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Development of Soymilk—A Review

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ABSTRACT

Some implications of the use of soymilk in food are discussed. Nutritional comparisons of soymilk with other food proteins are made and the product offers some promise for food formulation.

INTRODUCTION

Soybean has been used in the Far East for centuries and still forms part of the indigenous diet. The relatively low cost of soybean protein compared with animal proteins and the simple way in which it can be fashioned into palatable high protein food makes its use as a protein source particularly relevant to developing countries. In the Western world, it has, however, been utilised for a comparatively short time of about 50 years; first, as a source of oil for paints and varnish and, later, as an edible vegetable oil (USDA, 1977). In addition to these, there is an increasing emphasis on the use of soybean as an important source of low-cost protein supplementation to animal protein as the latter will become more expensive due to increasing scarcity. Modern technology has, therefore, been developed to allow for the processing of soybean into full-fat flour, defatted flour,

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protein isolate, protein concentrates, texturised soyprotein and spun soy protein (Circle & Smith, 1972). From these protein forms, new food products (Wolf & Cowan, 1975) have been developed such as high protein cereal, snacks (Wolf & Cowan, 1975), meat analogues (Horan, 1975) and infant foods (Graham *et al.*, 1971). However, the processes for the development of such foods require expensive and sophisticated technology which the developing countries can ill afford.

By contrast, soybean has come to be accepted in South-East Asia on its own merits. As meat and dairy products have generally been in short supply, the soy-based foods have made an important contribution to protein and fat requirements. Historically, a major influence in the development of soybeans for food in the region was to meet the requirements of vegetarians for vegetable proteins. The forms of the different traditional foods from soybean vary somewhat from country to country in these regions. Table 1 summarises the soy-based food products commonly consumed in Singapore.

TABLE 1
Traditional Soy-based Food in the Far East

Non-fermented products	*Fermented products*	*Others*
Soymilk	Soy sauce	Soybean oil
Soybean curd (*to-hwei, to-fu, to-kuah, to-hu-pok*)	Soy cheese	Soybean sprout
	Tempeh	
Yuba (*to-ki, to-pui, tim-chok*)		

SOYMILK

The processes employed in the preparation of these traditional foods, as shown in Table 1, are based on relatively simple methods and can often be produced by cottage industries using whole soybeans. One of the most important among these is *soymilk*. This is prepared by the traditional method in which the whole bean is soaked in water and then extracted with water; the water extract is then boiled and filtered through cheese cloth. The product thus obtained can be taken as such or flavoured with syrup and taken as a drink. The soymilk produced can also be further processed into various form of soybean curd (Table 1).

Singapore imports annually more than 50 000 tons of soybeans, which are used mainly for the production of soybean oil, soy sauce, soybean curd and soymilk. There are about 260 small backyard industries producing soymilk daily by the traditional method. The milk is sold freshly prepared in glasses or in take-away plastic bags. This is consumed daily by persons in all age groups and in all economic strata. Large industrial productions of soymilk using modernised methods and sophisticated equipment are packed in bottles, tetrapak, 250-ml cartons and tear tab cans. These products are sterilised either by the conventional sterilisation method or by the UHT method.

Soymilk has not gained popularity in the Western countries, chiefly because of its 'beany' flavour and the availability of cheap cow's milk, and is used only as a milk substitute by a group of people who cannot tolerate cow's milk. Much effort has been directed to the elimination of this 'beany' flavour to produce a bland product that is acceptable. The means employed to reduce the 'beany' flavour were by blanching the beans prior to milling (Schroder & Jackson, 1972), by presoaking the beans in aqueous ethanol and by treatment with hot water to inactivate the lipoxygenase activity. The Okamura-Wilkinson process utilised sprouted beans for soymilk extraction with the aim of reducing the beany flavour. In contrast, this same 'beany' flavour is well accepted by most Eastern palates and, in this region, soymilk has always been taken as a pleasant and nutritious drink without association with cow's milk. In Singapore the standard for soymilk has been laid down in the Food Regulation, 1974, specifying a minimum of 2·0% protein (total nitrogen × 6·25). Commercial samples of soymilk which have protein values of less than 2% protein are marketed as soydrink. The non-compliance by some firms is due to both economic and technological considerations. The technological problems in the processing of soymilk are precipitation during sterilising and storage and colour. From preliminary investigation, it appears that soymilk of high protein content (~2%) generally undergoes precipitation during sterilisation at 120°C for 10 to 15 min. There is a tendency for soymilk of high protein content to impart a darker colour to the product which is slightly intensified during sterilisation.

During certain periods of the year, as much as 200 tons of defatted meal are available daily as a by-product from the extraction of oil from soybean in Singapore. Studies have been undertaken to develop soymilk and soymilk powder from defatted soymeal with a protein content as high as factors such as stability, whiteness and consumer acceptability would

TABLE 2
A Comparison of the Chemical Composition of Commercial Soymilk with Soymilk from Defatted Meal

Proximate composition (%)	*Bottled soy beverage* I	II	III	*Market soymilk*	*Tetrapak soy beverage (UHT)* I	III	*Soymilk from defatted meal*	*Reconstituted soymilk from spray-dried powder*
Protein	1·0	1·6	1·1	1·8	1·5	1·9	2·5	1·8
Fat	0·23	0·35	0·59	0·60	0·26	0·66	1·3	1·2
Ash	0·10	0·20	0·18	0·06	0·11	0·23	0·31	0·36
Total solids	13·0	14·6	12·5	14·7	13·3	14·8	15·7	13·0

allow. An extensive analysis was carried out to ascertain the nutritional values of the soymilk and soymilk powder developed. The chemical and amino acid compositions of the product formulated from defatted meal, as compared with those of some commercial brands of soymilk, are given in Tables 2 and 3.

TABLE 3
A Comparison of the Amino Acid Composition of Commercial Soy Beverages with Soymilk from Defatted Meal (mg/ml of Sample)

Amino acid	*Bottled soy beverage* I	II	III	*Market soymilk*	*Tetrapak soy beverage (UHT)* I	III	*Soymilk from defatted meal*	*Reconstituted soymilk from spray-dried powder*
Aspartic acid	1·0	1·4	1·5	1·8	1·1	1·4	2·8	2·3
Threonine	0·3	0·5	0·5	0·6	0·4	0·5	0·9	0·7
Serine	0·3	0·6	0·6	0·6	0·5	0·6	1·1	0·9
Glutamic acid	1·6	2·3	2·4	2·8	1·9	2·3	4·4	3·5
Proline	0·5	1·0	0·6	0·8	0·7	0·9	1·4	1·5
Glycine	0·4	0·4	0·6	0·7	0·4	0·4	1·0	0·8
Alanine	0·4	0·5	0·6	0·7	0·4	0·5	1·1	0·8
Valine	0·5	0·6	0·7	0·8	0·5	0·6	1·0	0·9
Cystine	Trace	Trace	0·2	Trace	Trace	Trace	Trace	Trace
Methionine	0·1	0·2	0·1	0·2	0·2	0·2	0·4	0·3
Isoleucine	0·5	0·6	0·7	0·7	0·5	0·6	1·1	0·9
Leucine	0·7	1·1	1·0	1·1	0·9	1·1	1·8	1·5
Tyrosine	0·2	0·3	0·5	0·5	0·2	0·3	0·8	0·6
Phenylalanine	0·4	0·7	0·7	0·8	0·5	0·7	1·2	1·0
Histidine	0·3	0·5	0·6	0·7	0·4	0·5	0·9	0·7
Lysine	0·6	1·1	1·1	1·2	0·9	1·0	1·9	1·6
Arginine	0·6	1·0	1·4	1·2	0·9	1·1	2·1	1·6

PREPARATION OF SOYMILK POWDER BY SPRAY-DRYING

The advantages of producing a powder from a liquid are the reduction in bulk volume, resulting in the saving of storage and transportation costs and also in the extension of the storage life and stability of the appropriately packaged product.

Many methods are available for drying liquid foods to produce a powder but spray-drying (Master, 1972) has evolved in recent years to become the most important method of drying milk and milk products (Hall & Hedrick, 1972). Thus, spray-drying has the advantage of minimising thermal damage because of the exceedingly short residence time in heat contact and increased rate of evaporation.

These characteristics are especially important in the drying of a heat-sensitive product like soymilk where retention of nutrients and flavour, etc., is necessary and where proteins are denaturable by heat, resulting in scorched flavour and poorer solubility of product than with conventional driers.

In spray-drying soymilk the inlet temperature used has a marked effect on the protein quality of the dried soymilk. The soluble nitrogen decreases rapidly with rising temperature (van Buren *et al.*, 1964). The redispersibility of soymilk protein after spray-drying is markedly affected by heating conditions before drying of soymilk and by the pH. Higher pH or lower concentration of soymilk during heating increased the dispersibility after drying. The protein dispersibility index of spray-dried whole soybean milk was found by Aminlari *et al.* (1977) to increase when sodium bisulphite was added to the soymilk before drying.

The extract of soymilk of the formulation shown in Table 4 was spray-dried by rotary atomisation in a Niro Production Minor Spray Dryer. The atomiser speed was 24 000 rpm; inlet temperature, 175 °C and outlet temperature, 65 °C. In this set up the feed rate was about 25 kg/h.

TABLE 4
Formulation of Soymilk for Spray-Drying

Extract of defatted soymeal	1:10 (meal:water)
Sucrose	12%
Palm oil	2·0%
Emulsifier	0·2%
Lecithin	0·2%
Total solids	19·2%

TABLE 5
Chemical Composition of Spray-Dried Soymilk Powder

	Proximate analyses of spray-dried powder (% age)
Moisture	3·2
Protein	15·2
Fat	11·0
Ash	37·0
Crude fibre	Negligible
Carbohydrate: Sugar	59·0
Others	7·9

TABLE 6
Amino Acid Composition of Spray-Dried Soymilk Powder

Amino acid	*Analyses (mg/g of powder)*
Aspartic acid	15·5
Threonine	4·8
Serine	7·7
Glutamic acid	27·1
Proline	9·0
Glycine	5·0
Alanine	5·6
Valine	5·6
Cystine	Trace
Methionine	3·7
Isoleucine	6·0
Leucine	10·3
Tyrosine	5·0
Phenylalanine	6·4
Histidine	4·6
Lysine	11·0
Arginine	11·0
Total	138·3

TABLE 7
Reconstitution Properties of Spray-Dried Soymilk Powder

Wettability(a)[a]	5·4
Dispersibility (%)[a]	72·9
ADMI solubility index (ml)	0·5
Nitrogen solubility index	82·2

[a] Method as described by Pyle (1975).

The chemical composition of the spray-dried soymilk powder obtained is shown in Table 5, the amino acid composition in Table 6 and the reconstitution properties in Table 7.

NUTRITIONAL VALUES OF SOYBEAN, SOYMILK AND SPRAY-DRIED SOYMILK POWDER

The nutritional values of foodstuffs are measured in terms of their protein, energy, vitamin and mineral contents as well as availability. For protein, the quality must also be taken into consideration. As part of our study, these factors were evaluated for soybean, soymilk and soymilk powder. The results obtained are then compared with several foodstuffs, selected on the basis of their known nutritional values.

Protein content/quality of soybean

The total protein (w/w %) of the whole soybean, defatted soymeal and full-fat soyflour ranges from 40–52% (Smith, 1964; Iriarte & Barnes, 1966; Meyer, 1967; Harmon *et al.*, 1969; Inglett *et al.*, 1969) while the spray-dried soymilk powder has a total protein content of approximately 16%. Table 8 sets out the compositions of the essential amino acids for infant/adult requirements, and of whole eggs, cow's milk, human milk and soyproducts from defatted meal. From such compositions it will be seen that the quality of the soyprotein compares favorably with that of the foodstuff listed. In addition to the essential amino acids comprising isoleucine, leucine, lysine, methionine phenylalanine, threonine, tryptophan and valine, cystine and tyrosine are included owing to their sparing effects on methionine and phenylalanine, respectively. Histidine is apparently required by infants and is therefore evaluated.

TABLE 8
Essential Amino Acids Pattern

Essential amino acid	*Requirement* Infant (mg/kg)	*Requirement* Adult M (mg/day)	*Requirement* Adult F (mg/day)	*A/E ratio of whole egg protein (mg/g total essential amino acid) (FAO, 1965)*	*Whole egg (mg/g protein)*	*Cow's milk (mg/g protein) (FAO, 1970)*	*Human milk (mg/g protein)*	*Soyproducts from defatted meal:* Soymilk (mg/g protein)	*Soyproducts from defatted meal:* Spray-dried soymilk powder (mg/g protein) Ang et al. (1978)	*Soyproducts from defatted meal:* Reconstituted soymilk powder (mg/g protein)
	Nat. Acad. of Sci. (1959)									
Histidine	32	—	—	—	24	26	25	36	30	39
Isoleucine	90	450	700	129	63	46	40	44	39	50
Leucine	150	620	1 110	172	88	93	86	72	68	83
Lysine	105	500	800	125	70	76	87	76	72	89
Phenylalanine }	90	220	300	114 }	99	53 } 100	34 } 66	48 } 80	42 } 75	56 } 89
Tyrosine }		900	1 100 [a]	81 }		47 }	32 }	32 }	33 }	33 }
Methionine }	85	350	200[b]	61 }	58	25 } 33	16 } 29	16 } 16	24 } 24	17 } 17
Cystine }		200	810	46 }		8 }	13 }	Trace }	Trace }	Trace }
Threonine	60	305	500	99	51	44	44	36	32	39
Tryptophan	22	157	250	31	15	14	16	?	?	?
Valine	93	650	800	141	69	57	45	40	37	50
Nitrogen (%)					1·78	0·55	0·19	0·40	2·43	0·29
Factor					6·25	6·38	6·38	6·25	6·25	6·25
Protein					12·4	3·5	1·2	2·5	15·2	1·8

[a] US National Academy of Sciences (1959).
[b] FAO (1970).

TABLE 9
Ratio of Total Essential Amino Acids to Total Nitrogen in Selected Foodstuff[a]

Protein source	*E/T ratio (g/g total N)*
Whole egg protein	3·22
Cow's milk	3·20
Beef muscle	2·79
Human milk[b]	2·67
Fish	2·66
Soymilk[c]	2·4–2·58
Soyflour	2·47
Cottonseed	2·15
Peanut flour	2·08
White wheat flour	2·02

[a] FAO (1965).
[b] FAO (1970).
[c] Ang *et al.* (1978).

TABLE 10
Chemical Score of Soyprotein, Soyproducts and Other Protein

Source of protein	*Limiting amino acid*	*Chemical score*
Whole egg[a]	None	100
Cow's milk[b]	Sulphur amino acids	60
Human milk[a]	Sulphur amino acids	53
Soybeans[a]	Sulphur amino acids	69
Soymilk	Sulphur amino acids	
Spray-dried soymilk powder	Sulphur amino acids	
Reconstituted soymilk	Sulphur amino acids	
Defatted soyflour	Sulphur amino acids	
Fullfat soyflour	Sulphur amino acids	

[a] Source: Data compiled from Altschul (1965) and FAO (1965).

A further measure to assess the importance of soyproduct for nutrient supplementation is the computation of the ratio of the essential amino acids to the total protein. This ratio is an important indicator of the quality of the soyprotein as deficiency in non-essential amino acids will result in the essential amino acids being used for the syntheses of the non-essential ones. Table 9 shows that soyproteins are intermediate on this scale among the various protein-rich foods.

Soyproteins are found to be limiting in two of the essential amino acids—cystine and methionine. This is clearly reflected in Table 10 which lists the chemical score, a quantity that measures the extent to which a protein supplies limiting amino acid in comparison with a reference protein. Thus, for a balanced amino acid composition, fortification of soyprotein with methionine has been carried out previously.

Energy content

The energy content is determined from the content of carbohydrate, fat and protein, with the digestibility of each of the components, as well as the heat of combustion, being taken into account.

(i) Carbohydrate
The composition of carbohydrate varies from 22–29 % for whole beans to only 0·3–1·2 % for soymilk formulated and processed in our laboratory. The calorific value is estimated to be 1·68 cal/g. In practice, sugar is added to both the soymilk and soymilk powder for enhanced palatability. The total energy content of the soymilk/soymilk powder is therefore higher than the value of 1·68 cal/g. The most acceptable level of sweetness for the palates of Singaporeans has been found from taste panel studies to be around 9–10 % [w(sucrose)/w(soymilk)]. For spray-dried soymilk powder 10 % sugar is added to the feed, resulting in a spray-dried soymilk powder with a sugar level of 59·2 %. The reconstituted soymilk drink has the desired level of 9–10 %.

(ii) Oil
Soybean oil is highly digestible, with a calorific value of 8·37 kcal/g (Watt & Merill, 1963). Soymilk and spray-dried powder from the full fat soyflour will have a higher calorific value than those from the defatted meal. However, the soymilk/soymilk powder formulated from defatted meal contains 1–1·5 % added palm oil as this is much less costly and yet compatible with the soymilk.

(iii) Protein

Proteins are not utilised to any significant extent as a source of energy except under conditions of extreme calorific deprivation. However, for the computation of the total energy that can be derived from a single serving of soymilk or reconstituted soymilk from spray-dried soymilk powder, the contribution from the protein is included. This is obtained by multiplying the protein content by a factor of 3·47 cal/g (Watt & Merill, 1963). Values for the total energy thus computed are given in Table 11.

TABLE 11
Energy Content of Soymilk

Constituents	*Percentage composition*	*Approx. amount in 200 ml soymilk (g)*	*Factor (cal/kg)*	*Energy content (cal)*
Sugar	9	18	4·20	75·60
Carbohydrates	0·6	1·2	1·68	2·02
Fat	1·0	2	8·37	16·74
Protein	2·5	5	3·47	17·35
Total calories per 200 ml of soymilk				111·71

Vitamin content

Soymilks as prepared from a water extract of soybeans, full fat or defatted soyflour and meal, are not particularly rich sources of vitamins. However, on account of their low cost and widespread consumption among the people in ASEAN countries, soymilk, as well as soymilk powder, are ideal vehicles for vitamin fortification. Table 12 sets out the vitamin composition of the soyproducts. It will be seen that vitamin D and vitamin B12 should be added to the soymilk if it is to be used as a substitute for cow's milk.

Mineral content

The mineral compositions of soybean and soybean food products are shown in Table 13. It can be seen that the calcium content of traditional soymilk compares favourably with that of cow's milk (0·08 versus 0·11 %) (Shurpalekar *et al.*, 1961). The phosphorus content is high but about a

TABLE 12
Vitamin Content of Soybean and Soybean Food Products

Vitamin/Products	*Immature beans*	*Mature beans*	*Sprouts*	*Meal*	*Flour*	*Defatted soyflour*	*Curd*	*Milk*[b]	*Misc.*
β-carotene (pro Vit. A) (μg/g)	2·7	0·2–2·4						7·5	
Vitamin A (IU)	—	—	—	—	—	0·7–4·0	—	—	—
Vitamin B1 (thiamine) (μg/g)[a]	6·4	11·0–17·5	11·2–21·9	12·0–44·1	11·0–15·0	11–15	3·9	0·8	1·3
Vitamin B2 (riboflavin) (μg/g)[a]	3·5	2·3	4·8–7·0	2·7–3·3	4·0–4·4	24–44	3·7	1·1	1·4
Vitamin B6 (pyridoxine) (μg/g)[a]	3·5	6·4	14·1–17·7	8·8		4·8–12			
Vitamin B12 (cyanocobalamin)						0·6–20			
Vitamin C (ascorbic acid) (mg/g)	0·2	0·2	0·4			0		21·6	
Vitamin D (cholecalciferol) (IU)						0			
Vitamin E (tocopherols) (IU)						1·5			
Niacin (μg/g)[a]		20·0–25·9	29·9–48·0	19–40·0	20·3–29·1	40·9–67	5·5	2·5	
Pantothenic acid (μg/g)[a]	12	12	18·8–34·4	8·8		13–51			
Biotin (μg/g)[a]	0·5	0·6	1·1–1·7	0·2		1·7–6·6			
Folic acid (μg/g)[a]	1·3	2·3	3·7	4·0–4·9	0·8–0·9				
Inositol (mg/g)[a]		1·9–2·6	2·5–3·9	1·8–2·1		22–38			
Choline (mg/g)	2·0–3·3	3·4		3·5–3·8					

[a] Where a range of values is shown, the average value is very closely given by taking the average of the two extreme values.
[b] Unit is mg/litre except for vitamin A which is expressed as IU of vitamin A/litre.

Reference: Data is compiled from the following

Burkholder (1943)
Burkholder & McVeigh (1945)
Chang & Murray (1949)
Engel (1943)
Flynn (1949)
Guggenheim & Szmelcman (1965)
Hoff-Jorgensen *et al.* (1952)
Kellor (1974)
Kondo *et al.* (1954)
Miller (1945)
Mustakas *et al.* (1964)
Sherman & Salmon (1939)
Shurpalekar *et al.* (1961)
Sugawara (1953)
Van Duyne *et al.* (1945)

TABLE 13
Mineral Content of Soybean and Soybean Food Products

Soybean product/ minerals	*Calcium (%)*	*Phosphorus (%)*	*Mágnesium (%)*	*Zinc (mg/kg)*	*Iron (mg/kg)*	*Manganese (mg/kg)*	*Copper*
Immature bean	0·10	0·26			21·3		
Mature bean	0·16–0·47	0·42–0·82	0·22–0·24	37	90–150	32	12
Sprouts	0·40						
Meal	0·24–0·31	0·60	0·24–0·30	55–57	140	24–29	14–24
Flour	0·42–0·64	0·60		110–160			
Curd (*Tofu*)	0·80	0·80–1·0		105			
Milk (traditional)	0·76	0·15		68			
Milk (powder, proprietary)	0·7–1·0	1·1		30–170			
Misc.	0·11			35			
Matto	0·18	0·42		62			

Data compiled from the following:
Adolph & Chew (1968).
Bailey *et al.* (1935).
Carter & Hopper (1942).
Chang & Murray (1949).
Dewar (1967).
FAO (1954).
Guggenheim & Szmelcman (1965).
Harmon *et al.* (1969).
Miller & Robbins (1934).
Mitchell (1950).
Morse (1950).
Pantr & Kapun (1963).
Shurpalekar *et al.* (1961).
All values corrected for moisture content.

third to a half of this is present as phytic acid which cannot be utilised (Nelson, 1968). For infant formulation supplementing the soymilk with iodine has been emphasised (Anderson, 1961).

CONCLUSION

The use of defatted meal as a source of protein offers interesting possibilities. Besides quantity, good quality meal is essential if it is to be processed into foods for human consumption. The meal should be derived from good quality flakes of wholesome beans and subjected only to minimal heat treatment during the desolventising stage.

A comparison of the chemical and amino acid compositions of various commercial soymilks with soymilk from defatted meal and reconstituted soymilk for spray-dried soymilk powder is shown in Tables 2 and 3.

Soymilk and soymilk powder are two possible applications from the water-extract of soymeal. Other traditional foods, such as soybean curd and snack foods, could be incorporated with defatted meal in their production. As these foods are consumed in the national diets they are suitable vehicles for fortification to meet known deficiencies in essential nutrients. Such fortification would serve to provide a complete nutritional supplement in the form of a beverage for children of primary school age and for specific groups of people.

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REFERENCES

Adolph, W. H. & Chew (1968). The utilization of calcium in soybean diets. *J. Nutr.*, **5**, 379–85.

Altschul, A. M. (1965). *Proteins, their chemistry and politics*. Basic Books, New York.

Aminlari, M., Ferrier, L. K. & Nelson, A. I. (1977). Protein dispersibility of spray dried whole soybean milk base: Effect of processing variables. *J. Food Science*, **42**(4), 985–8.

Anderson, D. W. (1961). Problems in formulation of soymilk. *Proc. Conf. Soybean Products for Protein in Human Food USDA, Peoria*. **I**, 11.

Ang, H. G., Kwik, W. L., Lim, K. K., Tan, S. F. & Theng, C. Y. (1978). Development of traditional and new soyproducts using defatted soymeat. *Proc. Int. Soyal Protein Food Conference*, 53.

Bailey, L. H., Capen, R. G. & Lechlerg, J. A. (1935). The composition and characteristics of soybeans, soybean flour and soybean bread. *Cereal Chem.*, **12**, 41–472.

Burkholder, P. R. (1943). Vitamins in edible soybeans. *Science*, **98**, 188–90.

Burkholder, P. R. & McVeigh, I. (1945). Vitamin content of some mature and germinated legume seeds. *Plant Physiol.*, **20**, 301–6.

Carter, J. L. & Hopper, T. H. (1942). Influences of variety, environment and fertility level on the chemical composition of soybean seed. USDA Tech. Bull. 787.

Chang, I. C. L. & Murray, H. C. (1949). Biological value of the protein and the mineral, vitamin and amino acid content of soymilk and curd. *Cereal Chem.*, **26**, 297–305.

Circle, S. J. & Smith, A. K. (1972). *Soybeans chemistry and technology*. AVI Publishing Co., Westport, Conn.

Dewar, W. A (1967). The zinc and manganese content of some foods. *J. Sc. Fd Agri.*, **18**, 68–71.

Engel, R. W. (1943). The choline content of animal and plant products. *Nutr.*, **25**, 441–6.
FAO Food Composition Tables (1954). *Minerals and Vitamins for International Use*. Food Agri. Organ. UN Nutri. Studies, 11.
FAO Nutritional Studies (1970). No. 24.
FAO Protein Requirement (1965). *Food and Agricultural Organisation UN Nutrition Meeting Report*, Ser. 37.
Flynn, L. M. (1949). Report on determination of folic acid. *J. Assoc. Offic. Agri., Chemists*, **32**, 464–78.
Graham, G. G., Placko, R. P., Morales, E., Acevedo, G. & Cordano, A. (1971). Lysine enrichment of wheat flour; prolonged feeding of infants. *Amer. J. Clin. Nutr.*
Guggenheim, K. & Szmelcman, S. (1965). Protein rich mixture based on vegetable foods available in Middle Eastern countries. *J. Agric. Fd Chem.*, **13**, 148–51.
Hall, C. W. & Hedrick, T. I. (1972). *Drying of milk and milk products*. AVI Publishing Co., Westport, Conn.
Harmon, B. G., Becker, D. E., Jensen, A. H. & Baker, D. H. (1969). Nutrient composition of corn soybean meal. *J. Animal Science*, **28**, 459–64.
Hoff-Jorgensen, E. P., Moustgaard, E. & Mohler, J. P. (1952). The content of B vitamins in some ordinary feedstuffs: The application of an improved medium for vitamin determinations with *Lactobacillis casei*. *Acta Agr. Scand.*, **2**, 305–11.
Horan, F. E. (1975). Meat analogues. In: *New protein foods*. Vol. 8. (Altschul, A. M. (Ed.)), Academic Press, New York.
Inglett, G. E., Cavins, J. F., Kwolek, W. F. & Wall, J. S. (1969). Using a computer to optimize cereal-based food composition. *Cereal Science Today*, **14**, 69–74.
Iriarte, B. V. R. & Barnes, R. H. (1966). The effect of overheating on certain nutritional properties of the protein of soybeans. *J. Food Technol.*, **20**, 131–4.
Kellor, R. L. (1974). Defatted soyflour and soygrits. *JAOCS*, **51**, 774–801.
Kondo, K., Iwai, K. & Yoshida, T. (1954). Folic acid in plant tissues. III. Determination of folic acid and folinic acid in plant tissues. *Fd Sc. Res. Inst. Kyoto U. Bull.*, **13**, 67–9.
Master, K. (1972). *Spray drying*. Leonard Hill Publishers.
Meyer, E. W. (1967). Soybean concentrates and isolates. *Proc. Intern. Conf. Soybean Protein Foods USDA Peoria, Ill.* ARS-71-35.
Miller, C. D. (1945). Thiamine content of Japanese soybean products. *J. Am. Dietet. Assoc.*, **21**, 430–2.
Miller, C. D. & Robbins, R. C. (1934). The nutritive values of green immature soybeans. *J. Agri. Res.*, **49**, 161–7.
Mitchell, H. H. (1950). Nutritive factors in soybean products. *Soybean and soybean products*, Vol. I (Markley, K. S. (Ed.)), John Wiley & Sons, New York.
Morse, W. J. (1950). Chemical composition of soybean seed. *Soybean and*

soybean products, Vol. I (Markley, K. S. (Ed.)), John Wiley & Sons, New York.

Mustakas, G. C., Griffin Jr, E. L., Allen, L. E. & Smith, O. B. (1964). Production and nutritional evaluation of intrusion-cooked full-fat soy flour. *JAOCS*, **41**, 607–14.

Nelson, T. S. (1968). Effects of phytate on the calcium requirements of chicks. *Poultry Science*, **47**, 1985–9.

Pantr & Kapun, A. S. (1963). A comparative study of the chemical composition and nutritive value of some common Indian pulses and soybean. *Ann. Biochem. Eyptl. Med.* (*Calcutta*), **23**, 457–60.

Pyle, J. R. (1975). Private communication.

Schroder, D. J. & Jackson, H. (1972). Preparation and evaluation of soybean curd with reduced beany flavour. *J. Food Science*, **37**, 450–1.

Sherman, W. C. & Salmon, W. D. (1939). Carotene content of different varieties of green and mature soybeans and cowpeas. *Food Res.*, **4**, 371–80.

Shurpalekar, S. R., Chandrasekhara, M. R., Swaminathan, M. & Surahmanyan, V. (1961). Chemical composition and nutritive value of soybean and soybean products. *Fd. Sci.* (*Mysore*), **11**, 52–64.

Smith, A. K. (1964). Tempeh: Nutritive value in relation to processing. *Cereal Chem.*, **41**, 174–81.

Sugawara, T. (1953). The formation of ascorbic acid in plants. V. The germination of seeds and production of ascorbic acid. *Japan, J. Botany*, **14**, 125–46.

US Department of Agriculture (USDA) (1977). *US fats and oils statistics, 1950–71.* Stat. Bull. No. 489, 49. US Department of Agriculture, Washington, DC.

US National Academy of Science (1959). *Evaluation of protein nutrition.* Nat. Res. Council Publication, 711.

Van Buren, J. P., Steinkraus, K. H., Hackler, L. R., El. Rawi, I. & Hand, D. B. (1964). Indexes of protein quality in dried soymilks. *J. Agricultural Food Chemistry*, 524–8.

Van Duyne, F. O., Bruckhart, S. M., Chase, J. T. & Simpson, J. I. (1945). Ascorbic acid content of freshly harvested vegetables. *J. Amer. Dietet. Assoc.*, **21**, 153–4.

Watt, B. K. & Merill, A. L. (1963). *Composition of foods. Raw, processed and prepared.* USDA Handbook.

Wolf, W. J. & Cowan, J. C. (1975). *Soybeans as a food source.* (Revised edition), USA, CRC Press, 60–5.