.7–6.6, at intervals of 0.1 pH units. The pH levels of slurries prepared (Table 1) fell within this range although slurries could not be prepared to a specified pH.

Significant factors and interactions

Heat treatment was the only single factor not significantly affecting toxin production, as was the case in the analyses of variance of the spoilage data. The relative contributions of significant factors controlling toxin production is illustrated by the analysis of deviance in Table 13, where the total deviance (variation) was 1366. Including a term for sorbate in the model reduced the deviance by 110. Similarly, including terms for salt and temperature further reduced the deviance by 80 and 154 respectively. The most significant single factors were pH and storage temperature. Sorbate, salt and inoculum level were also significant, but somewhat less important than pH or storage temperature.

Many of the significant interactions involved storage temperature. The salt×storage temperature interaction may only be significant because 4.5% salt was no more effective than 3.5%. The pH×storage temperature interaction indicated that increasing storage temperature resulted in significantly more toxin production at 'high' pH. Again this interaction was probably only significant because of the large main effects of these two factors. Increasing storage temperature also resulted in significantly more toxin production when the inoculum was 10^3 spores per bottle.

Table 7. Probability (%) of toxin production by *Cl. botulinum* type A and B*, in pork slurry containing 40 μg/g sodium nitrite, 550 μg/g sodium isoascorbate, inoculum 10 spores per bottle

NaCl (% on water)	pH of slurry	potassium sorbate (0.26% w/v)	Unheated				‡LOW heat				‡HIGH heat			
			†15	17.5	20	35	15	17.5	20	35	15	17.5	20	35
2.5	5.7	−§	21	45	66	38	40	67	83	60	34	61	78	53
2.5	5.7	+§	6	17	33	13	15	34	55	28	11	28	48	22
2.5	5.8	−	28	55	74	53	44	71	86	70	36	64	81	62
2.5	5.8	+	9	24	43	23	17	39	60	37	12	31	52	30
2.5	5.9	−	35	64	82	69	48	75	88	78	38	67	83	71
2.5	5.9	+	12	31	53	36	19	43	65	48	13	34	56	38
2.5	6.0	−	44	73	87	81	51	78	90	85	40	69	85	78
2.5	6.0	+	17	40	64	51	21	48	70	59	14	36	59	47
2.5	6.1	−	53	80	91	89	55	81	92	90	42	72	87	84
2.5	6.1	+	22	50	73	67	24	53	75	69	15	39	63	57
2.5	6.2	−	61	85	94	94	59	84	94	93	44	74	89	88
2.5	6.2	+	29	60	80	79	27	57	79	78	17	42	67	66
2.5	6.3	−	69	90	96	97	62	86	95	95	46	77	90	92
2.5	6.3	+	36	69	86	88	30	62	82	84	18	45	70	74
2.5	6.4	−	76	93	97	98	66	88	96	97	48	79	92	94
2.5	6.4	+	45	76	91	93	33	66	85	89	19	48	74	80
2.5	6.5	−	82	95	98	99	69	90	97	98	50	81	93	96
2.5	6.5	+	54	83	94	96	36	70	88	93	20	52	77	86
2.5	6.6	−	87	97	99	100	72	92	97	99	53	83	94	97
2.5	6.6	+	62	88	96	98	40	74	90	95	22	55	79	90

*Inoculum consists of a mixed suspension of equal numbers of spores of five strains of *Cl. botulinum* type A and B.

†Storage temperatures (°C)

‡LOW = heated in water at 80°C for 7 min which raised centre temperature to 70°C; HIGH = heated in water at 80°C for 7 min, plus 70°C for 1 hr.

§ + = Sorbate present at stated level; − = sorbate absent.

The percentage probabilities are rounded to the nearest whole number.

Although heat treatment was not significant overall, it interacted with several other factors: the HIGH heat treatment was significantly more effective at 'high' pH. The addition of sorbate was less effective after HIGH heat treatment, but had a greater effect at the 10^3 inoculum level.

Discussion

This work was initiated, following published claims that sorbate was an effective inhibitor of *Cl. botulinum* in experimental bacons (Ivey *et al.*, 1978) and canned comminuted pork (Ivey & Robach, 1978), to establish whether potassium sorbate also inhibited outgrowth of *Cl. botulinum* in this pork slurry system, which differs in several respects from the canned, comminuted pork above, and chicken-frankfurter emulsions of Sofos *et al.*, (1979d).

Table 8. Probability (%) of toxin production by *Cl. botulinum* type A and B*, in pork slurry containing 40 μg/g sodium nitrite, 550 μg/g sodium isoascorbate, inoculum 10 spores per bottle

NaCl (% on water)	pH of slurry	potassium sorbate (0.26% w/v)	Unheated				‡LOW heat				‡HIGH heat			
			†15	17.5	20	35	15	17.5	20	35	15	17.5	20	35
3.5	5.7	–§	4	13	28	20	10	27	49	39	7	22	42	33
3.5	5.7	+§	1	4	9	6	3	9	20	14	2	7	16	11
3.5	5.8	–	6	18	37	33	11	31	55	50	8	24	46	41
3.5	5.8	+	2	5	13	11	3	10	24	20	2	7	18	15
3.5	5.9	–	8	25	48	48	13	35	60	61	9	26	50	51
3.5	5.9	+	2	8	19	19	4	12	28	28	2	8	20	21
3.5	6.0	–	11	32	58	64	14	39	65	71	9	29	54	60
3.5	6.0	+	3	11	26	31	4	14	32	38	3	9	23	28
3.5	6.1	–	15	41	68	77	16	44	70	79	10	31	58	69
3.5	6.1	+	4	15	35	46	5	17	37	49	3	10	26	36
3.5	6.2	–	20	51	77	87	18	49	75	85	11	34	62	76
3.5	6.2	+	6	21	45	62	5	19	43	60	3	12	29	45
3.5	6.3	–	26	61	83	93	21	53	79	90	12	37	66	82
3.5	6.3	+	8	28	56	76	6	22	48	70	3	13	33	54
3.5	6.4	–	34	70	88	96	23	58	82	93	13	40	69	87
3.5	6.4	+	11	37	66	86	7	26	54	78	4	14	36	63
3.5	6.5	–	42	77	92	98	26	62	85	96	14	43	72	91
3.5	6.5	+	16	46	75	92	8	30	59	85	4	16	40	72
3.5	6.6	–	51	83	95	99	29	67	88	97	15	46	75	94
3.5	6.6	+	21	56	82	96	9	34	65	90	4	18	44	79

Key as for Table 7.

Our results show that the addition of 0.26% sorbate in the presence of 40 μg/g nitrite significantly reduced spoilage and toxin production in pork slurry. The effect was greater at 3.5% salt than 2.5%, at pH values below 6.0, and at low storage temperature. The beneficial effect of sorbate was reduced if 10^3 spores per bottle were used as the inoculum. For example, in a slurry containing 2.5% salt, at pH 5.8, with no heat treatment and inoculated with 10 spores per bottle the predicted probability of toxin production after storage at 15°C was reduced from 28 to 9% by the addition of 0.26% potassium sorbate. If the pH was 6.4, but all other conditions were the same, the addition of 0.26% potassium sorbate reduced the predicted probability of toxin production from 76 to 45% (Table 7). If the inoculum was 10^3 spores per bottle, the predicted probability of toxin production at pH 5.8 was reduced from 62 to 15%, and at pH 6.4 from 93 to 60% when sorbate was added (Tables 7 and 10).

Our results support U.S. claims (Ivey *et al.*, 1978, Ivey & Robach, 1978) that potassium sorbate delayed the growth of *Cl. botulinum* in bacon containing

Table 9. Probability (%) of toxin production by *Cl. botulinum* type A and B*, in pork slurry containing 40 μg/g sodium nitrite, 550 μg/g sodium isoascorbate, inoculum 10 spores per bottle

NaCl (% on water)	pH of slurry	Potassium sorbate (0.26% w/v)	Unheated				‡LOW heat				‡HIGH heat			
			†15	17.5	20	35	15	17.5	20	35	15	17.5	20	35
4.5	5.7	−§	2	8	20	26	5	17	38	47	4	14	32	40
4.5	5.7	+§	1	2	6	8	1	5	14	18	1	4	11	14
4.5	5.8	−	3	11	28	40	6	20	44	58	4	15	35	49
4.5	5.8	+	1	3	9	14	2	6	17	26	1	4	12	20
4.5	5.9	−	4	16	37	56	7	23	49	68	5	17	39	58
4.5	5.9	+	1	4	13	24	2	7	20	35	1	5	14	26
4.5	6.0	−	6	21	47	71	8	27	55	77	5	19	43	67
4.5	6.0	+	2	6	19	38	2	9	24	45	1	6	16	34
4.5	6.1	−	8	29	58	82	9	31	60	84	5	21	47	75
4.5	6.1	+	2	9	26	54	2	10	28	56	1	6	18	43
4.5	6.2	−	11	37	68	90	10	35	65	89	6	23	51	81
4.5	6.2	+	3	13	35	69	3	12	33	67	2	7	21	52
4.5	6.3	−	15	47	76	94	12	39	70	92	6	25	55	86
4.5	6.3	+	4	18	45	81	3	14	38	76	2	8	24	62
4.5	6.4	−	20	56	83	97	13	44	75	95	7	27	59	90
4.5	6.4	+	6	25	56	89	4	17	43	83	2	9	27	70
4.5	6.5	−	27	66	88	98	15	48	79	97	7	30	63	93
4.5	6.5	+	8	33	66	94	4	19	48	88	2	10	30	77
4.5	6.6	−	34	74	92	99	17	53	82	98	8	33	66	95
4.5	6.6	+	12	42	75	97	5	22	54	92	2	11	33	83

Key as for Table 7.

approximately 3.5% salt (on water) and 0 or low (40 μg/g) nitrite, and confirm the greater effectiveness of sorbate at 'low' pH (Sofos *et al.*, 1980a).

The non-linear effect of storage temperature and salt was not apparent in earlier analyses (Roberts *et al.*, 1981a, b, c) and is difficult to interpret. From Fig. 1, the linear predictor rises steeply with increasing storage temperature and peaks between 20 and 35°C, finally falling towards 35°C. Since no intermediate temperatures were studied it is not advisable to estimate the temperature at which the maximum linear predictor occurs, or to use this model to generate probabilities of toxin production between 20 and 35°C. The model is quadratic and generated values of p are heavily dependent on the 35°C data because of the large gap between 20 and 35°C.

The intention of this work was to investigate toxin production at lower storage temperatures rather than to determine the optimum temperature for its production. Hence our inability to define accurately the temperature at which the maximum amount of toxin is produced should not be over-emphasized.

Table 10. Probability (%) of toxin production by *Cl. botulinum* type A and B*, in pork slurry containing 40 μg/g sodium nitrite, 550 μg/g sodium isoascorbate, inoculum 1000 spores per bottle

NaCl (% on water)	pH of slurry	Potassium sorbate (0.26% w/v)	Unheated				‡LOW heat				‡HIGH heat			
			†15	17.5	20	35	15	17.5	20	35	15	17.5	20	35
2.5	5.7	−§	54	81	92	90	74	91	97	96	68	89	95	94
2.5	5.7	+§	11	31	55	50	24	53	75	71	19	46	70	65
2.5	5.8	−	62	86	94	94	77	93	97	97	70	90	96	96
2.5	5.8	+	15	40	65	65	27	58	79	79	21	49	73	73
2.5	5.9	−	70	90	96	97	80	94	98	98	72	91	97	97
2.5	5.9	+	20	50	74	78	30	62	83	86	22	52	76	80
2.5	6.0	−	77	93	98	98	82	95	98	99	74	92	97	98
2.5	6.0	+	27	59	81	87	33	66	86	90	23	55	79	85
2.5	6.1	−	83	95	98	99	84	96	99	99	75	93	98	99
2.5	6.1	+	34	68	87	93	36	70	88	93	25	58	81	89
2.5	6.2	−	87	97	99	100	86	96	99	100	77	94	98	99
2.5	6.2	+	42	76	91	96	40	74	90	96	27	61	84	92
2.5	6.3	−	91	98	99	100	88	97	99	100	79	94	98	99
2.5	6.3	+	51	82	94	98	44	78	92	97	29	64	86	95
2.5	6.4	−	93	98	100	100	89	97	99	100	80	95	98	100
2.5	6.4	+	60	87	96	99	47	81	94	98	30	67	88	96
2.5	6.5	−	95	99	100	100	91	98	99	100	81	95	99	100
2.5	6.5	+	68	91	97	99	51	83	95	99	32	70	89	97
2.5	6.6	−	97	99	100	100	92	98	100	100	83	96	99	100
2.5	6.6	+	75	94	98	100	55	86	96	99	34	72	91	98

Key as for Table 7.

Published data on the temperatures for maximum rate of growth of *Cl. botulinum* are relatively poor, and the most complete study remains that of Ohye and Scott (1953). From their nephelometric study of growth of ten strains each of types A and B at temperatures from 12.5 to 45°C, the temperature at which maximum rate of growth occurred is clearly between 37 and 42.5°C, and from their Fig. 1 appears to be *c.* 40°C. Toxin titres were not performed, and the yield of cells was less at 42.5 than at 37°C.

The non-linear effect of salt (Fig. 2) was at first believed to be the result of apparently achieving considerably lower levels than formulated for 4.5% salt, but repeating the statistical analysis with detected salt levels confirmed this non-linearity (Fig. 3). Robach (1980) investigated the combined effects of salt, potassium sorbate and storage temperature on outgrowth of *Cl sporogenes* in laboratory medium and reported that increasing salt levels (1, 3 or 5%) enhanced the inhibition attributable to sorbate (0.1, 0.2 or 0.3%) at 24 and 37°C. No interaction between salt and sorbate was evident in our slurry. Robach

Table 11. Probability (%) of toxin production by *Cl. botulinum* type A and B*, in pork slurry containing 40 μg/g sodium nitrite, 550 μg/g sodium isoascorbate, inoculum 1000 spores per bottle

NaCl (% of water)	pH of slurry	Potassium sorbate (0.26% w/v)	Unheated				‡LOW heat				‡HIGH heat			
			†15	17.5	20	35	15	17.5	20	35	15	17.5	20	35
3.5	5.7	−§	15	43	69	79	31	65	85	91	26	58	81	88
3.5	5.7	+§	2	8	20	30	5	17	38	51	4	13	32	44
3.5	5.8	−	21	52	78	88	35	69	88	94	27	61	83	91
3.5	5.8	+	3	11	28	45	5	20	44	62	4	15	35	54
3.5	5.9	−	27	62	84	93	38	73	90	96	29	64	85	94
3.5	5.9	+	4	15	37	60	6	23	49	72	4	16	39	63
3.5	6.0	−	35	71	89	96	42	77	92	97	31	67	87	96
3.5	6.0	+	5	21	47	74	7	26	55	80	5	18	43	71
3.5	6.1	−	43	78	93	98	45	80	93	98	33	70	89	97
3.5	6.1	+	8	28	58	85	8	30	60	86	5	20	47	78
3.5	6.2	−	52	84	95	99	49	83	95	99	35	72	90	98
3.5	6.2	+	10	36	68	91	10	34	65	91	5	22	51	84
3.5	6.3	−	60	89	97	99	53	85	96	99	37	75	92	99
3.5	6.3	+	14	46	76	95	11	38	70	94	6	24	55	88
3.5	6.4	−	69	92	98	100	57	87	96	100	39	77	93	99
3.5	6.4	+	19	56	83	97	12	43	75	96	6	27	59	92
3.5	6.5	−	76	94	99	100	60	89	97	100	41	79	94	99
3.5	6.5	+	25	65	88	99	14	47	79	97	7	29	63	94
3.5	6.6	−	82	96	99	100	64	91	98	100	43	81	95	100
3.5	6.6	+	33	73	92	99	16	52	82	98	8	32	66	96

Key as for Table 7.

(1980) also reported an interaction between storage temperature and sorbate, both in the presence and absence of salt. In our slurry no interaction between sorbate and storage temperature was evident but there was a significant interaction between salt and storage temperature.

Allergic skin reactions in some laboratory workers, and panellists testing the sorbate-treated bacon, resulted in the U.S.D.A. refusing GRAS status to potassium sorbate in bacon (Anon. 1980). Consequently interest in the extended use of sorbate has waned. This limited study has demonstrated an inhibitory effect of 0.26% potassium sorbate against *Cl. botulinum* in pork slurry, and emphasizes the importance to that inhibition of low pH values and low storage temperatures. Use of potassium sorbate at higher pH values and higher storage temperatures could result in the proposed combination of potassium sorbate, nitrite and ascorbate having a less inhibitory effect on growth of *Cl. botulinum* than 156 μg/g nitrite.

Table 12. Probability (%) of toxin production by *Cl. botulinum* type A and B*, in pork slurry containing 40 μg/g sodium nitrite, 550 μg/g sodium isoascorbate, inoculum 1000 spores per bottle

NaCl (% on water)	pH of slurry	Potassium sorbate (0.26% w/v)	Unheated				‡LOW heat				‡HIGH heat			
			†15	17.5	20	35	15	17.5	20	35	15	17.5	20	35
4.5	5.7	−§	8	30	59	84	19	51	78	93	15	44	73	91
4.5	5.7	+§	1	4	14	36	2	10	28	59	2	8	23	52
4.5	5.8	−	12	39	69	91	21	56	82	95	16	47	76	93
4.5	5.8	+	1	6	20	52	3	12	33	69	2	9	26	61
4.5	5.9	−	16	48	77	95	24	61	85	97	17	50	79	95
4.5	5.9	+	2	9	27	67	3	14	38	77	2	10	29	70
4.5	6.0	−	21	58	84	97	26	65	88	98	18	54	82	97
4.5	6.0	+	3	13	36	80	4	17	44	84	2	11	33	77
4.5	6.1	−	27	67	89	99	29	69	90	99	20	57	84	98
4.5	6.1	+	4	18	47	88	4	20	49	89	3	12	36	83
4.5	6.2	−	35	75	92	99	33	73	92	99	21	60	86	98
4.5	6.2	+	6	25	57	93	5	23	55	93	3	14	40	88
4.5	6.3	−	43	81	95	100	36	76	93	99	23	63	88	99
4.5	6.3	+	8	32	67	96	6	26	60	95	3	15	44	91
4.5	6.4	−	52	87	97	100	40	80	95	100	24	65	89	99
4.5	6.4	+	11	42	76	98	7	30	65	97	3	17	48	94
4.5	6.5	−	61	91	98	100	43	82	96	100	26	68	91	100
4.5	6.5	+	15	51	83	99	8	34	70	98	4	19	52	96
4.5	6.6	−	69	93	99	100	47	85	96	100	27	71	92	100
4.5	6.6	+	19	61	88	99	9	38	75	99	4	21	56	97

Key as for Table 7.

Table 13. Analysis of deviance on factors controlling toxin production by *Cl. botulinum* in pork slurries.

Factor/interaction	Degrees of freedom	Deviance*	Mean squares	Significance ($P = <0.01$)
Potassium sorbate	1	110	110	S
Storage temperature	1	154	154	S
Salt	1	80	80	S
Heat treatment	2	6	3	NS
Inoculum level	1	67	67	S
pH of slurry ('low'/'high')	1	157	157	S
Salt×salt (i.e. S^2)	1	16	16	S
Storage temperature×storage temperature (i.e. T^2)	1	104	104	S
Sorbate×heat	2	10	5	S
Salt×storage temperature	1	19	19	S
pH×heat	2	30	15	S
pH×storage temperature	1	16	16	S
Storage temperature×inoculum	1	9	9	S
Sorbate×inoculum	1	9	9	S
Residual	270	579	2.14	
Total	287	1366		

S = significant
NS = not significant
*The contributions of the factors or interactions significantly affecting toxin production are reflected by the magnitude of figures in the deviance column.

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The determination of isolated soybean protein in raw and pasteurized meat products

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Summary

Sodium dodecyl sulfate-polyacrylamide gel electrophoresis was used to determine the isolated soy protein content in raw and pasteurized meat products. This method determined soy protein (±0.5%) by using an internal standard protein (haemocyanin) to compensate for variations in the meat. The detection limit for meat products was 0.5%. Several possible meat and non-meat interferences were examined and none were found to interfere. The assay cannot be used on retorted products.

Introduction

With the growing use of soybean proteins in meat products, the need for a competent method of their detection and quantification has also grown. The methods previously used, reviewed by Olsman and Krol (1978), can be divided into six categories: microscopy and histochemistry, analysis of chemical (non-protein) soybean constituents, immunology, use of tracers, analysis of amino acids and peptides, and electrophoresis. Although none of these was entirely successful, electrophoresis was the most promising for the analysis of isolated soy protein (ISP).

Polyacrylamide gel electrophoresis has often been used for detection or quantification of non-meat proteins mixed with those of meat (Parsons & Lawrie, 1972; Hofmann & Penny, 1973; Lee *et al.*, 1975; Lee *et al.*, 1976; Guy & Willcox, 1977; Homayounfar, 1977; Persson & Appleqvist, 1977; Hashizume & Noguchi, 1978). However, few studies have tried to analyse soy protein in actual or simulated commercial meat products. In one such study by Beljaars & Olsman (1977), ten different meat products (two raw, four pasteurized and four

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sterilized) were analysed by eleven laboratories. Results were promising for the raw and pasteurized samples, but those for the sterilized samples were unsatisfactory.

Different measurements from the scans of electrophoresed proteins have been used to determine the amount of soy protein in a meat product. These included the area of the characteristic soy peak(s), the area ratio of a soy peak to one or more meat peaks, and the area ratio of a soy peak to all the peaks. These methods were affected by the amount of protein entering the gel and by the variations in meat proteins. The objective of this study was to develop a quantitative method that would be independent of protein variations.

Materials and methods

Preparation of meat products

Sausage products were prepared by typical production methods. Lean beef, pork, salt and spices were chopped with ice. Fatty meats were then added and chopping resumed briefly. The mixture was passed through an emulsion mill and stuffed into casings. The sausages were smoked and cooked to an internal temperature at 70°C. After a water shower, they were chilled to 5°C.

The composition of the sausages was 12.9% protein, 20.0% fat and 63.2% moisture. When hydrated, isolated soy protein (ISP) was to be added (with the first chopping), the formula was adjusted to provide constant composition. The known ISP concentrations, 0.5–4.1% of the total meat product, allowed for shrinkage.

The meat protein products examined for interfering protein bands were obtained locally and assayed 'as is'. The vegetable protein samples were available in our laboratory. The soy protein products used for standard curves were commercial samples.

The ham products were prepared as simulated, commercial boneless-hams (Hawley & Tuley, 1977). Isolated soy protein was added to the ham pumping solution; the amount of soy protein added (3.2 and 3.5%) was calculated from the uptake of the brine solution and the concentration of ISP in the solution. The hams were massaged gently to distribute the protein brine (no loss of fluid occurred during massaging).

To determine the effect of thermal processing, a sausage product containing 2.0% ISP was divided into three lots. One lot remained raw, one was pasteurized normally as sausage (70°C internal temperature), and one was canned and retorted for 15 min at 121°C. The ISP content was confirmed to be 2.0% by means of a tracer (TiO_2).

Preparation of samples for electrophoresis

Sampling. The ends of the sausages were discarded and samples 7.5 cm in length and 2.0 cm in diameter (20 g) were taken from the cores, unless marked

otherwise. Large and heterogenous sausages were pre-mixed, then sampled several times to obtain a representative portion. At least two samples were taken from each sausage. The hams were sampled similarly.

Acetone extraction. Each 20 g sample was homogenized in 200 ml of acetone in a Sorvall Omni mixer for 1 min, then centrifuged at 18 000 *g* for 15 min. The pellets were washed by this procedure twice and air-dried on a watch glass overnight. The residues were gound in a Mikro-Mill for 30 sec and weighed.

Protein extraction. The sample dispersing solution was 8.0 M urea, 3.0% sodium dodecyl sulfate (SDS), 2.0% 2-mercaptoethanol and 0.01% haemocyanin (from Sigma Chemical Co., U.S.A.). Ten percent of the powder (200–350 mg) obtained from the acetone extraction, representing 2.0 g of the original sample, was suspended in 30 ml of the dispersing solution. The suspension was blended with a Polytron® homogenizer for 1 min and stirred or shaken for 2 hr. The solution was then centrifuged at 35 000 *g* for 20 min at 20°C. If the supernatant was turbid, it was filtered through Whatman No.4 filter paper. Of the protein solution, 1 ml was diluted with 1 ml of sample dispersing solution containing 0.1% bromophenol blue but *without haemocyanin*; 100 ol were then applied to the gel.

Soy standards were prepared from acetone-extracted ISP products in the same manner as the meat proteins. The amounts dispersed (20, 40, 60, 80 and 100 mg) were equivalent to 1.0, 2.0, 3.0, 4.0 and 5.0% ISP in the meat products. The soy standards were included on each gel run.

Electrophoresis. The slab gels, containing 6.0% acrylamide (0.3% as bis-acrylamide), 8.0 M urea, and 0.1% SDS, were 0.1 M phosphate buffer, adjusted to pH 8 with solid Tris-phosphate, prepared in a vertical gel electrophoresis apparatus (EC Apparatus Corp., U.S.A., Model EC 474). Ammonium persulfate and TEMED (N,N,N$^-$,N$^-$-tetra-methylenediamine) were used for polymerization. The gels were cooled by 25°C water throughout polymerization and electrophoresis.

The circulating buffer was 0.1 M Tris-phosphate, pH 6.8 with 0.1% SDS. After the samples were applied, electrophoresis was performed with a constant 100 V (EC Apparatus Corp., U.S.A., Model EC 454) for 20 hr. The current was between 300–400 mA.

After electrophoresis, the protein bands were fixed with 10% TCA for 4 hr. The gels were stained for 4 hr with Coomassie blue (0.25% in 30% methanol and 10% acetic acid) and de-stained for 2–3 days with 30% methanol – 10% acetic acid. Gentle agitation of the gel was necessary throughout to promote even and consistent staining and de-staining. Gels were stored in 10% acetic acid.

Quantification of soy protein

The gels were scanned with a Shimadzu CS-910 dual-wavelength TLC scanner and transmittance/absorbance at 610 nm was recorded. Heights and areas of the soy and internal standard (haemocyanin) peaks were measured from a baseline, connecting valleys as illustrated in Fig. 1. The soy peak value in meat samples was corrected for protein recovery (see *Results*) and the ratios of soy to

haemocyanin were calculated. The soy standards were plotted to obtain a standard curve, then soy concentrations in the meat products were determined.

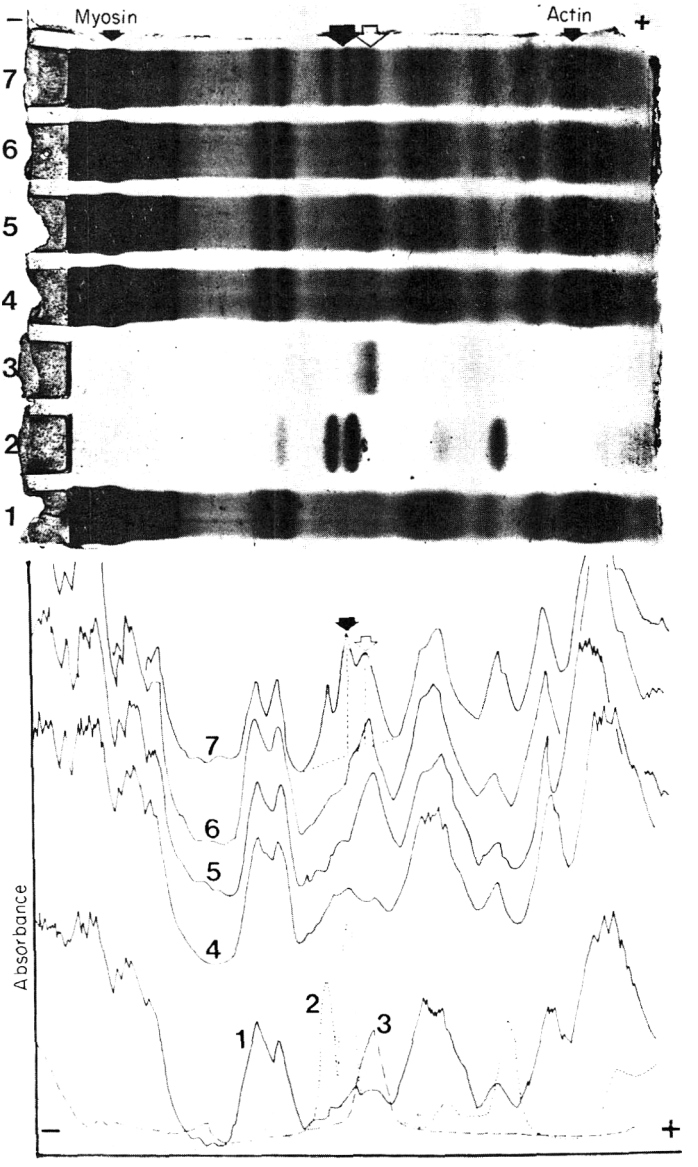

Figure 1. Polyacrylamide gel and spectrophotometric scan of (1) all-meat sausage, (2) ISP, (3) haemocyanin, (4) sausage with 0.5% ISP, (5) all-meat sausage+haemocyanin, (6) sausage with 0.5% ISP+haemocyanin and (7) sausage with 2.0% ISP+haemocyanin. Dark arrows indicate soy protein band and peak used for detection and quantification. Light arrows indicate haemocyanin band and peak. Scan (7) shows the method of measuring peak heights.

Results

The soy protein band selected for detection and quantification was also used by Smith (1975), Persson & Appleqvist (1977) and Hashizume & Noguchi (1978). It appears between actin and myosin (Fig. 1).

A background of meat protein, including many minor bands, is evident throughout the electropherogram. Haemocyanin was selected as the internal reference protein because it is located next to the soy band (Fig. 1) and therefore will be similarly affected by the background material. Also because of the background, the detection limit for soy protein in sausages was determined to be 0.5% (Fig. 1).

Interferences

Several sources of meat ingredients were examined for possible interference with the method (Fig. 2). The meat protein background depends upon the species, the lean content (see pork sausage) and the presence of organ meats. No major bands interfered with detection or quantification; however, the baseline would vary too much to quantify soy protein without all-meat controls or the addition of an internal reference protein.

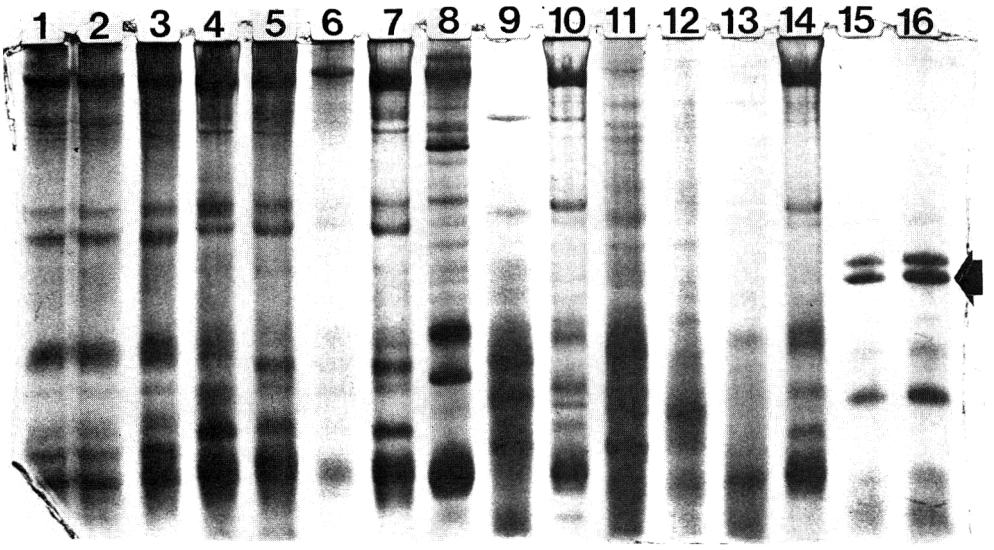

Figure 2. Electropherograms of various processed meat-product ingredients. (1–2) Turkey, (3) chicken, (4) lamb, (5) ham, (6) pork sausage, (7) lean pork, (8) pork stomach, (9) beef liver, (10) beef heart, (11) pork kidney, (12) beef brains, (13) pork spleen, (14) beef tongue and (15–16) ISP.

Other plant proteins were also examined as possible interferences (Fig. 3). Only one band, in pea protein, was near the characteristic soy protein, but it could be easily distinguished.

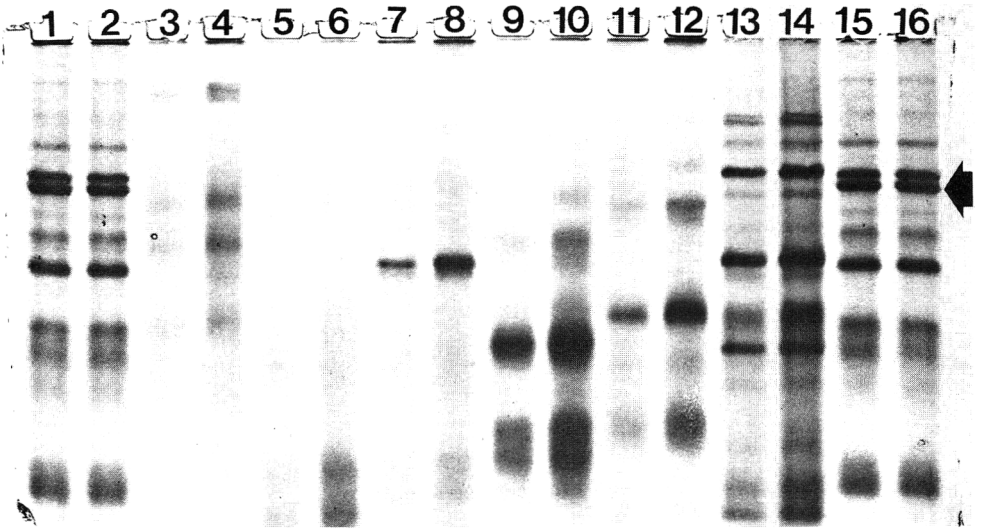

Figure 3. Electropherograms of plant proteins, (1–2) ISP, (3–4) wheat gluten, (5–6) corn protein, (7–8) cotton-seed flour, (9–10) oat protein, (11–12) peanut protein, (13–14) pea protein and (15–16) ISP.

The standard curve

Haemocyanin was used at 0.01% so that its peak height and area were equivalent to those of the characteristic soy peak in meat products containing 1.0% ISP. Both peak heights and areas were used for quantification of the soy protein, but peak height ratios were more precise and reproducible (Fig. 4). Guy & Willcox (1977) also used peak heights for quantification of soy protein in meat products by electrophoresis.

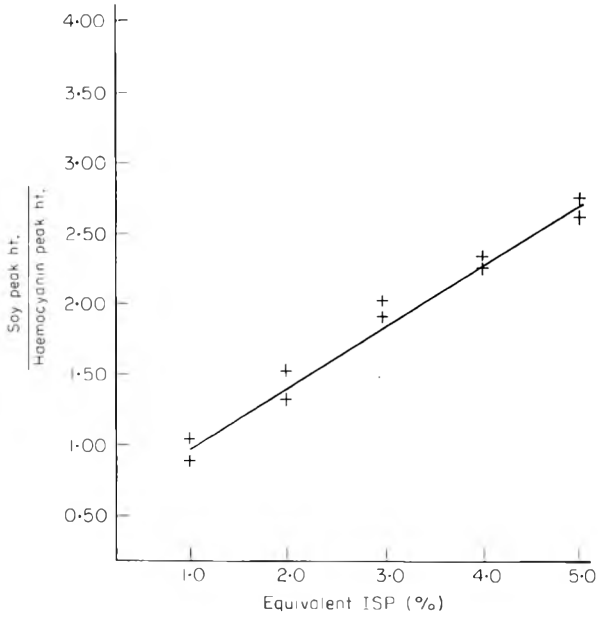

Figure 4. Standard curve for determining ISP in meat products based upon ISP-acetone powder and haemocyanin peak heights.

Recovery of soy protein in the meat product

Since the acetone-extracted proteins were a light powder, it was inevitable that some physical loss would occur during handling. Therefore, some method of correction for protein yield was necessary for soy quantification.

Protein loss was checked during solubilization and electrophoresis by mixing together acetone-extracted ISP and meat proteins in amounts equal to the 1.0–5.0% soy levels in meat. The peak ratio curve obtained from these mixtures was coincident with the one for ISP alone. Therefore, no protein loss occurred during the protein solubilization and electrophoresis steps.

To check protein loss during acetone extraction, hydrated ISP was added in known amounts to meat samples, which then underwent acetone and protein extractions. The amount of solids lost was the difference between the theoretical and actual yields. The theoretical yield, 3.30 g, assumed no loss of protein or ash from the meat. The actual yield was 2.53 ± 0.16 g of solids, 76.7% of the theoretical. When these samples were electrophoresed, the calculated soy recovery was 82% (± 3.0%) of the theoretical.

It is recommended that each analyst determine protein recovery, especially if sample sizes are changed. The 82% recovery of soy protein was consistent for sausages and independent of total protein composition. This factor was used to correct the peak heights and areas of the soy peak in meat electropherograms.

Quantification of soy protein in the meat product

The soy concentrations determined for sausages containing 1.0–4.1% ISP are given in Table 1. Better accuracy and reproducibility are obtained with peak heights.

Table 1. Analytical results* of sausages containing different levels of ISP

	Levels of added ISP in sausage							
	1.0%		2.0%		2.9%		4.1%	
Sample Number	Height	Area	Height	Area	Height	Area	Height	Area
1	1.27	1.10	2.16	1.53	2.02	2.01	4.42	2.93
2	0.83	0.95	1.68	2.21	2.34	2.69	3.96	4.21
3	1.06	0.67	1.77	2.80	2.37	2.72	—	—
Mean	1.06	0.91	1.89	2.18	2.23	2.47	4.19	3.57
S.D.	±0.25	±0.27	±0.25	±0.60	±0.11	±0.38	±0.68	±0.91

*Percentage of meat product.
Each value given is the average of two determinations on that sample.

Different areas of the sausage with 4.1% soy were sampled to examine possible differences in recovery due to heating. The results are in Table 2. Again, the values from peak heights were more accurate. No appreciable

differences were seen due to heating, since lower protein recoveries were not observed in the surfaces of the samples.

Analysis of the simulated commercial ham samples (with 3.2 and 3.5% ISP) indicated that they contained 2.56 and 2.78% soy protein respectively. Results of analyses on other commercial hams were also lower than expected. However, protein recovery studies were not conducted on these samples.

In general, the protein bands of hams with soy protein were less distinct than those of the sausages. These differences might be an effect of salt concentration on staining as indicated by Hofmann (1977), but otherwise are unexplained.

Table 2. Analytical results* of samples taken from different locations in sausages†

	Location							
	At skin‡		2 cm from skin		2 cm from centre		At centre	
Sample number	Height	Area	Height	Area	Height	Area	Height	Area
1	5.4	3.2	4.0	2.8	4.9	2.7	4.5	4.1
2	3.2	4.0	3.9	2.8	4.3	3.2	4.2	3.6

*Percentage of meat product.
†4.1% added ISP.
‡Sampled as a slab instead of cylinder.
Each value given is the average of two determinations from the sample.

Effects of thermal processing

The gel obtained with the raw, pasteurized and retorted sausages is shown in Fig. 5. The ISP content of the raw and pasteurized samples was found to be 2.0% (average of duplicates). However, the retorted sample was devoid of the characteristic soy bands. Hofmann (1973) had also observed the disappearance of meat protein bands in heated meat samples.

Discussion

Advantages of an internal standard

To our knowledge, this is the first use of an internal standard protein in quantitative electrophoresis. Limulus crab haemocyanin was chosen because of its proximity to the quantified soy peak. Use of an internal standard corrects for the many sources of error which may occur in quantification by conventional electrophoresis. Differences in peak resolution, sample application, staining and de-staining, and scanning procedure between standards and samples are all minimized or eliminated. In our experience, quantification without an internal standard is difficult, if not impossible.

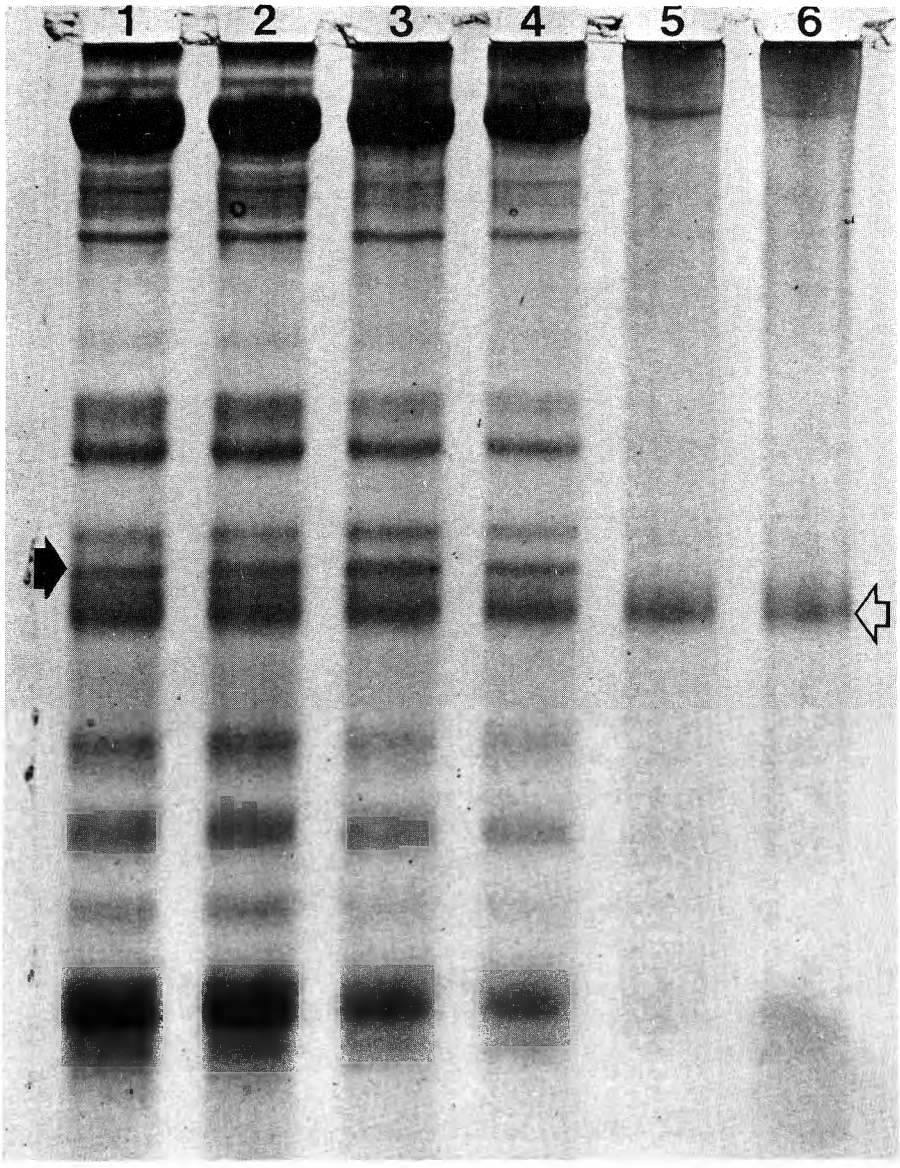

Figure 5. Electropherograms of raw and heated sausage samples: 1–2 are raw, 3–4 pasteurized to 70°C internal temperature and 5–6 retorted at 121°C for 15 min. Dark arrow indicates ISP band; light arrow indicates haemocyanin.

Peak height vs *peak area*

As can be seen from Fig. 1, the soy peak areas are difficult to quantify. The soy peaks fall on a sloping baseline (from meat background) and are fused. We had difficulty in programming a commercial integrator to integrate the desired peak areas, therefore we were forced to use a laborious, time consuming method for accurate peak area measurement.

Our results show that measurement of peak heights is rapid and precise. Considering that many laboratories that employ this method may not have sophisticated equipment available, measurement of peak heights is the preferred method.

In a survey of the integration methods used in gas chromatography, peak height measurement was most popular. We believe quantification of soy protein electrophoretic peaks is analogous to the quantification of gas chromatographic peaks and therefore the measurement of peak heights is justified. For a more complete discussion of peak height as a method of integration, see McNair & Bonelli (1969).

Application of this method

This method has been successfully applied in our laboratory and the Ralston Purina Laboratory in Belgium. This method is presented in detail because we find electrophoretic determinations and comparisons are made with many different types of equipment and procedure.

We believe $\pm 0.5\%$ is near the limit of precision for this method, considering the variability of commercial soy products. Soy protein isolates vary in their protein content even though all are over 90% (N $\times$ 6.25). Also we have observed a small variation in soy protein peaks due to soybean variety. Since it is not always possible for the analyst to know the source of isolate or its protein content, these factors cannot be used to correct the assay.

Conclusion

Soy protein in raw and pasteurized meat products can be determined with this method. The analysis does not depend on the meat content of the product since it utilizes an internal standard protein. The detection limit is 0.5% soy protein in the meat products tested and accuracy is within 0.5%. Many possible sources of interferences were examined and none hindered detection or quantification. This method can also be used for soy flours and soy concentrates, providing the type of product is known. For a regulatory procedure, the concentration of the internal standard can be adjusted to assay for specific soy concentrations in the product.

Acknowledgment

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Hot curing Wiltshire bacon

A. A. TAYLOR, B. G. SHAW, P. D. JOLLEY AND G. R. NUTE

Summary

A process combining multi-needle injection and dry salting of whole baconsides before they have been completely chilled can produce acceptable Wiltshire bacon in only 5 days from slaughter. Eating quality and storage stability of sliced and vacuum packed, hot cured bacon were similar to those of dry salted bacon made from conventionally chilled sides. The yields of hot cured and cold cured raw bacon were similar, but cooking yields of hams were over 3.0% higher with hot curing.

A continuous hot curing process from slaughter, through carcass preparation, multi-needle brine injection, dry salting to chilling could simplify Wiltshire bacon processing. The concept could be particularly useful to a processor lacking the specialized facilities for traditional immersion curing.

Introduction

Processing meat before it has been chilled reduces the time, and in some cases, the energy required for manufacturing meat products. When applied to processes involving curing, there are additional advantages. If the curing ingredients are added soon after slaughter and before the carcass has been completely chilled, they diffuse more readily throughout the muscles and cured colour develops more quickly and uniformly (Mullins, Kelley & Brady, 1958; Arganosa & Henrickson, 1969; Henrickson *et al.*, 1969). Yield of raw product may be improved and cooking losses reduced (Weiner *et al.*, 1964; Weiner *et al.*, 1966; Goutefongea & Schimman, 1973). These advantages to the processor are obtained without adversely affecting eating quality (Mandigo & Henrickson, 1966; Mandigo & Henrickson, 1967; Davidson *et al.*, 1968; Henrickson *et al.*, 1969) and in some cases improve it (Mandigo, Thompson & Weiss, 1977).

Most studies on hot curing of pig meat have been concerned with processing of pieces of meat, mainly hams, which are then chilled by immersion in

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refrigerated brine. The principle of hot curing has not been extended to Wiltshire processing of whole sides since it is not practicable to chill these large pieces during immersion curing. Hot curing is more suited to a modified Wiltshire process in which immersion is replaced by dry salting (Taylor, Shaw & Jolley, 1980), where bacon sides are hung individually after brine injection and dry salting, and are therefore more easily chilled. This form of dry salting can produce Wiltshire-style bacon more quickly than the traditional immersion process without impairing storage stability or eating quality. The present study was designed to investigate the stability and quality of bacon made more quickly by combining hot curing with dry salting.

Materials and methods

Hot curing was evaluated by comparing the properties of hot cured collar and back bacon with those of dry salted bacon made from conventionally chilled sides. Curing procedures were designed to give bacon with back lean containing 4.0–5.0% salt and 60–100 mg/kg nitrite. Nitrate was not included in the injection brine since it has no apparent benefit in a dry salting process (Taylor *et al.*, 1980).

Bacon manufacture

Bacon was made from eight Grade A pigs from a factory production line, the left side of each pig receiving one treatment and the right side the other. After slaughter and dressing, all sides were held at 1°C until 4.5 hr from slaughter by which time the pH (factory mean) in *M. longissimus dorsi* had reached 6.0. Sides for hot processing were then prepared as for Wiltshire curing, but the hind-legs were left on to allow sides to be hung during curing. The mean temperature in the deep leg was 32°C and the surface was at 17°C. Sides were injected with a brine containing NaCl (23.1% wt/vol) and $NaNO_2$ (2494 mg/kg), using a Swissvac Cur-O-Mat multi-needle machine, to an average weight gain of approx. 10%, before passing through a dry salting machine (Wright Pugson Ltd) which sprayed 0.7–1.0 kg dry NaCl per side over the whole surface. The sides were then hung at 5°C until sampling.

Sides to be cold cured were cooled overnight at 1°C. At 24 hr post-slaughter, when the temperature in the deep leg was approximately 5°C, the sides were dressed for Wiltshire curing, injected with brine and dry salted in an identical manner to the cold cured sides, then hung at 5°C until sampled.

Sampling, packing and storage

Hot cured sides were sampled 5 days post-slaughter, and cold cured sides 6 days post-slaughter. Portions of collar (forward from the middle of the shoulder pocket) and back (forward from the last rib) were taken from each side and

transported under refrigeration to the Meat Research Institute where they were held overnight at 1°C before slicing.

Collar portions were sliced to give twenty-four slices of 3 mm thickness, which were vacuum packed in Metathene X pouches (Metal Box Ltd, London), three consecutive slices to a pouch, to give eight packs from each side. The packs from the eight sides in each curing treatment were grouped according to an 8×8 Latin-square design so that, at each of the eight examination times, when eight corresponding packs were sampled from each curing treatment, each side and each position in the sliced collar was represented. Packs were stored for up to 20 days at 5°C and up to 15 days at 15°C.

A portion of back from each side was sliced to give fifty-two slices (3 mm). The first twenty slices were used for organoleptic assessment and the remaining thirty-two slices were vacuum packed, four consecutively to a pouch to give eight packs per side. Packs were allocated as for collar bacon, but for periods of storage up to 35 days at 5°C and up to 20 days at 15°C.

Microbiological examination

All sides were sampled immediately after injection and again after the hanging period. The sampling technique and method of determining the total, viable count of bacteria on sides was as described by Taylor *et al.* (1980).

Total viable counts and lactic acid bacteria in vacuum packed samples of collar bacon and the lean (eye muscle) of back bacon were enumerated using the methods described by Taylor, Shaw & Jolley (1976).

Odour

When the packs were opened for examination, the odour was assessed by a panel of four experts who noted the presence of off-odours and judged whether these would cause the bacon to be accepted or rejected by a consumer.

Organoleptic assessment

The twenty slices of back bacon from each side were submitted to a ten-member taste panel. At each session, slices from four sides were assessed; since processing times were different, the two treatments had to be assessed on separate occasions.

Colour of fat and lean was judged on raw slices, which were then cooked on wire supports in a casserole in an oven at 175°C for 35 min (Taylor & Shaw, 1975) before assessment of flavour and cooked-lean colour. The panel was also asked to judge saltiness on a 9-point scale ranging from 'extremely salty' (+4) through 'ideal' (0) to 'extremely under salty' (−4).

Assessment of cooked gammons

Gammons were cut from each side, 6 days after slaughter (hot cured) and 7 days after slaughter (cold cured), weighed before and after removal of bones,

rind and excess fat, and were then cooked at the factory in moulds for 8 hr at 68°C. No water or polyphosphate was added and gammons were not tumbled. After they had been cooled, the cooked gammons were taken under refrigeration to the Meat Research Institute, weighed and the cooked yield of each gammon based on both trimmed and untrimmed weight before cooking determined. The gammons were then cut into enough 50 g slices (3 mm thickness) to supply 491 consumers. During this operation, slices were set aside periodically for subsequent bulking to provide hot cured and cold cured samples for chemical analysis.

Each consumer in the trial received one sample of each treatment over a 2 week period. During the first week of distribution, one-half of the consumers received the hot cured sample whilst the other half received the cold cured. This procedure was reversed the following week.

Each consumer was asked to score samples for appearance, flavour, texture, juiciness and saltiness. Appearance was judged 'acceptable' or 'not acceptable'; flavour and texture were scored on 8-point scales and saltiness on a 9-point scale as already described; juiciness was scored on a 5-point scale ranging from 'dry' (0) to 'extremely juicy' (4).

Chemical analysis

The pH of the bacon lean was measured at the beginning of storage and samples of lean were analysed, as described by Jolley (1979), for $NaNO_2$, NaCl and moisture.

The cooked gammons were analysed in the same way except that hot cured slices were combined to form a single bulk sample and cold cured slices were combined to form a further bulk sample.

Results

Bacon processing

Sides to be used for hot curing lost less weight during their short chilling stage than did their equivalent cold cured sides which were completely chilled before curing. Although this weight advantage was retained to some extent (Table 1) a paired t-test showed no significant difference at the end of maturation.

Table 1. Weight changes during processing of hot cured and cold cured bacon sides (means and s.d.).

Bacon samples	Wt. of side before injection (kg)	Wt. of brine injected (kg)	Wt. of dry-salt added (kg)	Wt. of side after maturation (kg)
Hot-cured	27.87 (±1.23)	2.73 (±0.30)	0.86 (±0.18)	29.49 (±1.45)
Cold-cured	27.12 (±1.36)	2.91 (±0.28)	0.64 (±0.22)	29.15 (±1.50)

Chemical analysis

Table 2 shows the pH and concentration of nitrite and salt in the bacon leans at the beginning of storage.

Table 2. Measurement of pH and analysis of nitrite, salt and moisture in lean of hot cured and cold cured collar and back bacon at beginning of storage.

Bacon samples		pH	$NaNO_2$ (mg/kg)	NaCl (% w/v)	NaCl (% on water)	Moisture (%)
Hot cured	Collar	5.95	161	5.1	7.5	68.2
	Back	5.65	135	2.9	4.0	73.1
Cold cured	Collar	6.05	135	4.5	6.4	70.6
	Back	5.75	131	3.9	5.5	70.9

Changes in the concentration of nitrite in collar bacon during storage at 5° and 15°C are shown in Fig. 1(a), and in back bacon in Fig. 1(b). In each instance the pattern of nitrite depletion was similar for both hot cured and cold cured bacon, notwithstanding slight differences in initial levels.

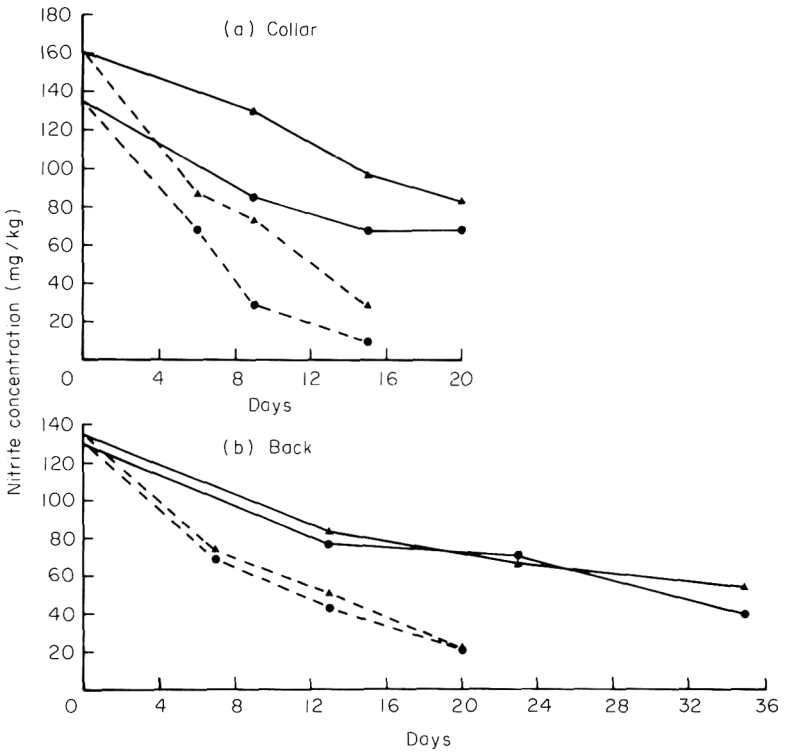

Figure 1. Changes in concentration of nitrite in (a) collar bacon and (b) back bacon during vacuum packed storage at 5°C (——) and 15°C (----). Hot cured (▲); cold cured (●).

Microbiology

There was no significant ($P < 0.05$) difference between total viable counts on hot and cold cured sides after injection or after the hanging-period. After injection, counts on hot cured sides were in the range 4.1–4.9 ($\log_{10}$ No./cm^2) with a mean of 4.6, whilst the range was 3.9–4.9 with a mean of 4.6 on the cold cured sides. After hanging, counts on hot cured sides were in the range 3.7–5.7 with a mean of 4.9, whilst the range was 4.4–5.0 with a mean of 4.6 on the cold cured sides.

Table 3. Effect of curing method on bacterial numbers on the lean of collar bacon during vacuum packed storage at 5 and 15°C.

Bacon samples	Days stored	Log_{10} (total, viable count/g) 5°C	15°C	Log_{10} (count of lactic acid bacteria/g) 5°C	15°C
Hot-cured	0	4.2	4.2	< 1.7	1.7
	6	—	4.4	—	4.3
	9	2.3	4.6	2.1	4.4
	15	5.7	7.4	5.3	7.0
	20	6.4	—	6.1	—
Cold-cured	0	4.2	4.2	1.7	1.7
	6	—	5.8	—	5.0
	9	4.2	6.9	2.7	6.1
	15	4.3	7.1	3.4	6.8
	20	4.6	—	3.9	—

Table 4. Effect of curing method on bacterial numbers on the lean of back bacon during vacuum packed storage at 5 and 15°C.

Bacon samples	Days stored	Log_{10} (total viable count/g) 5°C	15°C	Log_{10} (count of lactic acid bacteria/g) 5°C	15°C
Hot cured	0	3.6	3.6	< 1.7	< 1.7
	7	—	6.0	—	5.9
	13	4.4	6.9	3.3	6.7
	20	—	7.1	—	7.1
	23	4.5	—	4.5	—
	35	6.2	—	6.1	—
Cold cured	0	3.8	3.8	< 1.7	< 1.7
	7	—	5.7	—	4.4
	13	4.2	6.2	< 2.1	5.5
	20	—	6.8	—	6.2
	23	4.8	—	3.8	—
	35	4.7	—	4.1	—

Total viable counts and numbers of lactic acid bacteria in the bacon during vacuum packed storage are shown in Tables 3 and 4. During storage at 5°C, there were unusually small increases in total viable counts and counts of lactic acid bacteria on the cold cured bacon, whereas counts on the hot cured increased to relatively high numbers. High numbers of bacteria developed on all bacon stored at 15°C, the increase being most rapid on collar bacon after cold curing and most rapid on back bacon after hot curing.

Odour

All packs of collar bacon, hot cured and cold cured, were judged acceptable after storage periods of up to 20 days at 5°C and up to 15 days at 15°C. All back-bacon samples stored at 5°C were judged acceptable after 35 days. The only samples judged unacceptable were two packs of hot cured and two packs of cold cured back bacon after 20 days at 15°C.

Organoleptic assessment

Taste panel assessments of hot cured and cold cured back bacons are shown in Table 5. Differences in scores for the attributes examined were small and certainly not large enough to demonstrate any real differences between the two curing treatments.

Table 5. Effect of curing method on raw appearance, cooked colour and flavour scores (means and s.d.) for hot cured and cold cured back bacon. Saltiness is scored on a 9-point scale from 'extremely salty' (+4) through 'ideal' (0) to 'extremely under salty' (−4). All other scoring is on an 8-point scale from 'like extremely' (+7) to 'dislike extremely' (−7).

	Raw appearance		Cooked		
Bacon sample	Fat	Lean	Saltiness	Colour (lean)	Flavour
Hot cured	3.2 (±1.9)	1.9 (±2.6)	−0.3 (±1.5)	2.4 (±2.4)	−0.9 (±1.1)
Cold cured	3.5 (±2.2)	1.3 (±3.1)	0.1 (±1.2)	2.7 (±2.6)	−0.4 (±0.9)

Assessment of cooked gammons

The weight losses during cooking of gammons for the consumer test and the resulting yield of cooked meat are shown in Table 6. Cooked yield was significantly higher after hot curing.

The pH of the bulk samples of cooked gammon was 6.20 (hot cured) and 6.15 (cold cured). Analysis of these samples showed them to contain 85 mg/kg (hot cured) and 73 mg/kg (cold cured) Na NO_2, 3.0% (w/w) (hot cured) and 2.9% (w/w) (cold cured) NaCl and had dry-weight values of 35.2% (hot cured) and 36.3% (cold cured).

In the consumer trial, the appearance of the hot cured ham was judged

Table 6. Effect of curing method on weight changes in hot cured and cold cured gammons during trimming and cooking (means and s.d.).

Bacon sample	Gammon (untrimmed) (kg)	Gammon (trimmed) (kg)	Gammon (cooked) (kg)	Yield (% untrimmed wt)	Yield (% trimmed wt)
Hot cured	8.08 (±0.52)	5.63 (±0.43)	4.56 (±0.26)	56.5 (±1.8)	81.0 (±3.0)
Cold cured	8.10 (±0.56)	5.75 (±0.45)	4.47 (±0.32)	55.2 (±1.0)	77.7 (±1.8)

acceptable by 474 consumers and unacceptable by 17. The corresponding figures for the cold cured ham were 469 and 22 respectively. A chi-squared (χ^2) test on these results showed no significant ($P < 0.5$) difference in appearance between the two treatments. Results for the other attributes are shown in Table 7, whose paired t-tests showed no significant difference between treatments except for juiciness where the hot cured ham was slightly more juicy than the cold.

Table 7. Consumer test (491 tasters) scores for eating quality of hot-cured and cold-cured gammons.

Bacon samples	Flavour	Texture	Juiciness	Saltiness
Hot-cured	3.2 (±2.1)	2.2 (±2.5)	2.1 (±0.8)	0.2 (±1.9)
Cold-cured	3.2 (±2.1)	2.3 (±2.5)	1.9 (±0.8)	0.1 (±1.7)

Discussion

These experiments show that hot curing can be combined with dry salting to produce acceptable Wiltshire-style bacon within 5 days of slaughter. The short, initial chilling period used in this study hardened the fat and outside of the carcass, so that trimming was no more difficult than with conventionally chilled carcasses. Removing this preliminary stage would simplify and shorten the process further, but could make consistent trimming of sides difficult. Other workers have attributed differences in yield between hot and cold processing to differences in butchery (Mandigo *et al.*, 1977). In the present study, hot sides were heavier before injection and salting but, although similar weights of brine and salt were added at these stages, the hot sides lost more during subsequent maturation. There was no significant difference in the final yield of raw bacon from the two processes.

The hot cured bacon was similar in almost all respects to bacon made from pig sides which had been conventionally chilled before processing. Concentrations of nitrite and salt at the end of processing were similar for all bacons except hot-cured collar where levels were slightly higher. Changes in nitrite concentration during storage were similar for hot and cold cured collar and back

bacon at both temperatures and followed the pattern seen in earlier dry salting studies (Taylor *et al.*, 1980). There were no significant differences between bacons in any of the attributes assessed by taste panel.

A paired t-test showed that the losses from hot cured gammons during cooking were significantly ($P < 0.001$) less than from their cold cured counterparts. The extent of the difference varied with pigs, but in every case the yield based on weight before cooking was higher with hot curing. The difference was not so great when yield was calculated on weight of gammon before boning and trimming, largely because of more severe trimming of those detained for hot curing.

Side chilling is slower with hot curing because of the delay for preparation of the sides, brine injection and salting and also because chilling is carried out in the curing cellar rather than in a carcass chiller. This could increase microbial growth, although the presence of salt on hot cured sides would have an inhibiting effect on bacteria on the surface. In these experiments, microbial counts were very similar on hot and cold cured sides, and on slices during vacuum packed storage at 15°C. Counts on vacuum packed slices at 5°C increased more on hot cured samples than those on the cold cured, which were, however, unusually low in this experiment. The counts on hot cured samples were of the same order as those in previous experiments with cold cured, dry salted bacon (Taylor *et al.*, 1980), and the odour assessments confirmed that the hot cured bacon had a satisfactory shelf life.

By combining hot curing with dry salting the curer can have a continuous process from slaughter, through dressing, hot side trimming, brine injection, dry salting to chilling, which could simplify manufacture of whole bacon sides. A pre-chilling stage to facilitate butchery may be included, but can be considerably shorter than that used in this study if air temperatures below 0°C are used.

From what is known of the reactions involved in curing, there seems no limit on how soon processing can begin. The duration of processing depends on the time requied for uniform distribution of the curing salts throughout the side, and the time at which the bacon is firm enough for slicing; in these experiments it was considered that both requirements were satisfied within 5 days of slaughter.

In many cases, the advantages presented by a hot curing, dry salting process may not justify the alterations in procedure and equipment which would be necessary for its introduction, but the idea could be attractive to a processor wishing to produce Wiltshire bacon without the specialized facilities necessary for traditional immersion curing.

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Effect of cooking time on the quality, minerals and vitamins of spaghetti produced from two Italian durum wheat varieties

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Summary

Spaghetti was made from two Italian durum wheat varieties and cooked for 10, 15 and 20 min. Percentages of water absorption and cooking loss were determined. Measurable amounts of soluble nitrogen, starch, minerals and vitamins were found in the water used for cooking.

Minerals and vitamins were determined in cooked spaghetti. The percentage reduction of metals increased with increasing cooking time, but trace elements decreased after 10 min of cooking and then became stable at the longer times. It is preferable to cook spaghetti for 15 min.

Introduction

No studies have been concerned with the changes in contents of mineral elements and vitamins of spaghetti and cooked spaghetti. Calhoun, Bechtel & Bradley, (1958) and Czerniejewski *et al.* (1964) determined the vitamin and mineral content of wheat flour and bread.

Voisey & Larmond (1973) found that optimum cooking times for spaghetti ranged between 10–18 min and averaged 13 min. Grzybowski & Donnelly (1979), in their study on the cooking properties of spaghetti, demonstrated that the optimum cooking time for spaghetti was 15 min.

This paper presents quantitative data of the effect of cooking time on water absorption, cooking loss, analysis of cooking water, amount of nutritionally important mineral elements, some vitamins and their distribution in spaghetti during cooking.

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Materials and methods

Two Italian durum wheat varieties, Capeiti and Creso were obtained from the farm of Cerealicoltura, Rome, Italy. Semolina was milled and spaghetti was manufactured in the pilot plant of Cerealicoltura.

Fifty grams of spaghetti were cooked in 500 ml of boiling, distilled water for 10, 15 and 20 min at atmospheric pressure. After cooking and removing the water, the samples were weighed to obtain the water absorbing capacity of the spaghetti. The cooked samples were air-dried at 40°C, in a laboratory macaroni dryer and the relative humidity was lowered in a straight line gradient from 95% at the beginning to 61% at the end of the drying cycle.

Cooking loss (%) is the quantity of material lost to the water during cooking and is determined by weighing the air-dried, cooked spaghetti referred to, against the level 14% moisture basis of the uncooked product.

Soluble nitrogen, starch, riboflavin, niacin and pantothenic acid were determined by using the AACC Approved Methods (1969). Thiamin was determined according to Osborne & Voogt (1978). All determinations were carried out in triplicate.

The following method was used for preparing the mineral solution: A dry-ashing procedure was used for atomic absorption spectrophotometeric analyses of all elements. Triplicate 1.00 ± 0.05 g dried samples were weighed into clean, dry platinum crucibles. Each sample was pre-ashed and ashing was completed by placing the sample in an electric muffle furnace at 500°C for 4 hr. The ash was dissolved in 5 ml of 20% HCl. The solution was warmed to effect complete solution and filtered through acid-washed filter paper (Whatman No. 42) into 100 ml volumetric flasks. After diluting to volume, the solutions were ready for analysis by atomic absorption spectrophotometer.

A Varian Techtron Model 1100, atomic absorption spectrophotometer was used for mineral analysis. The instrument setting and other experimental conditions were in accordance with manufacturers specifications.

Results and discussion

Cooking quality

Percentage water absorption and cooking loss of cooked spaghetti by using increasing times are given in Table 1. Spaghetti of the Capeiti variety absorbed more water than spaghetti of the Creso variety, 81.1 and 69.8% respectively, after 20 min of cooking. The percentage of cooking loss is higher in the Capeiti variety. The difference, in cooking loss during the same time, between the varieties did not exceed 0.2%, and the difference inside the variety was 0.1% after cooking for 10 and 20 min. According to Grzybowski & Donnelly (1979), good spaghetti absorbs more water, shows firmness and stability after 15 min cooking, where cooking time is the prime determinant of quality.

Table 1. Effect of cooking time on water absorption, cooking loss and water used for cooking (soluble nitrogen and starch) in cooked spaghetti produced from two Italian durum wheat varieties

	Capeiti				Creso			
			Water				Water	
Cooking time (min)	Water absorption (%)	Cooking loss (%)	Soluble nitrogen (%)	Starch (%)	Water absorption (%)	Cooking loss (%)	Soluble nitrogen (%)	Starch (%)
10	61.1	4.6	0.16	3.8	64.1	4.2	0.14	4.0
15	70.1	4.7	0.19	4.2	68.6	4.5	0.16	4.1
20	81.1	4.8	0.21	4.3	69.8	4.6	0.18	4.2

Analysis of water used for cooking showed that the percentage of soluble nitrogen was slightly higher in the Capeiti variety than in the Creso variety during the three different periods. The data showed that cooking time affected the percentage of soluble nitrogen in the water. Also starch increased with increasing cooking time. It is not advisable to cook spaghetti more than 15 min in order to minimize loss of soluble nitrogen and starch.

Table 2. Effect of cooking time on the mineral composition of spaghetti produced from two Italian durum wheat varieties.

	Capeiti																	
Cooking time (min.)	Spaghetti (dry basis) (mg/100 g)									Water (mg/100 g)								
	K	P	Mg	Ca	Zn	Fe	Mn	Cu	Mo	K	P	Mg	Ca	Zn	Fe	Mn	Cu	Mo
0	311	284	113	30	16	2.2	3.1	3.2	3.4	—	—	—	—	—	—	—	—	—
10	292	283	110	30	16	2.1	3.0	3.1	3.3	6.0	0.2	1.8	—	—	—	—	—	—
15	266	282	108	29	15	2.1	3.0	3.1	3.3	18	1.1	2.0	—	—	—	—	—	—
20	261	281	106	29	15	2.1	3.0	3.1	3.3	22	2.1	3.1	0.2	—	—	—	—	—

	Creso																	
Cooking time (min.)	Spaghetti (dry basis) (mg/100 g)									Water (mg/100 g)								
	K	P	Mg	Ca	Zn	Fe	Mn	Cu	Mo	K	P	Mg	Ca	Zn	Fe	Mn	Cu	Mo
0	296	271	111	28	18	2.0	3.0	3.2	4.1	—	—	—	—	—	—	—	—	—
10	290	266	110	28	15	2.0	2.8	3.0	4.0	5	2	1	—	0.2	—	—	—	—
15	271	260	106	24	14	1.8	2.8	3.0	3.6	16	3	2	2	1.8	—	—	—	—
20	266	258	104	21	13	1.8	2.8	3.0	3.5	21	5	3	3.1	2.2	—	—	—	—

Mineral content

The Mineral contents of uncooked and cooked spaghetti are given in Table 2. Spaghetti is relatively high in potassium, phosphorus, magnesium and is low in iron, manganese, copper and molybdenum. However, considerable variation was found among cooking treatments. For example potassium in the uncooked spaghetti of the Capeiti variety was 311 mg/100 g. After cooking for 10, 15 and 20 min, the amount of potassium became 292, 266 and 261 mg/100 g respectively. The percentage reduction is 6.1, 14.5 and 16, after cooking 10, 15 and 20 min respectively. Magnesium was reduced by 2.6, 4.4 and 6.3%, after cooking 10, 15 and 20 min respectively.

The trace elements Fe, Mn, Cu and Mo varied in content after 10 min of cooking then became stable after 15 and 20 min of cooking. Copper was reduced by 3.1% after 10 min of cooking and there was no further reduction after longer periods. The Creso variety showed a similar reduction in metal content to the Capeiti variety.

Table 3. Effect of cooking time on vitamin content of spaghetti produced from two Italian durum wheat varieties.

	Capeiti							
	Spaghetti (dry basis) (mg/100 g)				Water (mg/100 g)			
Cooking time (min.)	Thiamin	Riboflavin	Niacin	Panto-thenic acid	Thiamin	Riboflavin	Niacin	Panto-thenic acid
0	0.19	0.11	2.2	0.85	—	—	—	—
10	0.11	0.08	1.1	0.80	0.06	0.02	0.10	0.03
15	0.10	0.06	1.08	0.73	0.07	0.04	0.11	0.11
20	0.10	0.05	0.01	0.68	0.08	0.05	0.15	0.15

	Creso							
	Spaghetti (dry basis) (mg/100 g)				Water (mg/100 g)			
Cooking time (min.)	Thiamin	Riboflavin	Niacin	Panto-thenic acid	Thiamin	Riboflavin	Niacin	Panto-thenic acid
0	0.18	0.12	2.4	0.81	—	—	—	—
10	0.12	0.09	1.3	0.78	0.04	0.02	0.21	0.02
15	0.11	0.06	1.2	0.74	0.05	0.05	0.18	0.03
20	0.11	0.06	1.2	0.74	0.05	0.05	0.18	0.03

The data for minerals in the water used for cooking are given in Table 2. It contained a measurable amount of potassium, phosphorus, magnesium, calcium and zinc and the iron, manganese, copper or molybdenum. Losses of different minerals in the water are relatively small for all cooking-times.

Vitamin contents

The effects of cooking time on the vitamin contents of the cooked spaghetti have been compared. The vitamin values for uncooked and cooked spaghetti are shown in Table 3. It will be noted that uncooked spaghetti showed considerable variations in vitamin contents.

In the Capeiti variety thiamin was reduced by 42 and 47.5% after cooking for 10 to 15 min respectively. The loss after 20 min was equal to the loss at 15 min of cooking. Riboflavin was reduced by 27.3, 45.5 and 54.5% after 10, 15 and 20 min of cooking. Pantothenic was reduced by 6, 14 and 20% after 10, 15 and 20 min of cooking.

In the case of the Creso variety, the reduction of riboflavin and niacin were similar to that of the Capeiti variety but reduction in thiamin and pantothenic was less, as shown in Table 3.

The water used for cooking contained measurable amounts of soluble vitamins. In both varieties the quantities of vitamin leached out increased with increasing cooking time. It is preferable to cook spaghetti for 15 min to minimize loss of vitamins and minerals into the water. The cooked spaghetti will be firm, stable and acceptable for eating.

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The application of near infrared reflectance analysis to rapid flour testing

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Summary

Calibrations are presented for the analysis of flour for protein, moisture, particle size, colour and starch damage by means of near infrared (NIR) reflectance analysis. A commonly used NIR instrument was subjected to a thorough evaluation for its accuracy in flour testing for these parameters, by comparison of NIR with existing methods of analysis over an extensive period of time. The accuracy and precision of NIR for the parameters studied were satisfactory for quality control purposes and therefore the technique has an important place in the rapid flour testing.

Introduction

Near infrared (NIR) reflectance analysis is a rapid, non-destructive technique for the analysis of opaque samples, and the principles and broad applications of the technique have been described previously (Osborne, 1981). Near infrared reflectance is most commonly used for the examination of powdered samples such as ground cereals and flours, therefore intensive investigations have been carried out to develop practical calibrations for the routine analysis of wheat flour in the U.K. and Europe. Flour testing for quality control purposes in mills and bakeries comprises a number of chemical determinations in addition to physical measurements and dough testing. It has been the purpose of the work described in this paper to investigate the possibility of replacing as many of these as possible by NIR.

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0022–1163/82/0600–0355 $02.00

Materials and methods

The instrument

The InfraAlyzer 300B (Technicon Instrument Co. Ltd, Hants, U.K.) consists of a tungsten light source which is directed in turn through ten narrow bandpass interference filters onto the sample surface. The sample is packed into a sample holder, in which it is compressed against a glass window. The diffusely reflected light from the sample at each wavelength is collected by means of an integrating sphere and focussed onto a lead sulphide detector. The detector response is amplified with a logarithmic response amplifier, digitized and fed to the microprocessor unit. In the microprocessor, the logarithmic value of the reflectance signal is compared with that of a reference ceramic-tile and stored as a relative log reflectance value. There will therefore be ten such values obtained for each sample scanned, corresponding to the wavelengths of the ten filters in the instrument.

Calibration

The InfraAlyzer was calibrated by scanning a number of samples (between 50–350) of known composition as determined by chemical and physical methods and recording the log reflectance values (L_1–L_{10}) for each sample. The following equation was then fitted by multiple regression analysis:

$$\%Y = F_0 + F_1L_1 + F_2L_2 \ldots\ldots F_{10}L_{10}$$

It is usually the case that only a few of the ten terms make a significant contribution to the equation and it is desirable to set most of the F values to zero. All possible subsets of the log values were searched to find those which, whilst involving as few filters as possible, fitted the data as well as the full equation, after allowing for the reduced number of terms. When this procedure produced more than one possible subset, the choice between them was made on chemical grounds, i.e. the subset whose filters had the most relevant assignments was chosen.

Methods of analysis

Protein and moisture were determined according to the methods of the International Organization for Standardization (ISO, 1975). Particle size was measured using an Alpine air-jet sieve (Alpine AG, Cheshire, U.K.), a laboratory apparatus in which reduced pressure applied to the underside of a 200 mm diameter woven-wire screen (76 μmesh) brings about sieving. Weighing the overtails from a 10 g sample sieved for 1 min provides a weight of 76 μ oversize. The grade-colour figure (GCF) was measured using a Kent-Jones and Martin flour colour grader Series 3 (Henry Simon Ltd, Cheshire, U.K.). Starch damage was measured by the method of Farrand (1964).

Samples

Calibration sample sets were selected from a total of 577 straight run white flour samples, 379 Bühler milled from single variety U.K. home-grown wheats (1979 harvest) and 198 commercially milled flours, to cover the range normally encountered for the parameter under study. To evaluate the calibrations obtained, a further 209 samples of Bühler milled flour (1980 harvest) and 357 samples of commercially milled flour were used for prediction experiments over a 1 year period.

Results and discussion

Near infrared reflectance analysis has many advantages for quality control, including speed, good reproducibility, no need for skilled personnel or chemicals. However, NIR is an indirect technique and the instrument needs careful calibration in order to achieve reliability in the results obtained. It is relatively easy to obtain a calibration, using a limited number of samples, which has very good accuracy. However, such a calibration is likely to need frequent adjustments over a period of time, as it is used to predict values for sample types which differ from those used in the calibration. In order to achieve calibrations which are stable with time and valid for a wide range of flour types, large numbers of samples were studied, covering all common types of white flour. The details of these calibrations for protein, moisture, particle size, colour and starch damage, and their performance over a period of time are discussed below.

Table 1. Calibration constants (F-values) for InfraAlyzer 300B (U.K. flour)

Filter position	Filter wavelength (nm)	Protein (%)	Moisture (%)	Particle size*	Colour	Starch damage†
0	—	12.48	13.70	5.699	32.43	10.02
1	2050	0	0	0	0	1025
2	2310	0	−143.6	0	0	− 224.8
3	2230	0	76.58	−11.02	0	204.6
4	2139	0	0	0	0	−1814
5	2180	493.7	0	0	0	0
6	1445	0	0	0	0	− 251.5
7	2100	−323.1	0	0	0	1156
8	1940	0	81.67	0	0	− 126.5
9	540	0	0	0	259.8	0
10	1680	−243.4	0	0	− 76.72	0

*Particle size calibration is $\log_e$ (air-jet sieve—2)

†Starch damage F values have been divided by 10, so the result needs to be multiplied by 10 to obtain Farrand units.

Protein

The calibration (Table 1) was obtained using fifty-seven samples of Bühler milled flour and a limited number of predictions of the protein content of commercially milled flour were carried out. However, to check the calibration more thoroughly a much larger number of samples were tested over a period of time. Consequently during the period March–November 1980, 357 samples of commercially milled flour, received at FMBRA for routine protein testing, were examined by both Kjeldahl (ISO, 1975) and NIR methods. These samples came from a wide variety of sources and included all types of flour, from soft English to Canadian Western Red Spring and so had a wide range of protein contents.

Figure 1 shows a plot of NIR *vs* Kjeldahl protein-contents, together with the line on which the points should lie. There is a small bias present, the NIR protein-contents being 0.09% too low on average. The standard deviation (s.d.) of the differences between NIR and Kjeldahl results was 0.20%, or 0.22% without bias correction, with 80% of the observed differences in the range ± 0.27% and 97% in the range ± 0.45%. A further calibration carried out using 379 samples of Bühler milled flour gave an almost identical calibration to that in Table 1 with an s.d. of 0.22. Thus, the calibration is valid for U.K. commercially milled flours and Bühler milled flour from home-grown wheats. The s.d. found is in line with those for other universal calibrations: Williams & Panford (1980) reported a standard error (s.e.) of prediction of 0.24% for protein on 2700 samples of Canadian wheat, and Bell (1980) reported 0.15% for a universal calibration for U.S. white pan-bread flours on a much smaller number of samples covering the narrow range 11.2–13.6%.

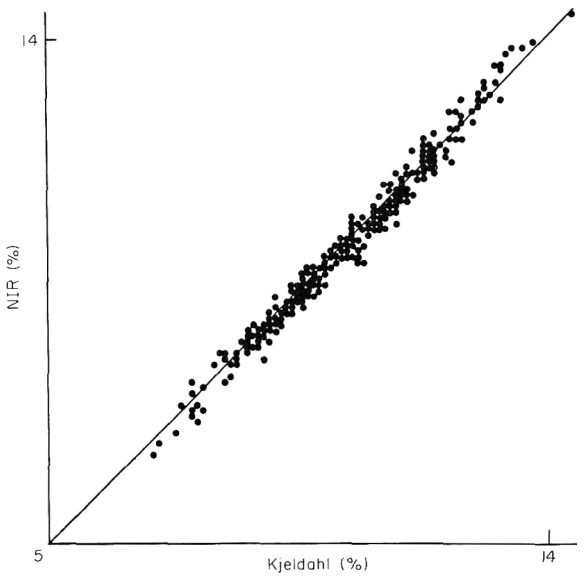

Figure 1. Prediction of protein content of white flour using an InfraAlyzer 300B (356 d.f.)

The accuracy of a method of measurement is normally defined as the s.d. of the differences between measurements and the true values. In this case the 'true' protein contents are not known; for even though Kjeldahl may be taken to be the definitive method of protein measurement, only single determinations were carried out, the results of which will themselves be subject to errors. The sizes of these errors depend on the reproducibility or precision of the Kjeldahl method, which may be assessed by comparing replicate measurements on the same sample. The s.d. of replicate Kjeldahl measurements is reported in the literature to be around 0.15% (Hunt *et al.*, 1977; Miller *et al.*, 1978; Williams *et al.*, 1978). Examination of a limited amount of unpublished FMBRA Kjeldahl data gives a figure of 0.10%. For comparison the precision of NIR protein measurements was estimated by repeatedly packing the sample into the sample cup, after subsampling each time; the precision was 0.06% (19 degrees of freedom [d.f.])

The best that can be done in assessing the accuracy of NIR protein measurements is to take Kjeldahl measurements as standard and subtract from the s.d. of differences above (0.20%) an allowance for the errors in the single-Kjeldahl measurements. This gives a s.d. of approximately 0.15% for the accuracy of NIR, i.e. for the errors which would be observed between NIR and a protein content determined precisely by many replicates of Kjeldahl. The corresponding figure for a single Kjeldahl is the same as the figures for precision given above, i.e. somewhere in the range 0.10–0.15%. Therefore, both the accuracy and precision of NIR protein testing within one laboratory are approximately equal to those of a single Kjeldahl determination.

Moisture

A good calibration (s.d. of differences 0.09%) was first achieved for moisture in Bühler milled flour against oven-drying at 101°C for 16 hr. The measurement of moisture in commercially milled flours, however, is usually carried out by the ICC method (ISO, 1979). Therefore the calibration was used to predict moisture contents as determined by the ICC method on fifty-nine samples of commercially milled flour and the prediction results were used to adjust the calibration for skew and bias. Using the corrected calibration (Table 1) to predict ICC moistures on another ninety-seven samples gave excellent results (Fig. 2) the s.d. of differences between the oven and NIR measurements was 0.17% over a range of 12.3–15.5%. The s.d. of replicates for the oven-drying method was 0.07% (39 d.f.). The precision of the InfraAlyzer was excellent when twenty samples were read in duplicate (after repacking) by three different operators. The precision for a single operator was 0.03% (19 d.f.) while that for all three was 0.05% with no significant biases.

Particle size

It is well known that particle size has a pronounced effect on NIR

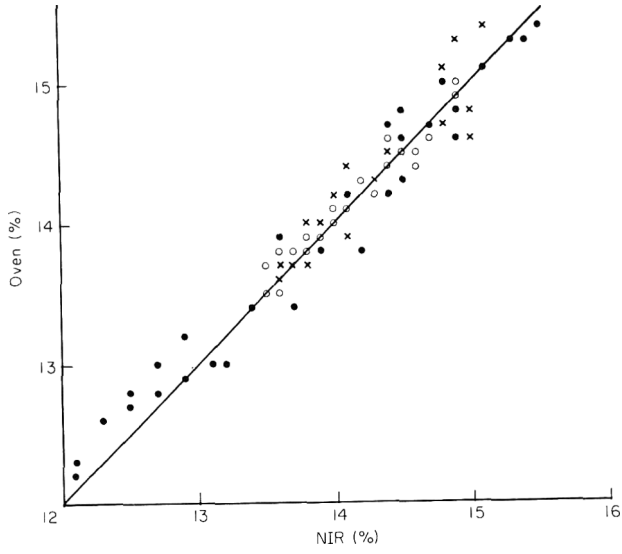

Figure 2. Prediction of moisture content of white flour using an InfraAlyzer 300B (96 d.f.). ●, Commercial; X, Bühler; O, several observations.

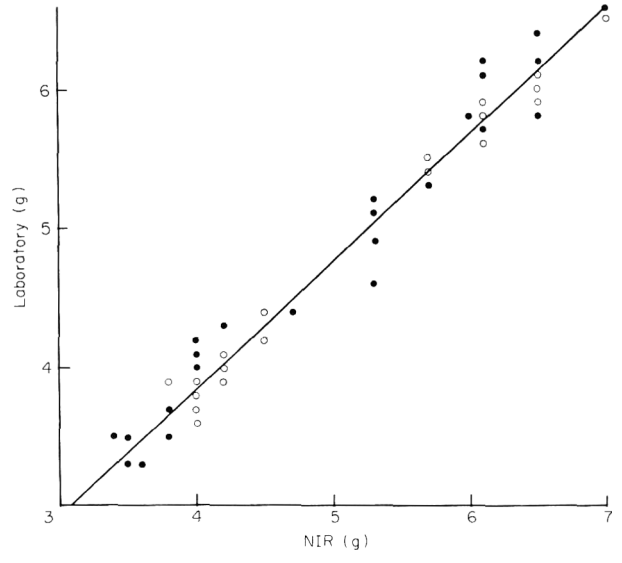

Figure 3. Prediction of flour particle size (76μ air-jet sieve) using an InfraAlyzer 300B (71 d.f.). ●, one value; O, more than one coincident value.

measurements (Osborne, 1980) and that this effect may be utilized for the NIR measurement of particle size (Douglas, 1980). The measurement against which NIR has been calibrated at FMBRA has been the 76 μ air-jet sieve (AJS) figure (Osborne *et al.*, 1981) and work so far has been carried out on Bühler milled flours only. The InfraAlyzer calibration (Table 1) used $\log_e$ (AJS-2) figures

against NIR to correct for slight curvature in the regression line (Douglas, 1980) and prediction results using this calibration for seventy-two samples were excellent (Fig. 3): a s.d. of differences of 0.16 g in the range 3.1–6.6 g. The s.d. of replicates for the air-jet sieve was 0.06 g (20 d.f.), while that for the InfraAlyzer (single operator) was 0.08 g (19 d.f.).

Flour colour (GCF)

Flour colour may be measured using a visible 'Agtron' filter (540 nm) with an NIR reference to correct for particle size and a good calibration between these values and the grade colour figure (GCF) (Kent-Jones *et al.*, 1956) was obtained for 379 samples of 1979 harvest Bühler milled flour. Prediction of GCF values for 100 Bühler milled flours from the 1980 harvest revealed a skew and bias which was corrected and the new calibration (Table 1) used to predict another 109 samples. The pooled s.d. of differences for the 209 samples was 0.44. The calibration was then used to predict eighty-one commercially milled samples with a s.d. of differences of 0.46 with no skew or bias (Fig. 4.) It has been suggested by the InfraAlyzer manufacturer that better prediction of colour can be obtained by polishing the cover of the sample holder between each reading. In fact no significant difference was observed using this technique on the eighty-one commercially milled samples. Also attempted recalibration for these samples gave a result ($r = 0.977$, $\sigma = 0.38$) which was no better than the original calibration ($r = 0.941$, $\sigma = 0.34$). The precision of the GCF measurement was

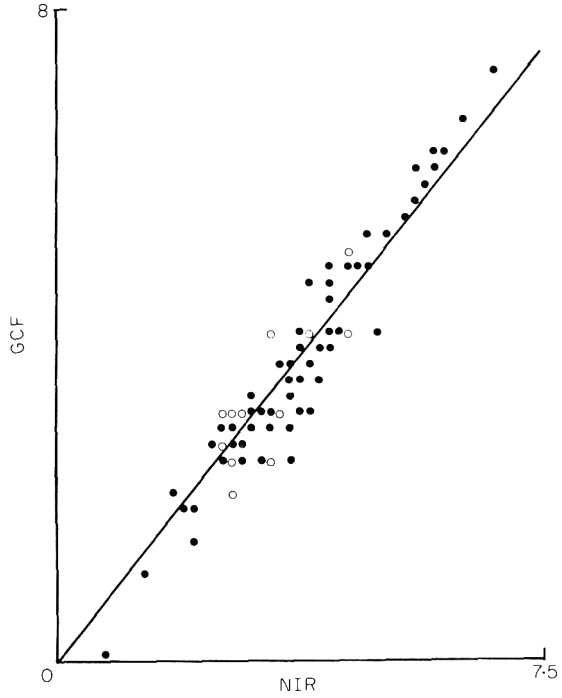

Figure 4. Prediction of flour GCF using an InfraAlyzer 300B (80 d.f.)

0.11 (63 d.f.) while the precision of the InfraAlyzer was also 0.11 (19 d.f.) for a single operator or three different operators. However, there was a significant operator bias with the InfraAlyzer, the means for the three operators being 4.32, 4.39 and 4.48.

Starch damage

Successful calibrations for starch damage in Farrand units (Farrand, 1964) have been achieved at FMBRA using the Neotec 6350 (Osborne & Douglas, 1981) and the InfraAlyzer 400R. The appropriate filters were fitted to the InfraAlyzer 300B and the F-values determined previously (Table 1) were entered. Several sets of samples of commercially milled flour were examined using this calibration and the results compared with Farrand values (Fig. 5). The total number of samples was 143 and the pooled s.d. of differences between NIR and Farrand was 3.2. The pooled s.d. of replicates for the manual determination was 2.0 (58 d.f.). The precision of NIR was 1.7 (single operator) and 1.8 (three operators) on 19 d.f. with a significant bias between operators—the means for the three operators being 26, 24 and 28.

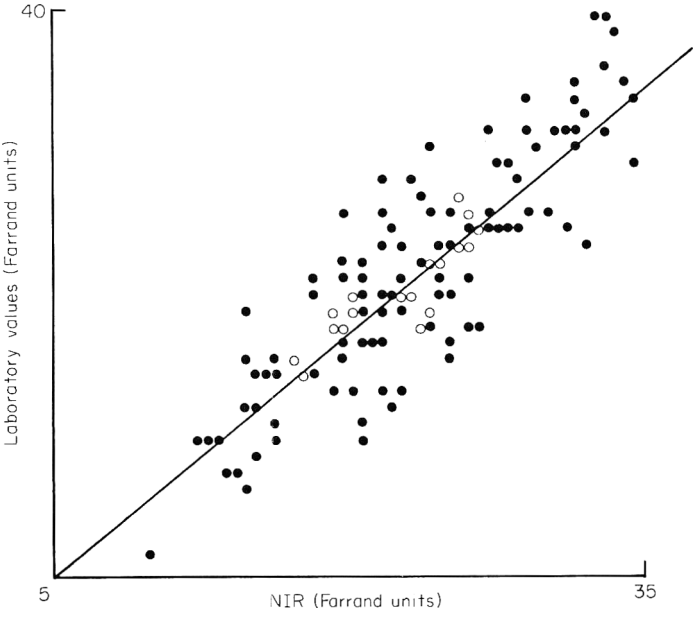

Figure 5. Prediction of starch damage of white flour using an InfraAlyzer 300B (142 d.f.).

Conclusions

Calibration constants (F-values) for those flour parameters which have been shown to be predicted accurately by the InfraAlyzer 300B are given in Table 1 and a summary of the prediction results is given in Table 2. It is believed that

Table 2. Summary of prediction experiments with InfraAlyzer 300B (Flour)

Parameter	Method	^{r}L*	^{r}I†	^{r}IO‡	^{r}P§
Protein	ISO 1871–1975 (E)	0.15	0.07	0.09	0.20
Moisture	ISO 712–1979 (E)	0.07	0.03	0.05	0.17
Particle size	76 μ AJS	0.06	0.08	—	0.16
Colour	Kent-Jones GCF	0.11	0.11	0.11	0.45
Starch damage	Farrand	2.0	1.7	1.8	3.2

*s.d. of replicates for laboratory method (includes subsampling).

†s.d. of replicates for InfraAlyzer (includes subsampling and repacking).

‡s.d. of replicates for between operators.

§s.d. of replicates of differences between InfraAlyzer and laboratory method (i.e. s.e. of prediction); This figure *includes* contributions from ^{r}L and ^{r}I/^{r}IO.

these calibrations will work for all the U.K., milled, straight-run, white flours, subject to individual bias corrections for separate instruments. Thus the NIR instrument has an important place in rapid flour testing.

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Baking quality and gluten amide level

J. A. D. EWART

Summary

MacRitchie (1979) has recently put forward evidence that the percentage of glutamine+asparagine in Australian wheat glutens was highly and positively correlated ($r = 0.756$; $P<0.01$) with baking quality, as measured by loaf volume per unit of flour protein. This finding has been tested for thirty-six English wheats. No significant correlation ($r = -0.036$; $P>0.1$) between loaf volume per g of flour protein (LV) and moles of amide per 100 g of gluten protein could be observed. When the disulphide bonds of some glutens which seemed to differ widely in amide content were reduced and blocked and the proteins examined by gel electrophoresis in 6 M urea at alkaline pH, the expected shifts in mobility due to the amide differences were not seen. The gliadin/glutenin ratios, calculated for a further thirty-six English-grown wheat samples from data already published, showed no correlation with LV. Since these ratios would be positively related to gluten amide level, this was additional evidence that the latter is not correlated with LV for English wheats. It was concluded that nearly all the amide fluctuations among glutens observed in this work were due to experimental error, and the true amide level varied little—probably by a small variation in the gliadin/glutenin ratio and, to a much smaller extent, by occasional mutations.

Introduction

MacRitchie (1979) made the potentially important discovery that the level of amide in gluten was highly correlated ($P<0.01$) with loaf volume per unit of protein in tests on Australian flours. The number of samples tested was thirty-seven from at least ten varieties, four of which were named.

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The purpose of this paper was to extend his finding to U.K. wheats in the hope of being able eventually to screen wheats for baking quality by using near infrared reflectance spectrometry.

Materials and methods

Loaf volumes

Loaves were baked from flour (280 g) by the long fermentation process of Fuller & Stewart (1970), modified in relation to bromate levels as described (Ewart, 1980). Loaf volumes were measured by displacement of rapeseed.

Gluten preparation

Flour (28 g) was mixed for 1 min in a Minorpin mixer with a volume of 1.0 g l^{-1} aqueous NaCl equal to the water absorption. The dough was hand-washed to gluten in 1.0 g l^{-1} NaCl (2 l) taking 15 min. The gluten was pressed with a polythene stopper into a sheet ~5 mm thick on the bottom of a 2 l beaker, standing in acetone-solid CO_2 mixture, till frozen, freeze dried, then ground with a pestle and mortar. After spreading on a sheet of paper, it was left overnight to come to equilibrium with atmospheric moisture, and stored in a capped specimen tube in a Kilner jar. Protein was taken as 5.7 × Kjeldahl N.

Amide determination

Gluten (0.3–0.4 g, accurately weighed) was refluxed in a 100 ml round-bottomed flask with 2 M HCl (20.0 ml) made from the concentrated acid (not ampoules, which contain $HgCl_2$). Duplicate samples of 2.0 ml each were removed at 2 hr and 5 hr measured from the onset of boiling. Before sampling, the flask was cooled in ice water and, by careful manipulation without disconnecting the ground-glass joint, the condensate in the lower part of the condenser was rinsed with the liquid in the flask to give a uniform mixture. Each sample was placed in a 10 ml measuring cylinder and covered with Parafilm.

Immediately before distilling a sample in a Markham still, 2 M NaOH, 20 g l^{-1} $Na_2B_4O_7$, 10 H_2O (2.0 ml) was added, mixed, and 1.0–2.0 μl applied to a narrow-range indicator paper to check that the pH was 9. Before rinsing in the sample, B.D.H. silicone anti-foaming agent (1 drop) was put in the still. Distillation at 4.7 ml min^{-1} was for 3.5 min, timed from the first flow of condensate into the receiver, plus a further 30 sec with the conical flask lowered to wash the condenser tip. The distillate was titrated with 0.01 M HCl using screened methyl-red indicator. Two protein blank titrations were also carried out, the protein being washed into the still followed by the pH 9 mixture. Corrected mean titres were extrapolated to zero time and, after allowing for incomplete NH_3 recovery (average 97.4%), the moles of amide per 100 g of gluten protein were calculated. The ammonia recovery readings were at the beginning (96.9, 96.5%), middle (98.0%) and end of the series (98.1%).

Electrophoresis of glutens

Gluten (30 mg) suspended in 8 M urea (900 μl) was treated with mercaptoethanol (100 μl), flushed with N_2 and kept overnight in a capped tube. Next morning acrylonitrile (190 μl) was added and the mixture left 0.5 hr before

Table 1. Gluten amide levels and loaf volumes per g of loaf protein (LV)

Row	Flour protein (%)	Variety or breeder's ref.	Place of growth	Hagberg falling number	LV (ml g^{-1})	Amide (mol[100 g gluten protein)
1	7.9	Mithras	Rosemaund†	147	63.7	0.247, 0.259
2	8.6	Mithras	Harper Adams†	193	53.9	0.269
3	7.9	Mithras	Cambridge	163	42.9	0.261
4	9.1	Mithras	Sparsholt†	218	42.4	0.261
5	7.5	TJB 989/7	Rosemaund	62	62.7	0.261, 0.209, 0.258
6	8.2	Norman	Harper Adams	120	61.8	0.266
7	8.6	Norman	Sparsholt	200	56.3	0.260
8	8.0	Sentry	Rosemaund	108	61.5	0.284, 0.273, 0.284
9	7.4	TJB 987/5	Rosemaund	67	61.2	0.256, 0.268
10	9.0	Prince	Harper Adams	173	57.9	0.275
11	9.0	Prince	Sparsholt	207	56.6	0.254
12	7.7	Aquila	Rosemaund	164	57.3	0.242, 0.250
13	8.3	Aquila	Cambridge	220	39.9	0.257
14	10.0	Flanders	Sparsholt	185	54.5	0.256, 0.274
15	8.0	Kinsman	Rosemaund	69	47.9	0.151, 0.230, 0.222
16	9.2	Kinsman	Sparsholt	164	45.9	0.265, 0.266, 0.263
17	8.6	Kinsman	Cambridge	191	36.5	0.246
18	8.2	Baron	Rosemaund	153	45.4	0.256, 0.255
19	10.2	Baron	Sparsholt	189	39.6	0.259
20	7.8	Rapier	Rosemaund	176	45.0	0.256, 0.261
21	8.8	Rapier	Sparsholt	189	41.4	0.267
22	9.1	Rapier	Myerscough†	125	41.2	0.273
23	8.4	Rapier	Cambridge	196	39.9	0.258
24	10.0	Maris Huntsman	Sparsholt	167	44.0	0.242, 0.272
25	9.4	Maris Huntsman	Cambridge	202	41.0	0.252
26	8.5	Abele	Rosemaund	173	42.9	0.239, 0.233
27	9.5	Abele	Harper Adams	152	41.9	0.256
28	9.8	Abele	Sparsholt	199	39.0	0.257
29	8.9	Abele	Cambridge	165	38.9	0.254
30	11.7	Vuka	Cambridge	187	42.8	0.284
31	11.8	Tabor	Cambridge	161	42.8	0.281
32	10.4	Brigand	Cambridge	156	42.1	0.275
33	10.6	Armada	Myerscough	150	40.3	0.277
34	11.9	Avalon	Cambridge	180	40.0	0.264
35	10.0	Galahad	Cambridge	163	40.0	0.267
36	12.1	Disponent	Cambridge	183	39.8	0.268
37*	13.0	Valdur (durum)	Cambridge	68	37.6	0.258
38*	12.7	CWRS	—	197	39.9	0.265

*Rows 37–8 were not used for correlating. Mean value of 54 observations = 0.257, including rows 37–8.
†Rosemaund, Harper Adams, Sparsholt and Myerscough are in Herefordshire, Salop., Hants and Lancs. respectively.

centrifuging. The supernatant liquid (~20 μl) was loaded in a channel of a polyacrylamide slab gel, 6 M in urea, made according to the method of Davis (1964) with slight modification, and subjected to electrophoresis for 4 hr at about 75 Vcm^{-1}.

Results and discussion

English wheats

In Table 1 and Fig. 1 the results are set out. The Hagberg falling numbers are based on the 5.0 g method (as were those of Ewart (1980) though unfortunately not stated). Although all the experimental values for amide are included in the last column of Table 1 and plotted in Fig. 1, only the mean value (where applicable) of each row was put into the computer when searching for correlation.

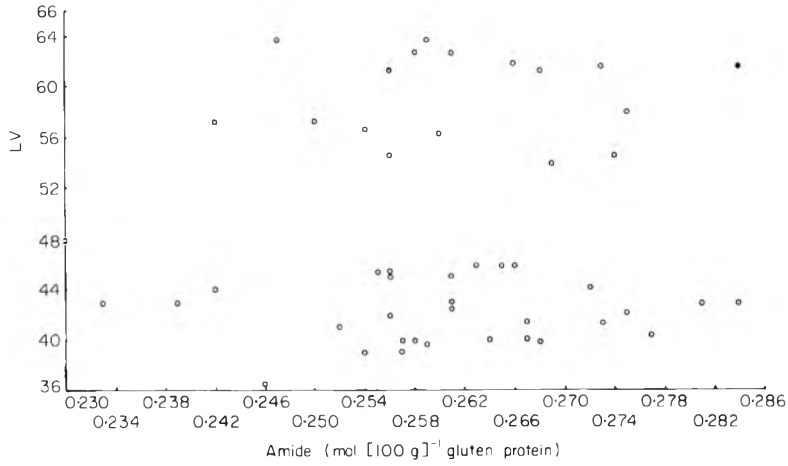

Figure 1. Loaf vol. g^{-1} flour protein (LV) *vs* mol amide $[100\ g]^{-1}$ gluten protein for thirty-six U.K. wheats. Three points, (0.151, 47.9), (0.222, 47.9) and (0.209, 62.7), lie outside the diagram. ●, Two coincident points.

No significant correlation ($r = 0.036$; $P > 0.1$) could be found between LV and gluten amide level which is expressed in mol $(100\ g)^{-1}$ gluten protein unless otherwise stated. Although not included in the thirty-six samples used to search for correlation, an English durum wheat and a Canadian Western Red Spring (CWRS) were also tested. (The LV of the CWRS in Table 1 is poor because this very high quality wheat was baked by a method quite unsuited to it). The two wheats were taken as examples of very poor and very good bread-making quality, yet their levels of amide (Table 1, rows 37 and 38) do not differ significantly from 0.257, the mean of all the determinations in Table 1. From duplicates, a value of 0.017 was calculated for the standard deviation (s.d.) of a single determination.

MacRitchie (1979), observing no changes in amide content of glutens after hydrolyzing for more than 45 min, used a time of 1 hr without further corrections. As it was noticed here that the slopes of the extrapolation lines fluctuated, two further correlations were made using the mean titres at 2 and 5 hr respectively. This was closer to the technique adopted by MacRitchie, and by eliminating errors in extrapolation, the s.d.'s at 2 hr and 5 hr improved to 0.013 and 0.009 respectively. In neither case, however, was any significant correlation observed.

Other evidence

Pence *et al.* (1950) measured the amide content of seventeen glutens from wheats exhibiting a wide range of baking quality. The mean value was 0.261 and the s.d. of an individual reading was 0.007. Their mean is slightly higher than in this work, but they did not extrapolate to zero time.

Although only four loaf volumes were mentioned in their paper, Dr D.K. Mecham has kindly supplied the author with all seventeen values (Table 2), and drawn his attention to the fact that the 'baking qualities' of these wheats (i.e. the slope of the regression line of loaf volume against protein content) were published later (Pence, Weinstein & Mecham, 1954).

The correlation coefficient of LV with gluten amide for the data of Pence *et al.* (1950) was -0.49 (P just < 0.05), in the opposite direction to that found by MacRitchie, but Cornford pointed out that as their amide results fell into only

Table 2. Amide levels, protein contents and 'baking qualities' of Pence *et al.* (1950, 1954) and loaf volumes supplied by Dr D.K. Mecham.

Variety	Protein content (%)	Amide ammonia (g [100 g]$^{-1}$ gluten protein)	'Baking quality' cc ([% flour protein]$^{-1}$ ±95% limits of confidence)	Loaf volume (ml)	Calculated LV (ml g^{-1} flour protein)
Hymar	5.7	4.2	30.5 ± 18.3	454	79.6
Yorkwin	7.6	4.3	35.4 ± 7.2	558	73.4
Rex	7.8	4.3	45.7 ± 24.4	583	74.7
Purkof	8.7	4.4	54.5 ± 13.5	645	74.1
Tenmarq	8.8	4.5	33.5 ± 12.6	600	68.2
Hymar	9.0	4.6	30.2 ± 6.4	618	68.7
Goens	9.1	4.4	31.7 ± 11.3	663	72.9
Baart	9.5	4.5	48.7 ± 9.9	614	64.6
Chiefkan	9.6	4.4	31.2 ± 28.9	531	55.3
Comanche	9.7	4.6	56.9 ± 60.8	629	64.8
Turkey	10.2	4.4	47.1 ± 5.5	665	65.2
Red Chief	10.3	4.5	48.9 ± 12.0	516	50.1
Pentad	11.6	4.5	44.0 ± 12.8	436	37.6
Premier	11.7	4.6	54.0 ± 6.1	639	54.6
Red Chief	12.9	4.5	50.8 ± 9.9	595	46.1
Turkey	13.4	4.4	61.6 ± 5.1	769	57.4
Thatcher	14.2	4.6	67.2 ± 1.6	888	62.5

five categories, the application of statistical methods applicable to continuous variables may have somewhat over-emphasized the significance.

'Baking quality' (Table 2), in contrast, showed weak positive correlation with gluten amide, $r = 0.414$ ($P \sim 0.1$). However, a few rather large errors were present in 'baking qualities', which are not strictly comparable with LV because protein levels of the flours were raised or lowered by re-adding their own starch, gluten and water solubles as appropriate.

In these laboratories in 1966, amide measurements were made on glutenins and gliadins from four flours (Ewart, 1967). Assuming equal quantities of glutenin and gliadin were present in the gluten, amide values of 0.265, 0.263, 0.277 and 0.264 were obtained respectively for Wichita, Conley, Cappelle-Desprez and Elite. Since the two American wheats would almost certainly have had higher quality glutens than the two English-grown, this evidence also does not imply any correlation. As strong wheats tend to be higher in glutenin any correction on these lines would lower the amide value of the strong glutens still further because glutenin has less amide than gliadin (Ewart, 1967; MacRitchie, 1979).

MacRitchie's results

MacRitchie's results (1979) indicate a good, positive correlation ($P < 0.01$) between loaf volume per unit of protein and percentage of anhydro (glutamine + asparagine) in gluten.

MacRitchie stated, 'the standard deviation per mean (glutamine + asparagine) determination was 0.3%'. Making an approximate calculation of the mean amide value of 32.42% (0.253 mol $(100\,g)^{-1}$ gluten protein) from readings off his Fig. 2, the coefficient of variation (c.v.) was therefore 0.9%. (The factor 128 he uses should actually be 127). The c.v.'s of Pence *et al.* (1950) and in this work were 2.7% and 6.5% respectively. If extrapolation errors were eliminated (as was done by MacRitchie) the c.v.'s are reduced in this work to 5.4% (2 hr) and 3.8% (5 hr). There is no indication of the c.v. to be expected in the paper of Eastoe, Long & Willan, (1961) which describes the technique used by MacRitchie. The titres used by Eastoe *et al.* (1961) were of a similar order to those employed in this work.

Electrophoretic evidence

The range of MacRitchie's results was 31.2–33.7, i.e. 2.5. He states that part of this will be due to scatter, so assuming that 95% of the results lie within $\pm 2 \times$ s.d., i.e. 1.2, about half the observed variability could be attributed to this cause. Accordingly it should be quite common for two wheats taken at random to differ by one third of the range that is not accounted for by random errors, say 0.4. In a polypeptide chain of 32 000 mol. wt, MacRitchie's mean value, 32.4, is equivalent to $(32.4 \div 128) \times 320 = 81$ residues of amide. A difference of 0.4 corresponds to 1 residue and so, on average, there should be a

charge difference of 1 unit per polypeptide chain at alkaline pH. In the English wheats, however, no significant difference in mobility could be detected, when glutens with apparently wide variations in amide content were reduced and blocked then run on polyacrylamide gels in 6 M urea at alkaline pH.

Nevertheless this experiment could be accounted for by postulating that the Glu + Asp content did not vary between wheats, but wheats with higher amide levels contained extra Gln + Asn. If this were so, a higher amide level would mean more Glx + Asx, but this is not supported by the results of Pence *et al.* (1950) where no significant correlation ($r = 0.094$) between content of amide and of Glx + Asx could be discerned.

Causes of gluten amide variation

There is now a mass of evidence that glutens exhibit varietal differences in the electrophoretic patterns of their constituent polypeptides, presumably due to genetic changes. Doubtless some of these mutations will involve Glx and Asx residues thus producing occasional small divergences in the amide contents of glutens.

There seems to be no evidence that any polypeptide chain from a true-breeding wheat will not retain its own amino acid sequence, hence within such a variety fluctuations in amide would most probably be achieved, as MacRitchie (1980) pointed out, by changes in the relative proportions of polypeptide chains, for example in the gliadin/glutenin ratio (IA/UT). This would be positively related to the amide content of gluten because gliadin has more (Gln + Asn) than glutenin (Ewart, 1967; MacRitchie, 1979). (Alterations in the ratio would not be detected by electrophoresis unless substantial enough to affect band intensities).

Gliadin/glutenin ratio

The gliadin/glutenin ratio, calculated from data for thirty-six U.K. wheat samples studied recently (Ewart, 1980), had a mean of 1.09 and ranged from 1.35–0.65 with a calculated s.d. for each value of 0.092. From published analyses (Ewart, 1967) it may be shown that the ratio would have had to extend from about 2–0.5 to account for the variation found in the Australian wheats by MacRitchie (1979). As only six IA/UT results lay outside the 95% confidence limits, this implied that although most of the range can be attributed to random error, there is some real variation. The gliadin/glutenin ratio showed no correlation with LV ($r = -0.092$), thus supporting the other experiments in this work.

Conclusion

The conclusion is that the level of amide in the glutens studied here may be variable due to two causes. There could be intervarietal fluctuation due to

mutations, but these are likely to be too small to be detectable by ordinary methods of amide determination. Furthermore, both between and within varieties, there may be minor disparities in IA/UT. Neither IA/UT nor gluten amide level appeared to have any correlation with baking quality. Thus attempts to extend to English wheats MacRitchie's finding (1979) have been unsuccessful. It is worth noting that the correlation found in the Australian wheats by MacRitchie (1979), for which no explanation exists at present (MacRitchie, 1980), must predict that good baking quality will be associated with high IA/UT, i.e. with lower levels of the glutenin that is usually regarded as determining baking strength.

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Dehydration of potato

I. Air and solar drying at low air velocities

M. N. ISLAM* AND J. M. FLINK†

Summary

Drying behaviour of potato in a natural convection, solar dryer was investigated. In drying experiments conducted at low air velocity, as found in the solar dryer, it was shown that air flow conditions are of critical importance for drying behaviour. As a result of the presence of extensive, external mass transport resistances in deep bed drying, the air flow behaviour of the bed was more important than the drying behaviour of the single pieces. Thus, for deep bed solar drying, 10×10 mm french cut potatoes dried faster than 5 mm slices. (This result was opposite to that found for drying in thin layers). Drying time was noted to increase less rapidly than bed depth increased, so overall dryer productivity increased with increasing bed depth, within the constraint that drying be completable in 1 day.

Introduction

In Bangladesh, potato is widely used as a vegetable, especially in winter which is the potato growing season. This gives a good nutritional combination with rice (the staple food) since their respective limiting amino acids are complementary. Potato is an especially productive crop in terms of dry matter and calories per acre. Bangladesh has the potential for producing as much as two to three times more potatoes per acre than is produced at present, but an important limitation to increased production is the lack of suitable preservation methods. Cold-storage warehouses are in limited use but this uses much energy which results in three to four times higher prices.

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A better solution would be development of processed potato products in Bangladesh, based on simple and inexpensive processes which, furthermore, do not involve major changes in food habits. One such modest approach would be dehydration, in which the major energy source is solar energy which is abundant in Bangladesh, especially in the potato harvesting season (during December–February, temperature varies between 26–28°C and rainfall between 0.5—2.5 cm). Direct solar radiation as an energy source in food processing is used all over the world for producing sun dried fruits, vegetables, fish, meat etc. While sun drying takes place at temperatures slightly above ambient, which can result in various biological contamination problems, solar drying at temperatures significantly above ambient improves product quality (due to shorter drying time), reduces risk of insect infestation and increases production rate.

Khan (1964) developed a direct absorber type solar dryer fitted with adjustable external mirrors, which he used for drying fruits, vegetables and fish. At air temperatures from 85–93°C in the drying chamber, he reported drying times of 5.5—11 hr depending on the product being dried and its final moisture content. According to Moy *et al.* (1977), Lawland built a wind ventilated, indirect solar dryer in 1965, which reportedly gave a much better end product than natural sun drying. Moy *et al.* (1977) reported on studies in progress on the utilization of solar energy in food dehydration, and described drying characteristics for different types of solar dryers (direct absorption type, indirect mode type and mixed mode type). They noted that addition of reflectors to direct absorption dryers is valuable for intensifying solar radiation, which helps to increase drying rate. In their study, they also noted the effects of piece size and bed loading density, and indicated that air flow condition in the dryer was important in regard to drying behaviour. They also indicated that their indirect mode dryer was relatively ineffective compared to the other types. Bryan, Charles & Berry, (1977) designed a solar dryer to collect direct and plane reflected solar radiation. While drying of parsley (at a loading density of 3.0 kg/m^2) could be completed within 6.5 hr (i.e. 1 day), it was necessary to use a supplementary air drying at night when drying diced carrots (at a loading density of 11.1 kg/m^2). Many studies on solar drying of grains have been reported in the literature (Islam, 1980), but it must be noted that these studies are of limited value relative to studies on food dehydration, since for grain drying only a low temperature rise of the drying air is necessary, while in food dehydration significantly higher air temperatures are desired.

In the current project, it was decided that the drying process should be independent of external energy (i.e. fossil fuel or electrical energy), both to save foreign exchange and allow implementation in rural areas, where energy resources are scarce. This decision means that air flow in the drying system is by natural convection, which results in low air velocities for drying. Most drying literature and analyses are based on higher air velocities, so that Fick's law can be applied without considering external resistance to mass transport. For low air velocity, natural convection drying of thin samples, such as generally exists for solar drying, drying analysis must consider both internal and external mass

transfer resistances, as noted by King (1968) and Vaccarezza & Chirife (1978). Vaccarezza, Lombard & Chirife (1974) have shown that for 4 mm slices, drying rate increases with increase in air velocity. Using results of a study by Saravacos & Charm (1962) in which low air velocity (2.0 m/s) was combined with low sample thicknesses (0.14–0.59 cm), Vaccarezza & Chirife (1978) demonstrated that the drying must have occurred with significant external mass transfer resistance, though the original authors neglected this fact in their analysis. Under conditions where external resistance has a significant role, the drying rate will be less sensitive to differences in sample thickness than theoretically predicted by drying analysis based on internal diffusion of water in the sample. In this case, the value of the exponent, n, of the power law equation representing the thickness dependence of the drying rate constant will have a value less than 2, which is predicted by Fick's unsteady state diffusion equation (Vaccarezza & Chirife, 1978). It has also been noted that the thickness dependence of sample temperature (so-called heat transfer effects) in drying can influence the n value (Vaccarezza & Chirife, 1978).

This project is aimed at investigating means for producing shelf stable products using processes suitable for implementation in rural areas of Bangladesh. This consideration resulted in the choice of dehydration as the method of preservation, while the condition of no external energy input resulted in the choice of solar drying with natural convection. In part II (p. 387) of this paper, the influence of osmotic concentration on solar drying is discussed.

Materials and methods

Basic procedure

Potato (Bintjee variety) was obtained from either the Danish Potato Research Station (Vandel Denmark) or at the local supermarket. The potato was peeled and cut into the desired sizes and shapes. In some cases samples were osmotically pre-concentrated in 45% sucrose/15% salt solution for between 4–18 hr prior to drying. At all steps of the process total sample weights were measured and samples taken for moisture contents. (Osmotic concentration will be described in more detail in Part II, p. 387.) The potato samples were placed in trays at the specified tray loading density and packing geometry and drying commenced. Weight loss was used as a measure of extent of drying, while sample and process temperatures were measured on a multipoint recorder using fine wire copper-constantan thermocouples. To simplify analysis of thin layer drying studies, air flow was parallel to the major faces of the sample, and for 10 mm samples the edges were sealed by gluing aluminium foil to the edges. For drying experiments with french cut potato samples (10×10 mm), three bed packing geometries were used: flat, upright and random. Flat was a tightly packed configuration with little space between pieces, upright packing had the

samples held vertically in the air stream, giving extensive open space, while random packing resulted from dumping the potato sample onto the tray and making only minor redistribution to ensure an even thickness across the tray.

Dryers

A 'two-way' drying system consisted of a basic dryer body that could be fitted to either an electric heater and fan unit or a 1.25 m^2 solar panel (Fig. 1). This 'two-way' system was necessary since solar drying experiments could not be conducted all year round in Denmark due to the short summer and unstable weather conditions.

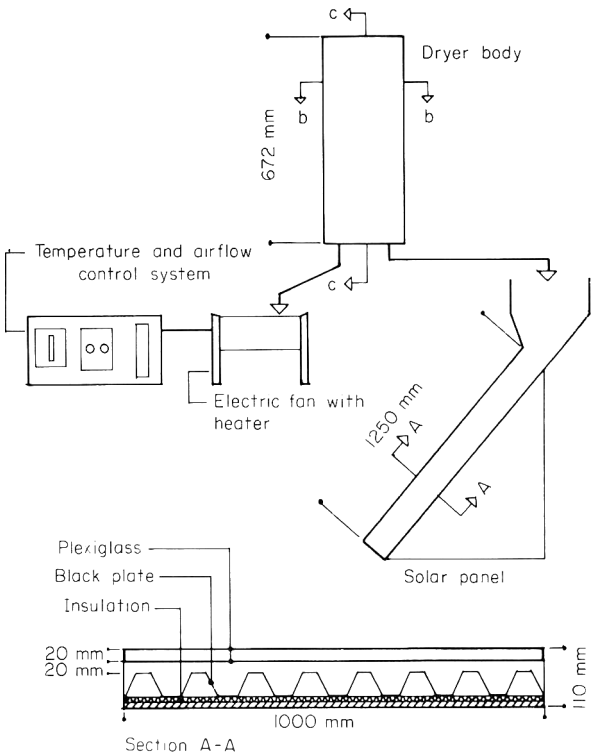

Figure 1. Schematic diagram of 'two-way' drying system with cross section of solar panel.

The dryer body could hold up to eight wire mesh trays (181×181 mm). For thin layer drying, wire mesh holders were used to hold the samples vertical so that air flow was parallel to the two major sample faces. Normally the air flow passed through the bed of sample on the tray and was thus generally perpendicular to one major face. The solar panel (Fig. 1) consisted of a corrugated, black plate heat absorber situated beneath a double glazed cover plate made of plexiglass sheets. The back and two sides of the panel are insulated with polystyrene foam. The panel was mounted at an angle of approximately 50° so as

to be roughly perpendicular to the incoming solar radiation in Denmark. In the panel air surrounding the black plate is heated, decreases in density and moves upwards, inducing a natural convection flow with fresh air coming in at the bottom opening. The heated air was used for drying by fitting the panel exit to the dryer body.

In the initial stages of this study, a small, electrically heated dryer was also used. In this dryer, air velocities up to 1.0 m/sec could be attained. By changing the dryer orientation, it could be used for either thin layer or deep bed drying studies.

Results and discussion

Thin layer drying

To examine the effect of air flow at low air velocities on drying rate, 5 mm potato slices were dried at 52°C (dry bulb) with either 0.47 or 1.0 m/sec air velocity. As seen in Fig. 2, drying rate is higher for the higher air velocity at any moisture level in the sample, which means that, for 5 mm thick samples drying at low air velocities, (values which approximate our average solar drying conditions), external mass transfer resistance is a significant proportion of the overall mass transfer resistance. In this case, analysis of drying by idealized diffusion equations will not apply.

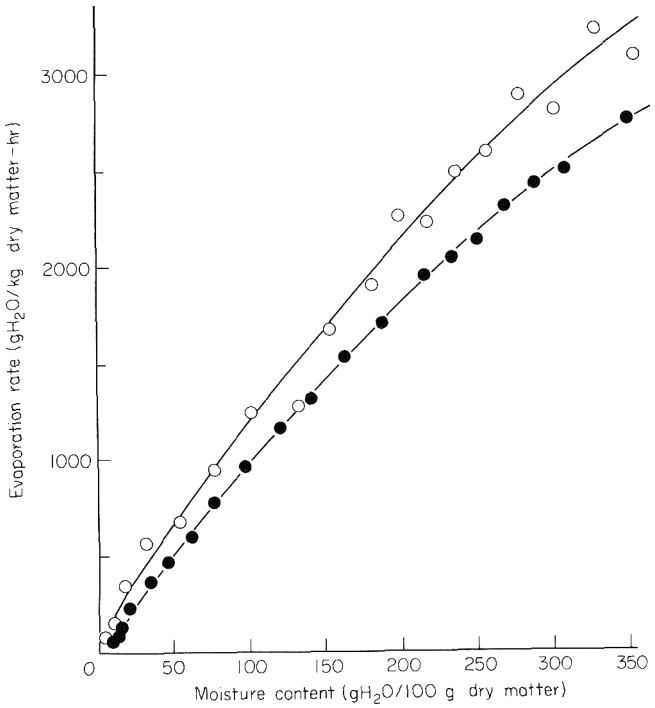

Figure 2. Effect of air velocity on drying behaviour of 5 mm potato slices. O, 1 m/sec; ●, 0.47 m/sec.

In another phase of this study, drying was conducted at a 2.5 m/sec air velocity for various sample thicknesses. The mass transport resistance balance (external *vs* internal) was evaluated from the exponent of the power law equation, relating drying rate to sample thickness, as described by Vaccarezza & Chirife (1978). From the drying results, n was found to have a value of 1.7. As n value goes from 1 (for totally external mass transport resistance) to 2 (for totally internal mass transport resistance, the calculation indicated that for pieces in the range 4.5-10 mm, a velocity of 2.5 m/sec will still result in some external mass transport resistance. Tests were not conducted at higher air velocities, since in our solar drying studies using samples up to 10 mm thickness, air velocity for natural convection is generally below 1 m/sec, and thus both external mass transfer resistance and air velocity will have a significant influence on drying behaviour.

Regarding sample geometry, one can note that the effective sample thickness is the important geometrical consideration relative to internal mass transport, while surface area per unit weight is the important geometrical consideration relative to external mass transport. Under conditions of low air velocities, where both external and internal mass transport are significant, both sample surface area and effective thickness are of importance, relative to drying behaviour. To investigate the effect of sample surface area and thickness on drying rate at low air velocity, three potato samples (5 mm and 10 mm slices and 10×10 mm french cut) were dried at 69.5°C and a 1.0 m/sec air velocity. The results (Fig. 3) show that 5 mm slices have a higher drying rate than either the 10 mm slices or the french cut, though the difference between 5 mm slices and french cut is much less than between either 5 mm and 10 mm slices, or french cut and 10 mm slices.

Consideration of sample geometry differences, especially surface area per unit weight and effective thickness (as equivalent infinite slab thickness), can give an explanation for the above results. If potatoes are cut into the geometries listed above, the surface area per unit weight for the 5 mm slices and 10×10 mm french cut are about equal, and about twice the value found for 10 mm slices. In determining the equivalent thickness as infinite slabs for the three geometries, the 5 and 10 mm slices can be considered to act as 5 and 10 mm thick infinite slabs, while the 10×10 mm french cut is the geometric intersection of two orthoganol 10 mm infinite slabs. Its calculated, effective thickness, expressed in terms of a single infinite slab, is approximately 7.8 mm. The faster drying of the 5 mm slices and french cut, relative to 10 mm slices, is due to both the higher surface area per unit weight and their lower effective thicknesses. The lower rate for french cut slices relative to 5 mm slices is presumably due solely to the higher effective thickness of french cut slices, since surface area per unit weight is essentially the same. As french cut slices have lower effective thickness, as well as higher surface area per unit weight than 10 mm slices, they dry faster and are closer to the 5 mm slice's behaviour. It must be noted here that the above results apply for thin layer drying, and that in deep bed drying (such as is the case for solar drying) it will be shown later that other factors, such as bed flow resistance, play an important role on the relative effectiveness of the various geometries.

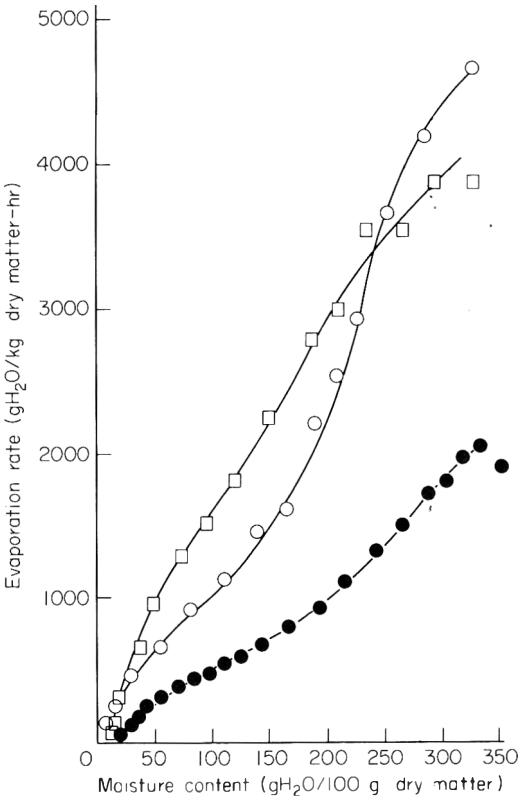

Figure 3. Effect of sample geometry (surface area and thickness) on drying behaviour of potato. O, 10×10 french cut; □, 5 mm slab; ●, 10 mm slab.

Deep bed drying

In contrast to the thin layer drying, where each piece is individually located in the air stream, in deep-bed drying the packing geometry of the sample in the bed can significantly influence the overall air flow conditions. Since, when drying at low air velocities, air flow conditions have a major influence on drying behaviour, the air flow resistances of 60 cm deep packed beds of the two more promising, sample geometries from thin layer drying experiments (5 mm slices and 10×10 mm french cut) were determined. It was found that the french cut samples gave less air flow resistance than the 5 mm slices, presumably due to the lower packing ratio for the french cut samples. This result means that under conditions of natural air convection, a bed of french cut samples will permit a higher air velocity through the bed than a bed of 5 mm slices of equal height. For the solar dryer, this effect will be critical, since the volume of drying air (and hence heat delivery and moisture removal capacity) is related to the air velocity achievable.

An important consideration in deep bed drying is bed depth. The overall efficiency of utilization of the drying air will increase as the bed depth increases, but at the same time total drying time for the bed also increases. As 1 day drying was a design requirement in this project, it was important to evaluate the relationship of bed depth and drying behaviour. Beds of 5 mm slices of 4, 8 and 12 cm depth were dried at 50.5°C and a fan power which corresponds to 1 m/sec under thin layer conditions. (The choice of constant fan power rather than constant air velocity was made with consideration to the expected air flow behaviour for the solar panel). Figure 4 shows that drying occurs more slowly as the bed depth increases, which is not surprising since more moisture must be evaporated for the thicker beds, and that, for a given fan power, air velocity should be higher for the thinner bed. At constant fan power, the decrease in air velocity in the bed as the bed depth increases followed a power law equation in which a three-fold increase of bed depth would give a halving of the nominal air velocity.

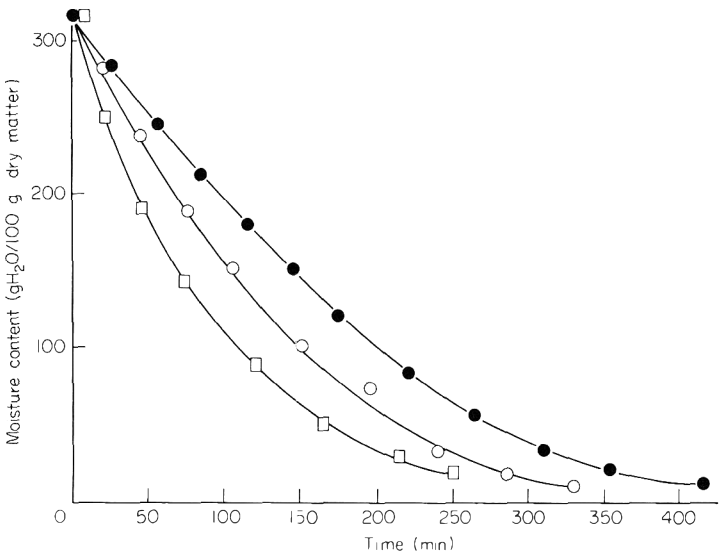

Figure 4. Effect of bed depth on drying behaviour of deep beds of 5 mm potato slices. T_{db} = 50.5°C. ●, 12 cm; O, 8 cm; □, 4 cm.

When the drying time to a specific moisture ratio (moisture content during drying/original moisture content) is considered (Fig. 5), it is seen that a tripling of the bed depth from 4 cm to 12 cm gave only a doubling of drying time. This result is apparently due to the improved efficiency of utilization of the heat in the drying air, since the 'end effects' at the top of the bed, which result in heat losses, are a smaller proportion of the total heat transferred in the bed throughout the drying. This observed drying behaviour is important since it indicates that bed depth should be as high as possible, within the limitation that drying of the top layer of the bed be completed in a single day.

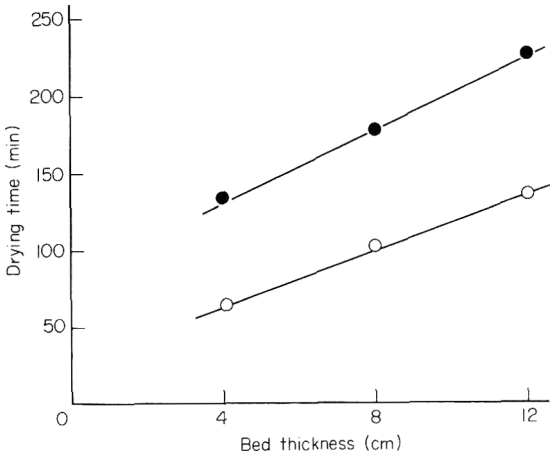

Figure 5. Influence of bed thickness of 5 mm slices on drying time to given moisture ratios. ●, Moisture ratio = 0.25; O, moisture ratio = 0.5.

Solar drying

Studies were conducted in the summer months with the solar panel fitted to the dryer body as shown in Fig. 1. The efficiency of the solar panel in converting solar radiation to heated air in the dryer body was evaluated at three air velocities, obtained by partial blocking of the dryer exit. Data shown in Table 1 indicates that with increasing air flow rate, solar panel efficiency increases, while outlet air temperature decreases. Measured efficiency (energy in exit air as % of insolation energy) ranged between 28–96%. In practice, meeting conditions needed for solar drying (namely, to have an adequate, dryer air temperature) will require operating the solar panel at suboptimal efficiency. The relationship of air velocity to solar panel efficiency and dryer air temperature can result in some reconsideration of the earlier statement regarding maximum bed depth, since bed depth, by effecting air velocity, will have a secondary effect on solar panel efficiency and dryer air temperature.

Table 1. Influence of air velocity on temperature rise and calculated efficiency of solar panel.

Air velocity (m/min)	Inlet temperature (°C)	Outlet temperature (°C)	Efficiency (%)
44	20.5	52.5	95.6
40	22.1	56.9	82.8
13	22.6	59.1	28.3

While the data in Table 1 indicate achieved temperature rises of 32–37°C at a 20–22°C ambient, we can note that on a few occasions when drying potato at a 29°C ambient, temperature rises of about 45°C were attained at an air velocity of about 0.25 m/sec.

In one experiment in which solar drying was compared with sun drying, it was observed that sun drying required about twice as much time as solar drying (13

vs 7.5 hr). Further, the solar dried product had better colour than the sun dried, presumably due to less overall enzymic-browning for the faster solar drying process. More rapid passage through the sensitive temperature and moisture ranges will also reduce the risk of microbial growth during solar drying, and since solar drying is conducted in an enclosed chamber, the aesthetic acceptability of the product will be improved.

Studies were conducted on the effect of bed depth in the dryer on the time required for solar drying. Equal thicknesses of potato samples were loaded in each of three trays, which were vertically stacked in the dryer body. As the trays are tight fitting in the dryer body, the system acts as a single bed, and yet the drying behaviour of the three layers can be analysed individually. A comparative study of bed depths of 9 cm (3 × 3 cm) and 4.5 cm (3 × 1.5 cm) showed that doubling the bed depth resulted in a 1.4 times increase in drying time (80 mins *vs* 112 min for the first third (tray) of each bed). These results closely follow those obtained in laboratory air drying of deep beds, and as noted earlier, is primarily related to improved utilization of the input energy as the bed depth increases. The above results also indicate that air velocity differences resulting from increased bed depth do not significantly alter the ability of the solar panel to deliver the required energy.

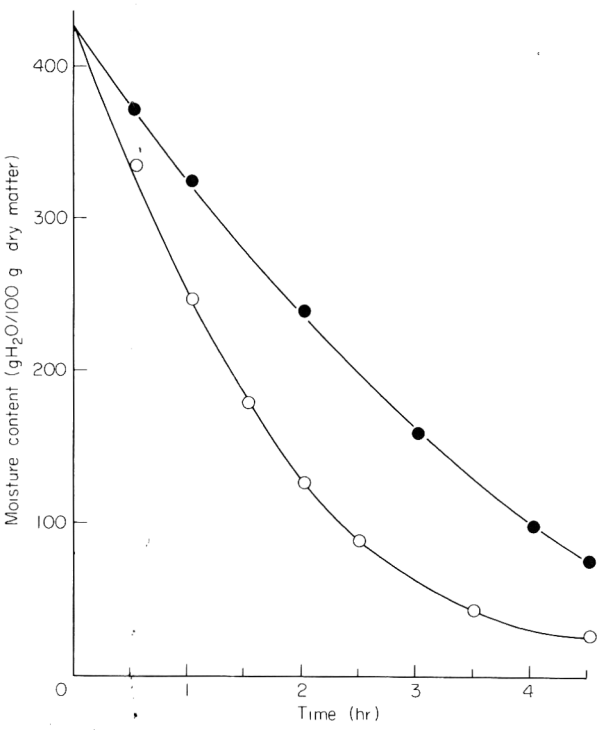

Figure 6. Comparative solar drying behaviour of potato in 5 mm slices and 10 × 10 mm french cut samples. ●, 5 mm slice; O, french cut.

It has been noted earlier that sample geometry has an influence on drying behaviour in thin layers, and on air flow behaviour in packed beds. As air velocity is important to the heat output potential of the solar panel, tests were conducted to evaluate the solar drying behaviour of three geometries, 5 mm slices, 10 × 10 mm french cut samples and 10 mm cubes. When the 5 mm slices were compared to the 10 × 10 mm french cut (at 8.0 kg/m^2, about a 3 cm bed), drying was significantly more rapid for the french cut (Fig. 6). This contrasts with the earlier noted results for drying in thin layers, and is most likely due to reduced air flow resistance for the french cut bed, with the resultant increase in air flow improving the dryer-solar-panel effectiveness. An attempt to further improve drying behaviour by preparing 10 mm cubes from the french cut samples (to give about a tripling of surface area per unit weight), gave instead a reduction in drying rate, which appears related to the poorer air flow characteristics of the cubes. This is undoubtedly due to the higher packing density, which resulted from converting the elongated french cut samples to tighter packing cubes.

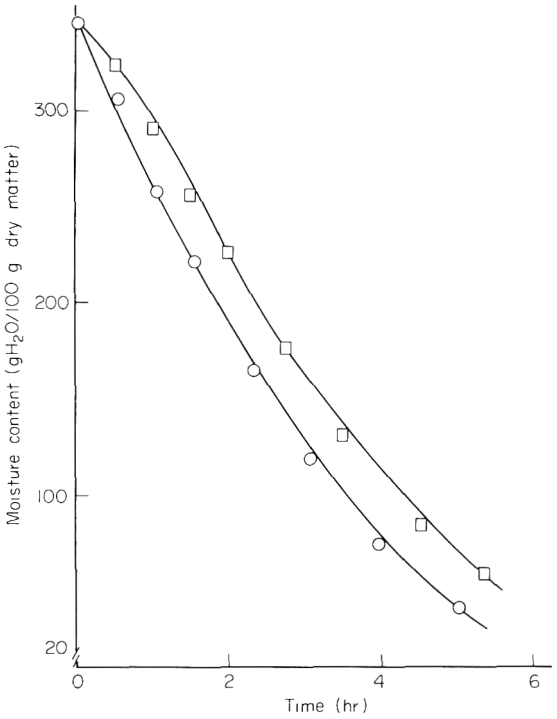

Figure 7. Comparative solar drying behaviour of 10 × 10 mm french cut potatoes, placed flat or upright in drying tray. O, upright; □, flat.

As it was apparent that, at the low air velocities present in a natural convection solar dryer, air flow behaviour is critical for drying behaviour, it was decided to examine the influence of orientation of french cut samples in the tray on the resultant drying behaviour. Three packing configurations, flat (packed pieces lying flat in the tray across the air stream), upright (pieces standing

vertically in the air stream) and random (pieces with random orientation to the air stream) were solar dried at a loading density of 16 kg/m^2. In Fig. 7, it can be seen that upright packing gave faster drying than the flat packing, presumably due to the lower air flow resistance when the pieces were oriented in the direction of the air stream. Since upright packing involved a special tray arrangement, which will be less practical in actual usage, a comparison of upright and random packing was made. From Fig. 8 it can be seen that there was no difference in drying behaviour for either the first or second trays, each having 16 kg/m^2 (i.e. total of 32 kg/m^2). From this it would appear that random packing would be preferred with respect to ease of handling.

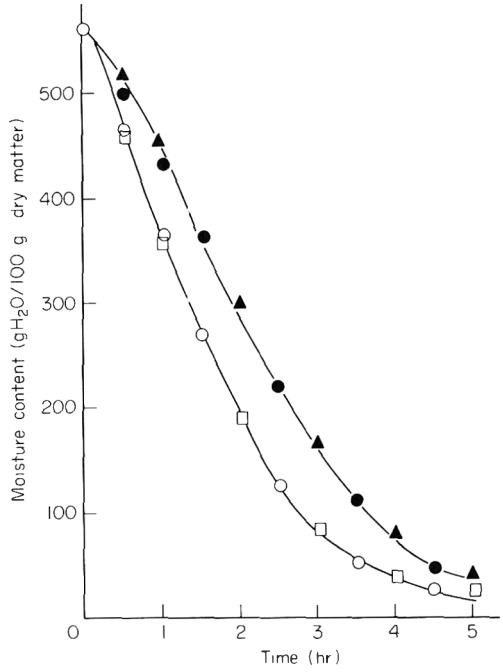

Figure 8. Comparative solar drying behaviour of 10×10 mm french cut potatoes, placed upright or randomly in the drying tray. O, upright and first tray; ●, upright and second tray; □, random and first tray; ▲, random and second tray.

Conclusions

From this study, it appears that drying of potato can be accomplished without using external energy-sources, by means of a natural convection solar dryer. However, it was observed that at the low air velocities present, drying occurs with significant, external mass transport resistances, and thus drying behaviour is strongly influenced by air flow conditions. It was also noted that air flow conditions were critical for the solar panel heat-transfer effectiveness. These two relationships regarding air flow are not necessarily complementary, and it was noted that the rates for drying 5 mm slices *vs* 10×10 mm french cut were

reverse for thin layers and deep beds, due primarily to the impact of air flow resistance differences when drying in beds. It was also noted that solar panel operation will generally not occur at the highest energy conversion efficiency, since outlet air temperature from the solar panel decreases with increasing air velocity and efficiency.

From the studies on sample packing, it was found that deep beds of random packed 10×10 mm french cut samples would result in the minimum drying time for a given set of solar drying conditions. The choice of bed depth depends somewhat on the solar and air conditions. Results from bed depth studies indicate that, in principle, there is an advantage in increasing bed depth and thus, a thickness which can be dried in 1 day at the given conditions would be desired. (Criteria for calculating this depth were not established in this study).

In Part II (p. 387) of this report, the influence of pre-concentration of potato on solar-drying behaviour will be presented.

Acknowledgments

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Dehydration of potato

II. Osmotic concentration and its effect on air drying behaviour.

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Summary

In Part I of this paper (Islam & Flink, 1982), the drying behaviour of potato in a natural convection, solar dryer was discussed. A number of factors were shown to influence the ability to complete the drying process within 1 day. In the current paper, we report on another approach to increase solar dryer throughput. It is shown that osmotic concentration in a 45% sucrose/15% salt solution, prior to solar drying, results in a two- to five-fold increase in product throughput, due to moisture loss and solids uptake in the osmosis step and higher, allowable, final moisture contents for the finished product. Product organoleptic quality was judged to be good and ascorbic acid retention was similar to that reported for commercial dehydration processes.

Introduction

In Part 1 of this paper, we discussed the aim of this project, i.e. the preservation of potato by dehydration without input of fossil fuel energy, and presented results of studies on drying potato under conditions found in a natural convection, solar dryer. While the requirement that drying be completed within 1 day was achieved, it is desirable to increase drying throughput, and to this end, osmotic concentration of the potato, prior to solar drying, was investigated. Osmotic concentration is a water removal process which is based on placing cellular materials (such as fruit or vegetables) into concentrated solutions of soluble solutes. Concentration results primarily from an osmotic water flow, caused by the water and solute activity gradients, across the cell's semi-permeable membrane. However, in natural food systems, there is always some

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leakage of solute into the food system which means that osmotic concentration is, in actuality, simultaneous water and solute diffusion processes.

Farkas & Lazar (1969), in continuation of earlier studies at Western Regional Research Laboratory, investigated the effect of temperature and solute concentration on osmosis kinetics and presented some information on process scale-up. Ponting *et al.* (1973) described osmotic concentration processes using sucrose or invert sugar for concentrating fruit pieces prior to air drying or dehydrofreezing. Flink (1975) reported that organoleptic quality of a number of freeze dried fruit products was improved following an osmotic-concentration step in a 60% sucrose syrup, and similarly Dixon, Jen & Paynter (1976) noted that highly acceptable, dehydrated apple slices could be produced by a combination of osmotic concentration and vacuum drying.

Hawkes & Flink (1978) investigated the possibility of using binary mixtures of solutes with sucrose as a means to reduce solute cost and/or improve osmosis effectiveness. From their studies on systems containing sucrose with either salt, maltodextrin or lactose, they showed that binary mixtures could be almost as effective as sucrose alone at the same total concentration. Moy, Lau & Dollar (1978) investigated the effect of combining organic acids and sucrose on the osmotic concentration of papaya and mango, and showed that acidification increased the rate of water removal for papaya. This resulted from changed tissue properties (reversal of pectin gelation) and not from the increase in solute concentration, since acids were added at concentrations (1.0–4.0%) which were low in comparison to the sucrose concentration (60%).

Flink (1980) reported improvements in retention of carotenoid pigments for freeze dried carrots which had been osmotically concentrated in a salt/sucrose binary mixture prior to freeze drying. Further, Hawkes & Flink (1978) and Flink (1980) have noted that with osmotic concentration as a pre-step to freeze drying, the water load to the freeze dryer is significantly reduced, improving drying process economics.

Since the osmotic concentration process generally results in some solute uptake, changes in the composition of the food material which can influence the subsequent drying step must be considered. One important property of a material, relative to drying, is its water sorption isotherm, since this will determine the degree of drying required to attain a stable water activity. A number of authors have described equations for predicting the water activity of intermediate moisture foods from their composition. Sloan & Labuza (1976), reviewing a number of these equations, noted that particular components, such as salt or glycerol, are particularly effective in reducing water activity, or conversely give higher moisture contents for a specific water activity level. Gal & Bankay (1971) studied the relationship of salt to overall solids, and its influence on the sorption of water in mixtures. They showed for casein/salt mixtures, that at salt concentrations in the system, which were below saturation with respect to the casein, increase in salt concentration resulted in increasing, equilibrium moisture content for a given water activity. Similarly, Shibata *et al.* (1976) noted that at water activities above 0.6, addition of salt to dried noodle gave higher moisture-contents on a total solids basis.

From the above information, one can note that osmotic concentration in a salt/sugar solution, prior to drying, results in:
(1) reduced water load to the dryer, due to water loss in osmosis;
(2) increased solids density due to solids uptake in osmosis; and
(3) a higher, allowable moisture content at the point of exit from the dryer, due to the influence of salt uptake on the water sorption behaviour of the product.

It thus appears likely that the duration of solar drying of potato can be shortened by an initial osmotic concentration step. This paper presents results of laboratory and solar drying studies on the effect of osmotic concentration on drying time and product quality. (While it is recognized that reconcentration of the osmosis solutions for re-use will be an essential step in an eventual drying process involving osmotic concentration, this process was not investigated in the current study.)

Materials and methods

Potato (Bintjee variety) was obtained from either the Danish Potato Research Station (Vandel, Denmark) or at the local supermarket.

Osmotic concentration was conducted for periods of 4–18 hr in a static bed at a solution/product ratio of 5 : 1. Some peeled potato pieces were individually marked with coloured pins so that osmosis behaviour could be analysed by the methods of Hawkes & Flink (1978). The sample was removed at the end of the osmosis period, quickly rinsed and then gently blotted with a cloth to remove surface moisture.

The procedures for handling and drying the potato samples, as well as the details of the laboratory and solar dryers are given in Part I. (Islam & Flink, 1982).

We determined diffusion coefficients and activation energies for diffusion using the methods described by Vaccarezza & Chirife (1978).

Water sorption isotherms of various freeze dried potato/solute mixtures were determined by gravimetrically measuring their water adsorption behaviour when held in evacuated desiccators over saturated salt solutions.

Moisture content was determined by vacuum oven drying (24 hr at 80°C and 50 Torr).

Ascorbic acid was determined by a modification of the AOAC methods (1965) 39.040 and 39.041 in which 2 g of the sample is extracted with 10 ml of 2.0% (w/v) oxalic acid. An aliquot of this extract is titrated with 2, 6-dichlorophenol-indophenol.

For organoleptic evaluation of the potato product, a typical Bangladeshi side dish was prepared. Rehydrated potato was cooked with twice its weight of a frozen vegetable mix, and then spices added. The cooked dish was served with rice to a mixed group, some of whom did not have experience with Bangladeshi food. These judges were asked to evaluate the characteristics of the potato component in the dish on a 9-point hedonic scale (1 = extremely poor; 9 = extremely good).

Results and discussion

To conduct this study, it was necessary to choose a water activity value at which the product would be considered to be shelf stable (i.e. stable with respect to prevention of microbial growth and enzymic colour changes). It was decided that a water activity of 0.7 would be satisfactory and in all drying studies, the desired, final moisture content of the product was defined to be the equilibrium moisture content for a water activity of 0.7.

Water sorption isotherm

While drying is a water desorption process and thus determination of water desorption isotherms would be more appropriate, simplicity of sample preparation (for example, when blending solutes in pre-determined amounts) weighed heavily in favour of determining the adsorption isotherm. This was judged to be acceptable, since when the sorption isotherm is used to define allowable moisture contents for the completion of drying, the hysteresis effect acts as a safety factor, in that the moisture content, defined by the adsorption leg of the isotherm for a given water activity, is lower than the moisture content for the desorption leg at the same water activity.

Water sorption behaviour was determined for various blends of potato solids with salt and/or sucrose. Initial studies, comparing potato slices with powder prepared from these slices, showed no differences in equilibrium water sorption

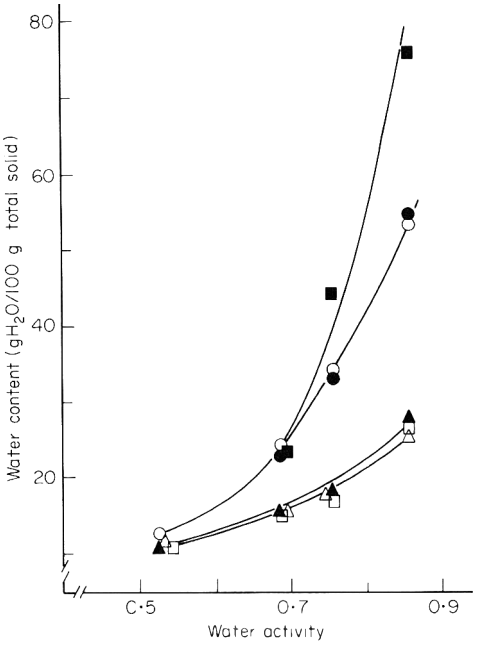

Figure 1. Effect of composition and concentration of added solutes on water sorption behaviour of potato. □, Potato powder; ○, 10% salt; ■, 20% salt; △, 10% sucrose; ▲, 20% sucrose; ●, 10% salt + 10% sucrose (percentages give g/100 g potato solid).

behaviour. When salt was blended with potato solids, there was an influence of the state of the salt over the water activity range of 0.44–0.75. While a blend of freeze dried salt and freeze dried potato had the same water sorption behaviour as a freeze dried salt/potato blend of the same composition, both had higher water sorption than an equivalent blend of freeze dried potato and crystalline salt in the range of 0.44–0.75. At 0.75, which is the water activity of a saturated, aqueous salt solution, the isotherms converged. The results shown in Fig. 1 are for samples prepared by wet blending all components prior to freeze drying. The water sorption behaviour is given in terms of water sorbed per 100 g *total* solids, which means that a binary blended system involves replacement of some of the first solids with the second solids in evaluating the resultant moisture content. In this case, it can be seen that blending sucrose with potato solids gives no change in the moisture content, and thus one would say (for example with sucrose blend at 10%) that per 100 g solids, replacing 9 g potato solids by 9 g sucrose has no effect on water sorption. On the other hand, replacement of some of the potato solids with salt gives an increase in water sorption, with the size of the increase appearing to depend on the amount of potato solid in the 100 g total solids which has been replaced by salt. The water sorption 'equivalence' of sucrose and potato solid is further demonstrated by noting that the 10% salt sample and the 10% salt/10% sucrose sample have the same water sorption behaviour.

As an example of the importance of this behaviour, we can note that at a water activity of 0.7, a potato sample which contains 9.0% of its solids as salt will have a moisture content of 27.5 gmH_2O/100 gm total solids while a plain potato sample (or a potato sample containing added sucrose alone) will have a water content of 16.5 gmH_2O/100 gm total solids. Thus, for a product containing salt, drying will be completed (to $a_w = 0.7$) at a higher, final moisture content. (It should be noted that the above effect is independent of any further preservative action which is specific to the presence of the salt).

Osmotic concentration

Before conducting the main tests on osmotic concentration, a preliminary test was conducted to evaluate the effect of 4 min steam blanching on subsequent osmotic concentration in 20% NaCl solution. The observed, reduced water loss and increased solids uptake clearly showed that blanching of potato is undesirable. It seems likely that loss of membrane integrity, due to heating, was the cause of the poor osmotic concentration behaviour.

A number of solutes were tested for their osmotic concentration effectiveness, measured by the loss of water (WL) from the potato, and the solids gained (SG) by the potato. These two effects combined to give an overall percentage of total solids for the osmosed sample which, when divided by the initial percentage of solids, results in a term called the normalized solids content (NSC). NaCl, KCl and lactose showed effective action, but due to solubility considerations were limited to concentrations below 25%. Sucrose, on the other hand, was tested at concentrations up to 60% solids. A comparison of the

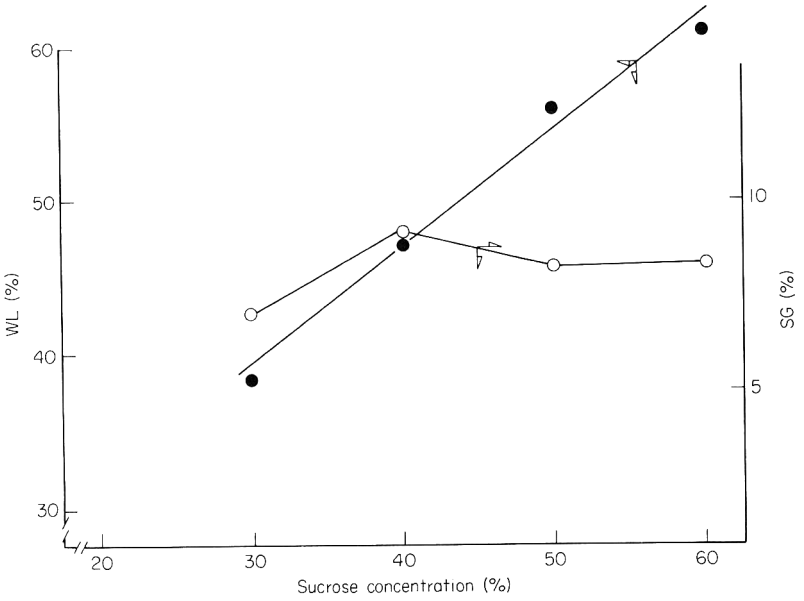

Figure 2. Water loss (WL) and solid gain (SG) for osmotic concentration of potato in sucrose solutions. ●, Percentage WL; O, percentage SG.

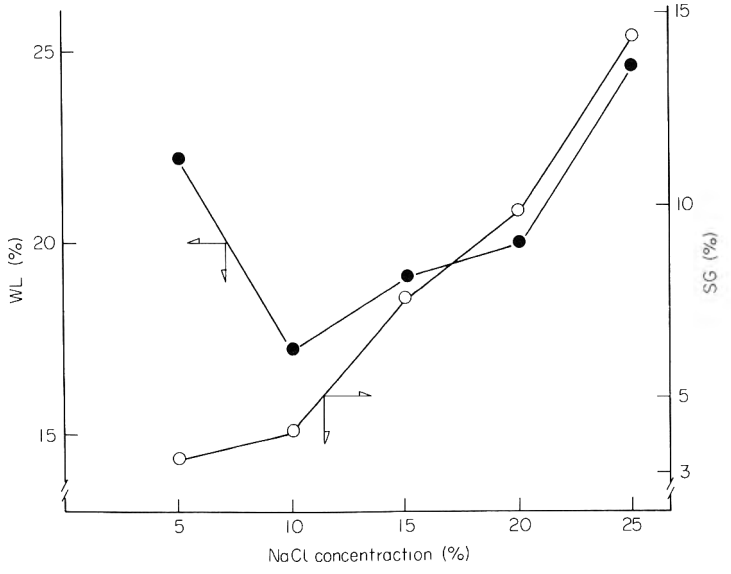

Figure 3. Water loss (WL) and solid gain (SG) for osmotic concentration of potato in sodium chloride solutions. ●, Percentage WL; O, percentage SG.

osmotic concentration results for sucrose and NaCl showed a basic difference in their osmosis behaviour. For sucrose (Fig. 2) it is noted that the increase in NSC, with the increasing percentage of sucrose in the osmosis solution, results primarily from increasing WL. The uptake of sucrose (SG) is roughly constant

for all sucrose concentrations. On the other hand, increasing NaCl (Fig. 3) gives increasing NSC by both increasing WL and SG. KCl showed little increase of WL with increasing KCl concentration, the NSC increases arising primarily from uptake of solids. These differences in osmotic concentration behaviour between the salts and sugars presumably arise from differences in size and molar concentration of the ionized salts *vs* the larger, unionized sugars. The smaller salt ions can more easily diffuse through the cell membrane, resulting in higher solids gained. This solids uptake at the same time reduces WL as the osmotic potential gradient is reduced. Sugars, being larger, cannot easily diffuse through the cell membrane, and thus the approach to osmotic equilibrium is achieved primarily by flow of water from the cell.

While the degree of osmotic concentration that can be achieved by use of NaCl alone is limited by its solubility in water, NaCl can be used in conjunction with more soluble solutes, such as sucrose. Replacement of some sucrose by NaCl results in a lower cost media, and additionally may have some taste advantages over a pure sucrose media, depending on the food material being concentrated. Furthermore, it has been already noted that uptake of salt in the concentrated product can have positive effects on the course of drying, primarily by raising the final, allowable water content for the dry product.

The NSC values for 18 hr osmosis treatments in nineteen salt/sugar blends are shown in Fig. 4. It can be clearly seen that both increasing sucrose (at constant

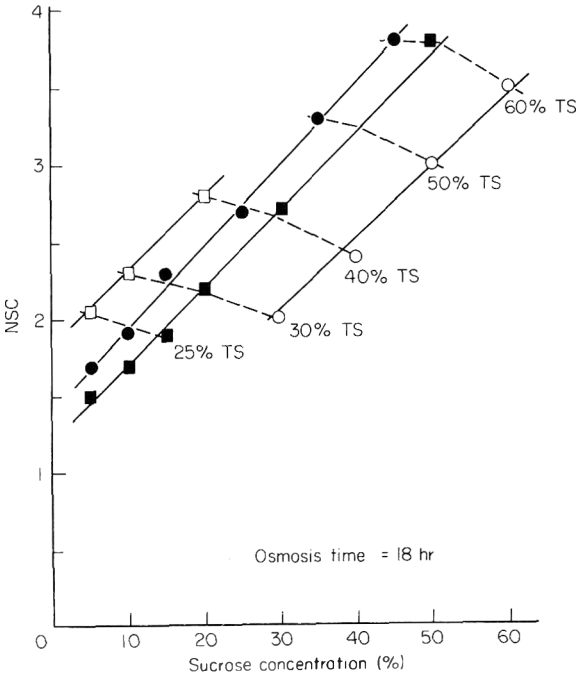

Figure 4. Normalized solids contents (NSC) for potato osmotically concentrated in sucrose/salt blends. (TS = total solids in osmosis solution). □, 20% salt; ●, 15% salt; ■, 10% salt; O, 0% salt.

salt concentration) or increasing salt (at constant sucrose concentration) results in increases in NSC. Further, it can be seen that for a given total solids (TS) concentration in the osmosis solution, the NSC is higher for the salt/sucrose blends than for the pure sucrose solution. This is undoubtedly due to the higher concentration on a molar basis for the blend. The highest NSC in Fig. 4 (about 3.8 for the 45% sucrose/15% salt blend) corresponds to an osmosed potato sample of 74% solids.

The results of the above tests show that sucrose alone, or in combination with salt can give high levels of water loss, and resultant, high solids contents prior to drying. The ultimate choice of blend will depend on many factors, such as solute cost, organoleptic compatability with the end product, or additional preservative action. To aid in designing osmosis solutions, diagrams giving sucrose/salt blends which results in given NSC values can be prepared. Figure 5 shows such a diagram for 18 hr osmosis treatments of 5 mm potato slices.

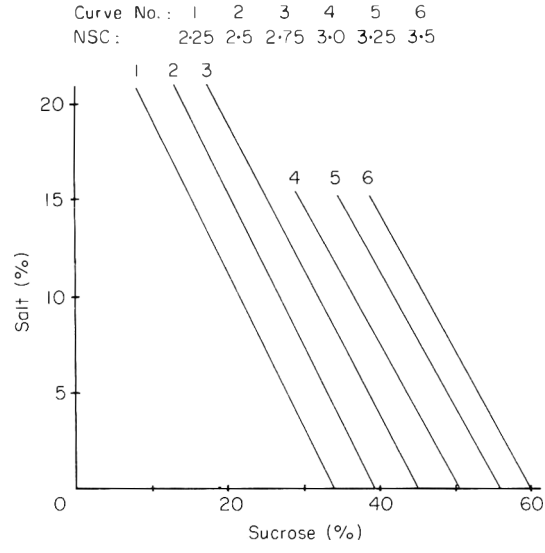

Figure 5. Sucrose/salt blending ratios for obtaining specified levels of concentration (NSC) of potato.

Osmotic concentration behaviour will depend on sample piece geometry and time in the osmosis solution. As has been shown in Part I (Islam & Flink, 1982) piece geometry is very important to solar drying behaviour and thus eventual choice of geometry and size may not be dictatable on the basis of osmosis considerations. However, tests were conducted to elucidate the influence of sample geometry, size and osmosis time on the degree of osmotic concentration, expressed as NSC. Results in Table 1 indicate that size and geometry have some influence on the extent of concentration, especially for short osmosis times. Osmosis behaviour at short times is undoubtedly primarily a surface area related transport phenomenon and a simple analysis of surface area/weight ratios shows 5 mm slices and 10 × 10 mm french cut samples to be about equal and about twice as large as 10 mm slices. Thus 5 mm slices and 10 × 10 mm french cut

Table 1. Effect of sample size and osmosis time on extent of osmosis of potato in a 50% sucrose/10% NaCl solution

	NSC		
Sample size	4 hr	6 hr	18 hr
5 mm slices*	3.13	—	3.63
10 mm slices*	2.22	—	3.23
5 mm slices†	—	2.96	3.08
10 × 10 mm french cut†	2.36	2.74	3.02

*Initial % solids = 20.2%.
†Initial % solids = 23.5%.

samples approach equilibrium more rapidly than 10 mm slices. At 18 hr, 10 mm slices still have a somewhat lower NSC value. For the 5 mm slices and 10 × 10 mm french cut, there is not much further concentration effect after 6 hr, which is in agreement with previously reported results of Hawkes & Flink (1978), Moy *et al.* (1978) and Hope & Vitale (1972). A final interesting point in Table 1 is the effect that initial solids content has on the measured NSC values. The two NSC values for 18 hr osmosis of 5 mm slices do not agree so well, but if expressed on a final solids basis (73.3 *vs* 72.4%) the agreement is much better. This fact indicates the importance of using a single raw material when comparing results for different process parameters, and of retaining as much test data (such as initial and final solids contents) as possible. Thus while NSC gives the degree of concentration achieved, it seems that the equilibrium value is more dependent on the total solids concentrations in the product and in the osmosis solutions.

The concentrated potato slices obtained from the osmosis tests of the nineteen salt/sucrose blends (data points of Fig. 4) were evaluated for their stability, determined by visual examination for mould growth and/or brown colour formation (due to residual enzymic activity). Samples were held at 26°C in watertight, sealed dishes. After 3 months storage, six of the nineteen original samples showed no mould growth, and of these six, only two also had no colour change. These two were the high salt samples, 45% sucrose/15% salt and 20% sucrose/20% salt. An informal evaluation indicated that there would be organoleptic problems associated with the 20/20% solution (strong salty taste), so 15% salt in an osmosis blend is probably the practical limit.

Osmotic concentration and laboratory air drying

The effect of osmotic concentration on subsequent air drying behaviour was investigated for 7 mm potato slices, concentrated in either 60% sucrose or 45% sucrose/15% salt, and dried at air temperatures of 52–68°C with an air flow velocity of 2.5 m/sec. From the drying curves obtained, the diffusion coefficient

of water (D) was found for the first falling rate period while the activation energy for diffusion was evaluated from a plot of 1 n D *vs* $\frac{1}{T_{abs}}$ (based on air dry bulb temperature). In all cases, the initial sample thickness (prior to osmosis) was used.

The results for these tests indicated that for all samples (osmosed and non-osmosed) drying rate increases as air temperature increases. This also meant that water diffusion increases with increasing temperature for each sample type. When the three sample types are compared at a given air dry bulb temperature (Table 2), it is seen that the water diffusion coefficients (and drying rates) decrease in the order no osmosis >60% sucrose >45% sucrose/15% salt. Osmosis appears to give a significant reduction in the rate of water transport during drying. An examination of the time required to achieve a moisture content corresponding to $a_w = 0.7$ (defined as the drying time) indicates that factors other than rate of water transport are influential. The 45% sucrose/15% salt sample, which has the lowest water diffusion rate, requires the least time to dry (60 min), while the 60% sucrose sample required 195 min, and the non-osmosed sample required 325 min.

Table 2. Effect of osmosis on drying behaviour*

Sample	Water Diffusion coefficient (cm^2/sec)	Drying time† (min)
No osmosis	8.72×10^{-6}	325
60% sucrose	4.48×10^{-6}	195
45% sucrose/15% salt	2.31×10^{-6}	60

*Drying at 65.5°C, 7 mm slices, 2.5 m/sec air flow.
†Time to obtain moisture content corresponding to 0.7 a_w.

The differences in water diffusion rates (and drying rates) can be attributed to the compositional changes which occur following osmosis. The uptake of sugar and/or salt, together with loss of water which occurs in osmosis gives increased internal resistance to moisture movement. Thus, when drying at the same air conditions, drying rates will be lower for osmosed samples than non-osmosed. The higher solids gain from salt containing osmosis solutions, together with salt's more hygroscopic nature, results in the lower drying rate for the 45% sucrose/15% salt sample when compared to the 60% sucrose. (There were indications that salt has some special effect on water diffusion rates as the activation energy for diffusion for sucrose/salt containing samples was much lower than for sucrose osmosed samples (3.9 *vs* 9.7 Kcal/mol). On the practical level this means that temperature has much less influence on drying rate for sucrose/salt osmosed samples than sucrose osmosed or non-osmosed samples.) These results are similar to those of Waterman (1976) who noted that drying of

salted fish (salt osmosed) is slower than non-salted fish and drying rate decreases as salt content increases, and Flink (1980) who observed that freeze drying of carrots following osmosis in 40% sucrose/5% salt solution gives slower drying rates than non-osmosed samples when compared on the basis of actual solids contents.

The observation that the time required to dry to a moisture content corresponding to a water activity of 0.70 is lower for osmosed samples (even though drying rate is lower) may be attributed to the higher solids content (up to three to four times higher) with which the osmosed product enters the dryer. For sucrose/salt osmosis, there is the added effect of the higher, final moisture-content at which the product is 'stable'. (With the 45% sucrose/15% salt osmosed sample, the required drying (to $a_w = 0.7$) is completed at a moisture content of 29% as compared to 17% for both 60% sucrose osmosed and non-osmosed samples).

Based on the above results, it can be concluded that the time required for air drying potato slices can be reduced by a factor of 2–5 by an osmosis concentration step prior to the air drying. Due to the effect of salt on the water sorption isotherm, sugar/salt osmosis solutions are to be preferred for pre-concentrating potato slices prior to air-drying. At a given total solution concentration, as salt content increases, drying time will decrease (dryer throughput increases) and osmosis solution cost will decrease. Organoleptic considerations, however, will limit the ultimate salt concentration, and in this study the 45% sucrose/15% salt osmosed sample which required the least drying time of all compositions tested (five times higher drying throughput than non-osmosed slices) was also organoleptically acceptable. Thus 45% sucrose/15% salt osmosed sample was considered the best choice for the subsequent, air drying studies, (particularly solar air drying), since drying can be completed in the shortest possible time. Further, the fact that the 45% sucrose/15% salt osmosed sample appears to be microbiologically stable, without further drying, gives an added safety factor to the process.

The drying studies reported above were conducted on a single layer of slices at an air flow of 2.5 m/sec in order to minimize external mass transport resistances. To more closely simulate solar drying conditions, a drying study was conducted in which 120 mm thick beds of osmosed (45% sucrose/15% salt) or non-osmosed potato slices (initial thickness = 5 mm) were dried at an inlet air temperature of 68.5°C and an air flow well below 1.0 m/sec (the fan power used gives a velocity of about 1.0 m/sec for a single layer of slices; the velocity obtained is much lower for the 120 mm thick bed and a second study conducted at the same time showed that external mass transport resistances are important at these air velocities). The respective drying times for the osmosed and non-osmosed samples were 90 and 260 min. When this (2.8×) reduction in drying time is coupled with the (2.0×) increase in dryer loading density (solids basis, kg solids/m^2), it is seen that the osmosed sample gives an approximately five- to six-fold increase in dryer throughput. Thus, it is seen that osmosis concentration benefits drying behaviour for thick beds under simulated solar drying conditions.

Osmotic concentration and solar air drying

A number of studies were conducted in which osmosed and non-osmosed samples were dried in the solar dryer. As noted in Part I (Islam & Flink, 1982) comparative studies under solar drying conditions are difficult since it is not possible to control insolation conditions. Thus, the best that could be done was to choose days for drying which had similar weather conditions and measure insolation levels. (In practice we were fortunate because good weather in Denmark appears to come in packets, i.e. several days of almost equal good weather—then clouds and/or rain). In accordance with the above noted situation the results noted below should be considered as demonstrations of solar drying behaviour which supplement and support the more controllable laboratory air drying studies which simulated solar drying.

Solar drying was compared with sun drying at a loading of 8.0 kg/m^2. These two dryings were conducted simultaneously, so sun and weather factors are equal. Similar to the results for non-osmosed samples in Part I, solar drying of osmosed samples was twice as fast as the corresponding sun drying. (For both solar drying and sun drying, the osmosed samples showed a marked improvement over the corresponding non-osmosed, but it is not possible to attribute this effect to osmosis alone due to the differences in solar dryer, inlet temperature).

The effect of osmosis on solar drying was investigated in two experimental series, using two osmosis procedures and two dryer loadings (Table 3). It is evident that the osmosed samples dry more quickly than the non-osmosed, which is, as usual, explained by the fact that the osmosed samples enter the dryer with a higher, initial solids content and that osmosed samples are stable at higher moisture content than non-osmosed sample. The osmosed, solar dried product also had a better colour, since the osmosis process (in 45% sucrose/15% salt) gives protection against enzymic browning. While it would be tempting to compare the effect of extent of osmosis (3 hr osmosis gave 50% total solids while

Table 3. Effect of osmosis treatment on solar drying behaviour of potato

Sample	Osmosis time (hr)	Loading density (kg/m^2)	Drying time (hr)*
Non-osmosed	—	8	7.5
Osmosed†	18	8	1.9
Non-osmosed	—	16	7.5
Osmosed‡	3	16	3.5

*Time (hr) to dry to moisture content corresponding to 0.70 a_w

†5 mm slices in 45% sucrose/15% salt at a 4:1 osmosis solution : potato ratio; 18 hr without circulation (static).

‡10 × 10 mm french cut in 45% sucrose/15% salt at a 2:1 osmosis solution : potato ratio; 3 hr with circulation.

18 hr osmosis gave 65% total solids) and loading density, the fact that the non-osmosed sample dried in the same time indicates that solar conditions were not equal for both series.

A drying test with osmosed samples was conducted to specifically investigate the effect of loading density on drying time. 45% sucrose/15% salt osmosed samples were dried at loading densities of 8.0 kg/m^2 and 4.0 kg/m^2, at an average temperature of 67.5°C at the dryer inlet (ambient temperature was 24°C).

The drying time was less for the lower loading density (80 min *vs* 112 min) but it is noted that doubling the loading density did not double the drying time.

The increase in drying time with increase in loading density is related to the higher amount of moisture to be evaporated and to change in the air velocity with bed thickness. As loading density increases, the amount of moisture to be evaporated also increases and thus more time is needed for evaporation. In addition, at a given air flow power, a thicker bed (i.e. higher loading density) gives higher air flow resistance with resultant decrease in air velocity. A lower air velocity can also give lower energy transfer from the solar panel to the air, which in turn gives slower drying under certain types of drying conditions.

The observation that drying time does not increase at the same proportion as loading density increases has also been noted in the laboratory air drying experiments. With higher loading density, it appears that heat is more efficiently utilized for drying than with lower loading density.

From the above, it appears that increasing loading density will give a definite advantage in solar drying (with natural convection flow) as far as drying throughput is concerned. However, from the point of view of product quality deterioration and the imposed constraint of single day drying, drying at a very high loading densities will not be possible. It appears obvious that there exists an optimum loading density for given air flow conditions which maximizes throughput for the allowable, overall drying time.

In an experiment similar to that reported in Part I for non-osmosed potato, the influence of sample packing in trays for osmosed 10 × 10 mm french cut sample, was examined. There was no difference in drying behaviour for upright or random packing, with the drying time for 16 kg/m^2 of osmosed potato being about 180 min (Fig. 6.), while the drying time for non-osmosed samples was about 300 min. For the same reasons as listed in Part I (ease of packing, air flow resistance, etc.), random packing of french cut potato in the trays is to be preferred.

Organoleptic evaluation

For the organoleptic evaluation, the potato product was prepared in a traditional Bangladeshi dish which involves cooking the rehydrated samples with fresh vegetables and serving together with rice. The taste panelists (two Bangladeshi, one Tanzanian, one American and four Danes) were requested specifically to evaluate the potato component of the dish on a 1–9-point hedonic scale. In all, three potato products (plain solar dried, plain osmosed in 45%

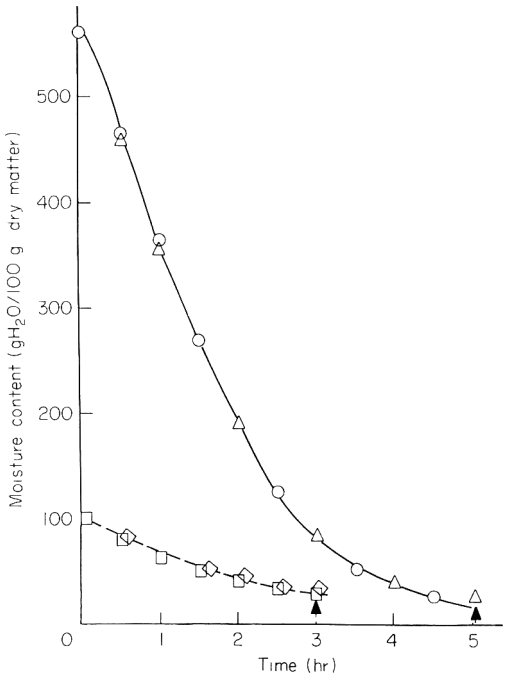

Figure 6. Effect of osmotic concentration on the solar drying behaviour of potato (Solid line = non-osmosed potato: O Upright packing/△ Random packing; Dashed line = osmosed potato: □ Upright packing/◇ Random packing. Arrows show time where moisture content corresponds to 0.7 a_w).

sucrose/15% salt and both osmosed in 45% sucrose/15% salt and solar dried) were evaluated. The panelists' scores were evaluated by an analysis of variance.

The results (Table 4) show that all products tested were acceptable. For all quality factors evaluated, the osmosed plus solar dried product had the highest test-scores, the differences being significant (95% level) for general acceptability and texture. A significant difference between osmosed plus solar dried and plain solar dried product was found for appearance. There was no significant difference for flavour for any of the samples.

Table 4. Organoleptic evalution of osmosed and/or solar-dried potato products (9-point hedonic scale)

Quality factor	SD*	OSM†	OSM+SD‡
Appearance	6.5 a§	7.38ab	7.88b
Texture	6.25c	5.5c	8.0
Flavour	6.86d	6.71d	8.14d
General acceptability	6.69e	6.19e	8.25

*SD = Solar dried.

†OSM = 6 hr osmosis in 45% sucrose/15% salt solution

‡OSM+SD = 3 hr osmosis in 45% sucrose/15% salt solution followed by solar drying.

§Sample means having the same letter suffix do not differ at the 5.0% level of significance.

The superiority of osmosed plus solar dried product over plain solar dried product is based on improved appearance and texture. The differences in texture may arise from differences in rate and extent of drying, together with the effect of infused solute(s). The differences in appearance are primarily due to difference in colour, the osmosed samples being much whiter than the plain solar dried. (It should be noted that colour of the plain solar dried could be improved by blanching or sulfiting). From this simple organoleptic evaluation, it appears that a high quality product can be obtained by osmotic concentration followed by solar drying.

Nutrient retention

Ascorbic acid levels were measured for plain solar dried, plain osmosed and osmosed plus solar dried products. While all processes resulted in vitamin C loss (Table 5), the loss levels are not as high as the 60% loss reported by Augustin *et al.* (1979) for commercial, dehydrated potato products, or the losses of up to 73% reported for 5 month warehouse storage of fresh potato (Hadzidev & Steele, 1976). With proper packaging, there should be little additional loss of vitamin C from the dehydrated potato products.

Table 5. Influence of processing methods on the retention of vetamin C

Sample Conditions	Vitamin C (mg) potato solid (100g)	Vitamin C retention (% of fresh)
Fresh	72.42	
Osmosed*	57.45†	79
Osmosed+ solar-dried*	44.40†	61.3
Fresh	87.63	
Solar-dried	39.9	45.5

*3 hr osmosis period in a 45/15 sucrose/salt solution.

†Since osmosis results in solute uptake, actual vitamin C concentration on a *total* solids basis in osmosed product is lower (osmosed = 32.4; osmosed+solar dried = 25.0 mg vitamin C/100 gms total solids).

Ascorbic acid losses during osmotic dehydration may be attributed to the leaching of the vitamin from the product to the osmosis solution. Jadhav, Steele & Hadzidev, (1975) noted that vitamin C losses occurred due to leaching during the blanching and cooling steps in production of dehydrated mashed potato. Ascorbic acid loss observed for the product produced by osmotic dehydration and subsequent solar drying may be attributed to the combined effects of leaching during osmosis and chemical degradation during the subsequent solar drying.

The observation that the non-osmosed solar dried product gave the lowest amount of vitamin C retention is probably due to the fact that the product was dried at a higher air dry-bulb temperature (56°C *vs* 47°C) and that drying requires a significantly longer time (270 *vs* 180 min).

From the results, it appears that any dehydration process will result in vitamin C losses. While differences in drying temperature prevent a direct comparison of osmosis plus solar drying *vs* plain solar drying, it is noted that the vitamin C losses (maximum of *c.* 55%) are no worse than that found for commercial dehydration of potato (*c.* 60%) (Augustin *et al.*, 1979).

Furthermore, the losses appear to be less than that which can occur during warehouse storage of fresh potato over 5 months (73%). Thus, in terms of our target 'consumers' (the Bangladesh rural population) the solar dried or osmosed plus solar dried products represent potential improvements in vitamin C levels for stored potato product.

Conclusion

From the above, it appears that by osmotic concentration and subsequent solar drying, a high-quality product can be obtained. Organoleptic evaluations indicated a high level of acceptability of the osmosed and solar dried product, while retention of ascorbic acid was comparable to that found in other dehydration processes reported in the literature.

From a number of drying studies, it is noted that osmosed samples, in general, give higher product throughputs than non-osmosed samples (*c.* four to six times higher on total solids basis), and solar drying of osmosed sample can be completed within a short period of time (*c.* 2–3 hr). In addition, the osmosed, solar dried product has a more attractive colour than the non-osmosed, dried product. Previous results obtained with non-osmosed samples, regarding the effects of air velocity and loading density on drying behaviour in the natural convection, solar dryer, were confirmed for the case of solar drying of osmosed samples.

Acknowledgment

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Range bias in sensory evaluation

R. L. McBRIDE

Summary

Using a panel of twenty-four tasters, the optimum sweetener concentration for a flavoured milk beverage was determined using two different approaches, single (sequential monadic) presentation and simultaneous multiple presentation. The estimate provided by the multiple presentation was shown to depend upon the particular sweetness range presented to assessors, but, after correction for this range bias, the estimate almost coincided with that from the single presentation.

Introduction

Human perception is relative, not absolute (Parducci, 1963). Consequently, in a sensory investigation where a range of stimulus intensities is presented to the assessor, each stimulus is not assessed in isolation: the score assigned a stimulus intensity is partly determined by its magnitude, relative to other intensities in the range. This phenomenon has been termed the *stimulus range effect* (Poulton, 1977). Another way of regarding this relativity of judgement is that assessors have a tendency to equate the centre of the response scale with the middle of the stimulus range presented, irrespective of the absolute intensities. Thus, the stimulus range effect has also been called the *centering bias* (Poulton, 1979).

Many experimenters overlook this pervasive bias, which becomes particularly troublesome when the aim of the investigation is to establish a criterion, or cut-off point. The experimenter may unwittingly pre-determine the outcome of such an investigation simply by employing a particular range of stimulus intensities. For example, in audition, Poulton (1977) showed that the estimate of what constitutes a just tolerable noise level depends to a large extent on the range of noise levels used in the experiment. When the intensity range presented was 52–84 decibels (dB), the estimate of just tolerable noise level was 73 dB; but

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when the range presented was 86–97 dB, the estimate rose to 90 dB – a fifty-fold increase in sound power.

In the sensory evaluation of food, it is also common practice for assessors to be presented with a range of stimuli to judge at a single session (multiple presentation). Logistically, such a procedure is attractive, since it is economical of assessors and time. It is also sensitive; when a number of samples are presented side by side, assessors are able to perceive even the smallest differences. However, such comparison between stimuli means that the multiple presentation procedure is likely to be susceptible to the stimulus range bias.

According to Poulton (1977, 1979), one way of avoiding the stimulus range bias is to have each stimulus judged by a different group of assessors. Unfortunately, this requirement would prove awkward for the many food scientists who rely upon the co-operation of a small panel for sensory testing. But there is a compromise procedure: The same assessors judge all stimuli, but each assessor judges only one stimulus per session (single presentation). Provided there is a reasonable interval between sessions (e.g. 24 hr), and overall the order of presentation is balanced, direct comparison between stimuli is precluded and stimulus range bias would therefore be unlikely to occur.

The aim of the present study was to check the efficacy of the alternative, single presentation technique as a means of overcoming stimulus range bias in sensory evaluation.

Experimental

Sensory testing was conducted to determine the concentration of glucose (dextrose) monohydrate needed to produce optimum sweetness in a new flavoured milk beverage. Apart from the sweetener, product formulation remained constant throughout the experiment. The testing facilities have been described previously (Christie, 1966). Two different approaches were employed.

Single presentation

The panel comprised twenty-four employees of the CSIRO Food Research Laboratory, all of whom had previous experience in sensory testing, but none of whom had previously tasted the test beverage. At one session a day for 4 consecutive days, assessors were presented with one 120 ml sample of chilled (8°C) beverage. Four concentrations of sweetener were used: 2.0, 4.0, 6.0 and 8.0% w/v glucose monohydrate. The panel was divided into four groups, each of six assessors, so that order of presentation could follow a Latin square design.

The response scale consisted of a line 150 mm long, anchored at opposite ends with the verbal descriptors 'Not nearly sweet enough' and 'Much too sweet'. The

centre of the scale was labelled 'Just right'. Assessors were instructed to drink the sample and to mark the line at the point which they considered best described their opinion of its sweetness level. The distance of each response from the centre of the scale was measured to the nearest millimetre and this served as the response score. Scores on the 'Much too sweet' side were taken as positive, the others as negative.

Multiple presentation

As a precaution against carry-over effects, there was a break of 2 weeks between the single and multiple presentation evaluations. While the panel, response scale and sample volumes were the same, the outcome of the single presentation evaluation suggested that a reduction in the glucose monohydrate concentrations would permit more accurate determination of the optimum sweetness level.

At one session a day for 3 consecutive days, assessors were presented with a different sweetness range: in the bottom range the glucose monohydrate concentrations were 0.5, 2.0 and 3.5% w/v; in the medium range 2.0, 3.5 and 5.0% w/v; and in the top range 3.5, 5.0 and 6.5% w/v. The three ranges overlapped so that two of the concentrations (2.0 and 5.0%) were common to two ranges, while one concentration (3.5%) was common to all three ranges. The panel was divided into three groups, each of eight assessors, so that order of presentation between ranges followed a Latin square design. Overall, the order of evaluation within each range was completely balanced. The samples within each range were presented simultaneously, and assessors were permitted to retaste samples if they wished. No information was given about session to session variation in sweetness levels.

Results

Single presentation

The mean response scores for the four concentrations of glucose monohydrate are given in Fig. 1. An analysis of variance (Latin-square) showed a significant main-effect for glucose monohydrate concentration ($F = 10.55$, d.f. $= 3/6$, $P < 0.01$), but no significant differences betwen the four groups of assessors. Computation of the least significant difference (LSD) revealed that the 8.0% level was rated significantly further from the centre of the scale ($P < 0.05$) than the 4.0% level, and that the 8.0, 6.0 and 4.0% levels were all rated significantly closer to 'Much too sweet' ($P < 0.05$) than the 2.0% level. In addition, there was no sessions effect ($F = 0.56$, 3/6): overall, the mean response scores at the last session were no different from those at the first. This result confirms that prior exposure to the single presentation condition could not have influenced the panel's performance in the subsequent multiple-presentation condition.

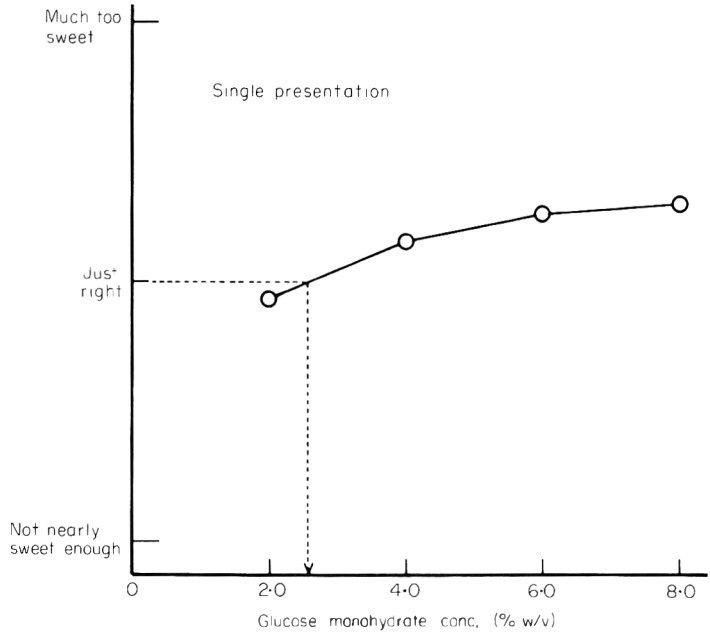

Figure 1. Single presentation procedure. Mean response scores (O) for each of the four glucose monohydrate concentrations; 2.0, 4.0, 6.0 and 8.0% w/v. The point at which the unbroken and broken lines intersect provides an estimate of the optimum concentration, *viz.* 2.6 w/v.

Multiple presentation

In Fig. 2. the mean response scores are plotted against the five glucose monohydrate concentrations, as presented in three different ranges. The solid lines link the points within each range. A two-way analysis of variance showed a highly significant main effect for concentration ($F = 25.8$, d.f. = 8/184, $P < 0.001$).

Computation of the LSD revealed that when the 3.5% level was presented as the strongest concentration (bottom range), it was given a significantly higher ($P < 0.05$) score than when presented as the weakest concentration (top range). Figure 2 also demonstrates an apparent inversion. The 2.0% level (middle concentration, bottom range) was rated closer to 'Much too sweet' than the 3.5% level (weakest concentration, top range). Furthermore, the 3.5% level (strongest concentration, bottom range) was rated closer to 'Much too sweet' than the 5.0% level (middle concentration, top range).

Discussion

The single presentation approach showed that the 2.0% level was considered not sweet enough by this panel, while the upper three levels were rated as too

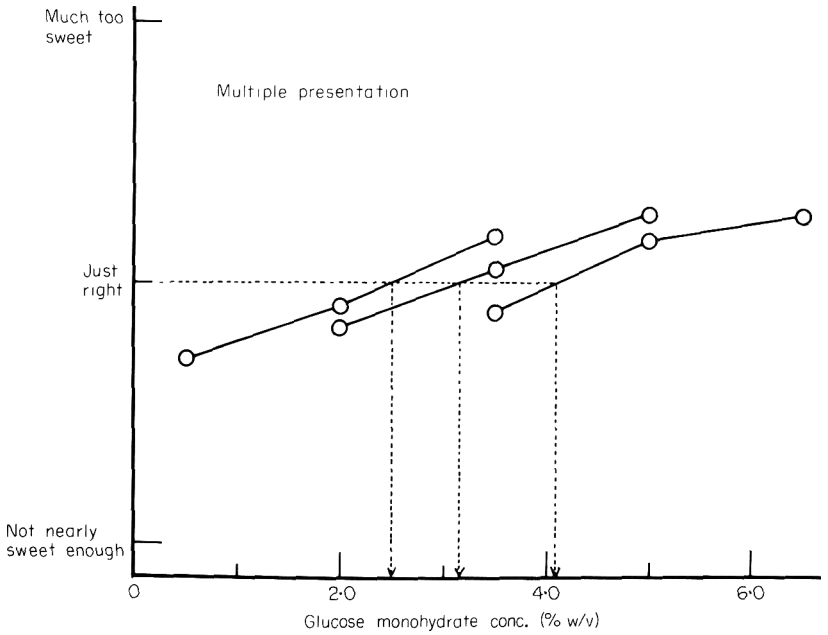

Figure 2. Multiple presentation procedure. Mean response scores (O) for the five glucose monohydrate concentrations, 0.5, 2.0, 3.5, 5.0 and 6.5% w/v as presented in three different ranges. The response scores within each range are connected by a solid line. Each range specifies a different estimate for optimum sweetness as indicated by the dotted lines.

sweet (Fig. 1). The estimate of optimum sweetener concentration may be read directly from the intersection of the unbroken and dotted lines, *viz.* 2.6% w/v.

Figure 2 clearly demonstrates a stimulus range effect: the mean response scores for the 2.0, 3.5 and 5.0% w/v concentrations were influenced by the ranges in which the concentrations were presented. When presented as the weakest concentration, 3.5% w/v was considered not sweet enough, but when presented as the strongest concentration it was considered too sweet. This finding has awkward implications for the food scientist who uses multiple presentation to estimate optimum sensory requirements.

Suppose, as is traditional practice, the experimenter had chosen just one of these ranges to establish optimum sweetener concentration (the particular range chosen would depend on the experimenter's hunch about optimum sweetness). Since all three ranges span the 'Just right' mark in Fig. 2, the investigator would, in each case, obtain an estimate of optimum concentration, but the estimate obtained would depend upon the range of test concentrations selected.

Graphically determined estimates (Fig. 2) of optimum sweetener concentration from the bottom, medium and top ranges are respectively: 2.5, 3.2 and 4.1% w/v glucose monohydrate. But which, if any, of these estimates is valid?

None of the estimates is valid. Fortunately, however, a procedure has been suggested for correcting for the stimulus range effect. Poulton (1977) showed

that, to obtain an unbiased estimate, the overall mean response score from a range of stimuli must correspond to the centre of the response scale.

Inspection of Fig. 2 reveals that the mean response to the bottom sweetness range is below the centre of the response scale, while the mean responses to the medium and top sweetness ranges both lie above the centre. This suggests that the unbiased estimate of optimum concentration lies somewhere between 2.5–3.2%, the estimates from the bottom and medium ranges. The unbiased estimate may be predicted more precisely by joining the mean responses to the bottom and medium ranges with a straight line. The point at which this line crosses the centre of the response scale represents the optimum glucose monohydrate concentration, *viz.* 2.7% w/v. Note that this estimate corresponds closely to 2.6% w/v, the estimate obtained from single presentation. This correspondence provides supporting *a posteriori* evidence that the single presentation was in fact free from stimulus range bias.

Recognition of the stimulus range effect casts a new perspective on established sensory evaluation techniques. Where the aim is to determine the optimum level of a sensory parameter, the so called 'sensitivity' of multiple presentation can be more a handicap than an advantage. For instance, the stimulus range effect also operates in conventional hedonic scaling, where several samples are assessed side by side. A mediocre sample may be considered acceptable when presented alongside poor quality samples; the same sample may be considered unacceptable when presented beside good quality samples (Kamenetzky, 1959; McBride, 1980; Riskey, Parducci & Beauchamp, 1979).

Although by employing two or more different stimulus ranges corrections can be applied for the stimulus range bias, food scientists require a simple, reliable sensory technique which provides an estimate free from such bias. This study suggests that the single presentation design may be such a technique since it conveniently bypasses the range problem.

Acknowledgment

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Book reviews

Principles of Design and Operation of Catering Equipment. By A. Milson and D. Kirk.
Chichester: Ellis Horwood, 1980. Pp. 440. ISBN 0 85312 132 X. £26.50 (soft-back version available).

Three major subject areas are presented, although an individual chapter may contain material from all three. These areas deal with the relevant theory connected with the major types of catering equipment, descriptions of the equipment itself and the use of numerical methods and computer solutions for solving (mainly) unsteady state heat transfer problems.

The first area covers sections on heat and mass balances, fluid flow, conduction, convection, radiation, microwaves, mass transfer, refrigeration, size reduction and mixing. The approach is similar to that presented in books dealing with unit operations or engineering principles, but the examples are of a catering nature, e.g. mass and energy balances on a chip fryer and an interest in prevention of dehydration during cooking and storage. In dealing with heat transfer processes an electrical analogy is used and the section on radiant heat transfer and microwaves is extremely comprehensive.

The descriptive section covers griddles, fry plates, heat pipes, forced convection ovens, water boilers, microwave ovens, fryers, grillers, different energy sources (and how to control them), vending machines and dishwashers. The descriptions are good and the equipment, well illustrated by means of diagrams.

The third, dealing with the use of numerical methods and computers for solving unsteady state heat transfer problems, is the most ambitious. The material covered includes the solution of unsteady heat transfer problems by the Schmidt method and the use of published charts; the heating effects of microwaves, the calculation of freezing and thawing times, setting up a general computer model for an oven, and a brief review of the computer modelling literature. Computers are obviously playing an important role in the design of many kinds of processes and equipment in the way they produce quick solutions to mathematical models describing the effects of changing design parameters on the performance of the equipment. The authors have tried to reflect this in this book by giving a 'rationale of computer models'.

I feel that the material is probably too advanced for Catering or Food Science students, and more appropriate for Food Technology or Engineering students. I found some of the explanations were inadequate, particularly when finite

difference techniques were first introduced in the Schmidt method. This is inevitable when trying to cover such a wide range of topics in a limited space.

Examples are provided at the end of each chapter and the worked solutions are given at the end of the book. There are seventy pages of Appendices, dealing mainly with physical properties of foods, and charts for solving heat transfer problems.

There are a few minor criticisms. Cross-referencing is on the whole poor. The main text contains sections on viscosity characteristics, thermal conductivity and thermal diffusion; no mention is made there of the data presented in the Appendices. The chapters on conduction and convection could have been better organized; there is a big section on convective heat transfer in the conduction section (fortunately cross-referencing is a little better here). The section on refrigeration is scanty and grossly oversimplifies the situation: the use of temperature entropy diagrams, with minimum explanation of the terms will probably mean very little to most students, and occasionally diagrams and symbols are not properly explained in the text.

I enjoyed reading this book, and found that it complemented some of the more conventional books on food processing unit operations. Whether the material is presented at the correct level for catering students is debatable: the text should certainly be investigated by students and practitioners of food science and technology.

M. J. Lewis

Developments in Food Preservatives. 1. Ed. by R. H. Tilbury.
London: Applied Science Publishers, 1980. Pp. x + 165. ISBN 0 85334 918 5. £14.50.

The editor sets the scene in his introduction by reviewing the historical background, the factors involved in the choice of preservative and some of the practical problems involved in their practical evaluation. The second chapter gives an overview of the development of preservatives legislation, past, present and likely future and brings together the details of present controls in Scandinavia, Canada, the U.S.A. and the E.E.C. countries with copious use of comparative tables. There follow reviews of the methods used in toxicological assessment and the toxicological status of the most important preservatives in current use; techniques for the detection and estimation of inorganic and organic preservatives; and recent developments in the understanding of their various modes of action and most effective application. Future trends considered in the final chapter are summarized in the prediction that 'the food preservatives of the 1980s will probably not be new and unusual compounds but rather will be new and unusual combinations of old and tried compounds and methods'. This is not a textbook or a comprehensive review of the use of food preservatives, nor indeed does it report any startling developments. For all that, it is a most worthwhile publication—just because it brings together discussion of

the law, microbiology, analytical chemistry, physico-chemical principles, toxicology and general scientific speculation, related to an important topic in the food area which is so often viewed from one of these directions alone. Accordingly it deserves a wide readership among specialists in the food area as well as providing a most useful overview and source of references for students of food science and technology.

E. C. Apling

Butterworths Law of Food & Drugs. Vol. 1 and Vol. 2. Ed. by A. A. Painter and B. Harvey.
London: Butterworths, 1980. Vol. 1 Pp. xii + (section A) ii + 26 (section B) i + 296 (section C) v + 1082. Vol. 2 Pp. vii × (section D) iii + 486 + (tables and index i + 11 + 89). ISBN 0 406 116105. £150.00.

Users of Bell and O'Keefe's *Sale of Food and Drugs* will have realized for some time that the format was gradually (even rapidly in recent years) becoming more and more unwieldy as it went from bound volume plus loose-leaf service volume to bound volume plus loose-leaf binder plus 'overflow' binder. Now the publishers have 'taken the bull by the horns' and to simplify up-dating, have gone fully loose-leaf. The first two volumes here reviewed comprise the following sections: (A) Introduction, (B) Food Statutes, (C) Food Regulations, (Vol. 1) and (D) Food Circulars and Reports, (finally) Tables of Statutes, Tables of Cases and Index (Vol. 2). European Economic Community legislation, medicines and poisons control, slaughterhouse regulations and similar matters are relegated to further volumes not submitted for review. The sections listed are completely updated to 1 January 1980 (a first service issue to include later amendments and substitute for outdated pages is, in fact, already available)—and are prepared according to a general scheme devised by John O'Keefe before his untimely death.

The two binders of the new work are certainly attractive in appearance and should be hard-wearing. As presently arranged the binder for Vol. 1 is already nearly full, while Vol. 2 uses only about one-third of the binder capacity. Since most consultations are likely to be with sections B and C (Food Statutes and Food Regulations respectively) inclusion of the Index in the other binder is awkward—but then the loose-leaf format leaves it to the individual user to arrange the whole to his own convenience. Such re-arrangement will cause no difficulty in replacing pages as service issues appear, since each section is numbered separately, with an appropriate letter before each page number. Undoubtedly the new system is *much* more flexible.

The second major innovation is to number each paragraph (or logical group of paragraphs) and to use *these* numbers, headed by a letter indicating the relevant section of the whole work, for cross-references and indexing. Repetition of these numbers at the top of the page makes finding a relevant paragraph superbly easy.

number of hiccups—and a number of cross-references and index entries have gone severely astray: several cross-references and index entries lead to paragraph numbers which are either wrong or do not exist—and several cross-references lead to numbers where the information referenced is not given because the relevant item has been revoked or otherwise up-dated and the *original* material has been eliminated, so that the reference leads the enquirer to an empty paragraph. However these are minor blemishes which will, no doubt, be corrected as further service issues are issued to up-date the work.

The section on Food Circulars and Reports is considerably more extensive than in the earlier work, though a bibliography of circulars and publications not included in this volume extends to five pages early in the section. It is difficult at first sight to fathom the principles which have determined the decision of the editors to include some circulars and reports *in extenso* and others merely in summary form. It is the conclusion of this reviewer that by and large the editors have made an excellent selection of material to include. The exclusion of a section covering established Codes of Practice is, however, more difficult to understand. Perhaps reserved for inclusion in a later volume?

The introduction gives a potted history of the development of the law—and administration of the law—of food and drugs and parallel Fertilisers and Feeding Stuffs legislation. In its account of the general line of development, this is not very different from the account given previously by John O'Keefe—but it does include some very useful new comments on the evident need for modernization and modification of the current statutes—in a recast discussion of pertinent aspects of considerations of criminal liability.

The editor effectively argues that a considerable portion of enforcement action should be transferred from shop to factory; and that as self-regulation, through Codes of Practice and the like, becomes steadily more practicable, it is indeed time to question the logicality of the continued use of the criminal law in the field of food and drugs control. The section also includes a useful discussion of the distinction between trading standards enforcement and the consumer protection movement.

The one remaining important criticism that I have concerns the choice of type sizes. In the older work editorial comments, notes and other material not included in the official publication were in very much smaller type than the quoted official material; here—although the type used *is* smaller, the difference is not such as to *clearly* distinguish the two kinds of material. This is particularly troublesome where comments are appended to the headnotes of Regulations (which are themselves given in smaller type than the Regulations themselves), and also makes it less easy to quickly locate reports of relevant legal cases.

Criticisms notwithstanding this is a most welcome revision of the 'food-law administrator's bible'; the editors have done a remarkably good job in recasting it into a format which can be readily up-dated for many years to come. Indeed they have done so well it seems churlish to criticise!

E. C. Apling

Fruit and Vegetable Juice Processing Technology. By P. E. Nelson and D. K. Tressler.
Westport, Connecticut: AVI Publishing Co., 1980. 3rd Edition. Pp. xv + 603
ISBN 0 87055 362 3

The original edition of this book published in 1961, and revised in 1970, was edited by D. K. Tressler and M. A. Joslyn. This new and revised edition has been expanded from 486 pages to 603 pages by the addition of new material and up-dating the references at the end of each chapter. Apart from the first chapter which discusses the economic development and organization in the United States' juice industry, the remaining twelve chapters are all commodity based *viz.* orange and tangerine; grapefruit; lemon and lime; pineapple, apple, grape; cherry, berry and other miscellaneous fruits; tropical fruit beverages; nectars, pulpy juices and blends; imitation beverages; tomato; and vegetable juices. Each chapter is written by specialists who are recognized authorities. Two of the chapters, i.e. orange and tangerine juice and grapefruit juice are by new authors and have been completely rewritten; the remaining chapters contain some new information but are essentially unchanged in format. The section devoted to blackcurrants by the late Dr Vernon Charley is essentially unchanged in this edition and unfortunately no reference has been made to his excellent monograph published in English in 1977 and based on the 1973 German edition. The sections concerning guava, mango and papaya have been considerably expanded including descriptions of a wide range of products.

Although this book is the most comprehensive single source of information on all aspects of fruit juices, there are some notable omissions, in particular the relatively small amount of information on physical properties, including rheological properties, and general microbiological aspects. The European reader will notice that there are no references to the scientific publications of the International Federation of Fruit Juice Producers including the Congress reports. Despite these points, the book remains the most important reference book on the subject and this revised edition will be welcomed by all those who are concerned with the production of fruit juices.

S. D. Holdsworth

Journal of Applied Bacteriology

The Society for Applied Bacteriology, which has just celebrated its 50th anniversary, launched the *Journal of Applied Bacteriology* in 1954. Since that time the *Journal* has grown in size, two volumes per year being published from 1975 onwards, in prestige and in the subject matter covered. It has established an international reputation with readers and authors; indeed each number of the *Journal* contains papers from worldwide sources. The Society's interest in the systematics and ecology of groups of microorganisms is reflected in the *Journal* and a major change in the organization of papers on systematic microbiology is detailed in a revised Instructions to Authors published early in 1982 as a supplement to Volume 52. The Instructions also give details of a novel form of publication, observation papers. These are intended to provide the *Journal's* readers with a succinct up-date of rapidly developing areas of microbiology. Such articles will be of particular interest to young scientists who seek conceptual enlightenment and senior persons in industry, Universities, etc., who need to keep abreast of developments in many areas of microbiology. Comprehensive reviews have become another important feature of the *Journal* and the publication of critical book reviews has attracted enthusiastic comment.

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Arrangement. Papers should normally be divided into: (a) Summary, brief, self-contained and embodying the main conclusions; (b) Introduction; (c) Materials and methods; (d) Results, as concise as possible (both tables and figures illustrating the same data will rarely be permitted); (e) Discussion and conclusions; (f) Acknowledgments; (g) References.

References. Only papers closely related to the author's work should be included; exhaustive lists should be avoided. References should be made by giving the author's surname, with the year of publication in parentheses. When reference is made to a work by three authors all names should be given when cited for the first time, and thereafter only the first name, adding *et al.*, e.g. Smith *et al.* (1958). The '*et al.*' form should always be used for works by four or more authors. If several papers by the same author and from the same year are cited, a, b, c, etc. should be put after the year of publication, e.g. Smith *et al.* (1958a). All references should be brought together at the end of the paper in alphabetical order. References to articles and papers should mention (a) name(s) of the author(s) (b) year of publication in parentheses; (c) title of journal, underlined, abbreviated according to the *World List of Scientific Publications*, 4th edn and supplements; (d) volume numbers; number of first page of article. References to books and monographs should include (a) name(s) and initials of author(s) or editor(s); year of publication in parentheses; (b) title, underlined; (c) edition; (d) page referred to; (e) publisher; (f) place.

Standard usage. The *Concise Oxford English Dictionary* is used as a reference for all spelling and hyphenation. Statistics and measurements should always be given in figures, i.e. 10 min, 20 hr, 5 ml, except where the number begins the sentence. When the number does *not* refer to a unit of measurement, it is spelt out except where the number is one hundred or greater.

Abbreviations. Abbreviations for some commoner units are given below. The abbreviation for the plural of a unit is the same as that for the singular. Wherever possible the metric SI units should be used unless they conflict with generally accepted current practice. Conversion factors to SI units are shown where appropriate.

SI UNITS

gram	g	Joule	J
kilogram	kg = 10^3 g	Newton	N
milligram	mg = 10^{-3} g	Watt	W
metre	m	Centigrade	°C
millimetre	mm = 10^{-3} m	hour	hr
micrometre	μ = 10^{-6} m	minute	min
nanometre	nm = 10^{-9} m	second	sec
litre	l = 10^{-3} m^3		

NON SI UNITS

inch	in	= 25·4 mm
foot	ft	= 0·3048 m
square inch	in^2	= 645·16 mm^2
square foot	ft^2	= 0·092903 m^2
cubic inch	in^3	= 1·63871 × 10^4 mm^2
cubic foot	ft^3	= 0·028317 m^3
gallon	gal	= 4·54611
pound	lb	= 0·453592 kg
pound/cubic inch	lb in^{-3}	= 2·76799 × 10^4 kg m^{-3}
dyne		= 10^{-5} N
calorie (15°C)	cal	= 4·1855 J
British Thermal Unit	BTU	= 1055·06 J
Horsepower	HP	= 745·700 W
Fahrenheit	°F	= 9/5 T°C + 32

Figures. In the text these should be given Arabic numbers, e.g. Fig 3. They should be marked on the backs with the name(s) of the author(s) and the title of the paper. Where there is any possible doubt as to the orientation of a figure the top should be marked with an arrow. Each figure must bear a reference number corresponding to a similar number in the text. Photographs and photomicrographs should be unmounted glossy prints and should not be retouched. Line diagrams should be on separate sheets; they should be drawn with black Indian ink on white paper and should be about four times the area of the final reproduction. Lines and lettering should be of sufficient thickness and size to stand reduction to one-half or one-third. Whenever possible, the originals of line diagrams, prepared as described above, should be submitted and not photographs, The legends of all the figures should be typed together on a single sheet of paper headed 'Legends to figures'.

Tables. There should be as few tables as possible and these should include only essential data; the data should not be crowded together. The main heading should be in bold with an Arabic number, e.g. **Table 2.** Each table must have a caption in small letters. Vertical lines should not be used.

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