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Food Chemical Investigation of Tofu and its Byproduct Okara

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ABSTRACT

Tofu, an oriental soy food now produced commercially in countries outside of its traditional home, was prepared from soybeans of the cultivars Edgar, Hutton and Prima. The product, which is cheese-like in character and in method of preparation, was produced according to a modified method which included the addition of a coagulant mixture consisting of calcium chloride dihydrate and calcium sulphate dihydrate at levels which not only resulted in good tofu yields, but also elevated the calcium levels in such a manner as to make the product comparable to cheese as regards the wet weight concentration of this essential dietary mineral.

Tofu, together with its fibrous byproduct, okara, and also the soybeans used in their manufacture, were subjected to food chemical analysis, namely the proximate as well as mineral and B group vitamin (thiamin, riboflavin and nicotinic acid) contents; in addition, specific analyses were performed to determine the contents of insoluble as well as soluble fibre, phytic acid, monosaccharides, oligosaccharides and starch. Average energy values were calculated from the data for protein, oil and total carbohydrates.

INTRODUCTION

The eastern soy food tofu, also referred to as soybean curd, is a protein rich, bland-tasting, non-fermented cheese-like product which had its origin in ancient times (Shurtleff & Aoyagi, 1979*a,b*; Tsai *et al.*, 1981; Wang & Hesseltine, 1982). Confined to the orient for millenia, the product has gained wide acceptance in western countries over the past few decades where it is now produced commercially on a significant scale (Shurtleff & Aoyagi,

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1979*a*,*b*; Wang *et al.*, 1983). The product is eaten either as the main protein component of a meal or is used as an ingredient in the preparation of innovative products such as vegetarian hamburger patties, ice cream and mayonnaise (Shurtleff & Aoyagi, 1979*b*).

Tofu manufacture is in many respects analogous to cheese-making, the essential difference being that a lactic acid-producing bacterial starter culture is not employed in its preparation. However, the process lends itself ideally to the production of what may be considered to be a vegetarian cheese analogue; as in cheese, the solids of tofu are composed chiefly of protein of high quality—the Net Protein Utilisation (NPU) of tofu is reported to be 65%, making it equivalent to chicken meat in terms of digestibility and assimilability (Shurtleff & Aoyagi, 1979*a*)—and oil; furthermore, calcium levels, characteristically high in dairy products, may be artificially boosted in tofu by the addition of calcium-rich coagulants. The emphasis during the present investigation was in producing tofu combining these attributes.

The tofu-making process generally involves the preparation of a soymilk (i.e. slurried soybeans) which is boiled, filtered and then treated, at high temperature, with the coagulant—analogous to the rennet used in cheese-making—which precipitates the proteins with the concomitant release of curds and whey; the curds are filtered off and moulded into shape under pressure. A large amount (approximately one third) of the original soybean mass is unavoidably lost during the first filtration step; the fibrous, protein and oil-rich byproduct obtained during this step is known as okara, or soy pulp, and finds an application in both human and animal feeding; the whey can be similarly utilised, but is a byproduct of relatively low nutritive value and has the disadvantage of containing appreciable amounts of flatulence-causing carbohydrates (Shurtleff & Aoyagi, 1979*a*,*b*; Liener, 1981; Rackis, 1981*b*).

This food chemical study was undertaken as part of a general investigation of oriental soy foods which are at present largely unavailable on the South African market, but which are considered to have the potential for commercialisation and which could contribute to the increased utilisation of vegetable protein of high quality for human consumption in this country (Van der Riet *et al.*, 1987).

MATERIALS AND METHODS

Soybeans

Quantities of food grade soybeans of the cultivars Edgar, Hutton and Prima were purchased from commercial seedsmen. These cultivars are produced chiefly in the Transvaal and prefer soils with a moderate clay content. Prima, which has an indeterminate growth habit, performs best in the cooler highveld areas; the remaining two cultivars are determinate types and are grown in the warmer northern regions of the province.

Tofu preparation

Tofu, as well as the byproduct okara, were prepared from each of the above soybean cultivars according to the following method.

One kilogram of washed soybeans was soaked overnight at 10°C in 10 litres of tap water; the beans and soak water were then passed through a colloid mill to produce soymilk; the soymilk was heated with constant stirring to 80–85°C in a steam-jacketed kettle, and then filtered through a single layer of cheese cloth, under pressure; the okara was collected and further treated as described below; the filtrate was then boiled for 20 min to inactivate trypsin inhibitors (Liener, 1981; Rackis, 1981*a*); the soymilk was transferred to a plastic bucket and cooled to 80°C; a coagulant mixture, consisting of 20 g of calcium chloride dihydrate ($CaCl.2H_2O$) and 50 g of calcium sulphate dihydrate ($CaSO_4 . 2H_2O$) was prepared by first dissolving the $CaCl_2 . 2H_2O$ in 500 ml of water and then suspending the $CaSO_4 . 2H_2O$ in this solution; the coagulant mixture, which provided concentrations of approximately 0·015M and 0·032M of $CaCl_2.2H_2O$ and $CaSO_4.2H_2O$ when diluted in the soymilk, respectively, was rapidly stirred in (*c.* 5 s) and the mixture was left for 30 min to allow the curds and whey to separate; the curds were filtered off under pressure using a single layer of cheesecloth. The resulting tofu was cut into approximately 2 × 3 × 3 cm cubes and submerged in water for 2 h prior to freeze-drying the material. The okara presscake was similarly freeze-dried. Moisture contents of the freeze-dried material, as well as samples of whole soybeans, were determined to enable absolute dry masses to be calculated. Whey was collected but analysed only for protein, oil and soluble solids contents.

Starch determinations were performed separately on a second batch of the same soybean cultivars, as well as tofu and okara prepared therefrom as described above.

Sample preparation

The freeze-dried material was pulverised in a pin mill, mixed for 30 min in a sample splitter and further stored in glass bottles at 5°C until analysed.

Analytical methods

The analytical methods employed were the same as those published in a previous paper on soybean tempeh (Van der Riet *et al.*, 1987) and are summarised as follows.

Protein, ash and oil were determined according to standard procedures. Moisture was determined by drying at 70°C under reduced pressure, and the results of food chemical analyses were expressed on a moisture free, full fat basis. Minerals (Ca, Mg, Fe, Na, K, Cu, Zn and Mn) were determined by atomic absorption spectrophotometry. Phosphorus was determined colorimetrically.

Defatted material was used for the determination of dietary fibre, starch and oligosaccharides. Insoluble and soluble dietary fibre were determined according to the method of Asp *et al.* (1983); total dietary fibre was calculated as the sum of the two values obtained. Starch was determined as glucose formed on enzymatic hydrolysis, according to the method of Batey (1982), as modified by van der Riet *et al.* (1987). HPLC methods were used to determine oligosaccharides (Wight & Datel, 1986) and phytic acid (Cilliers & van Niekerk, 1986).

Thiamin was determined according to a fluorimetric method as modified by van der Riet *et al.* (1987). Riboflavin was determined by HPLC, using the method of van Niekerk (1982) as modified by van der Riet *et al.* (1987) and nicotinic acid was determined microbiologically.

RESULTS AND DISCUSSION

Tofu of good quality, as judged in terms of appearance, texture, aroma, taste and mouthfeel, and high yield was made from all three soybean cultivars by means of the above procedure; on average 53% of the initial soybean dry mass was recovered in tofu, 34% in okara and 16% in whey, the latter figure being estimated by refractometry. An average of 72% of soybean protein was recovered in tofu, 23% in okara and 8% in whey; the respective average percentages for soybean oil were 82, 16 and <1.

Average energy values (kJ per 100 g) calculated by means of the recommended conversion factors for protein, fat and carbohydrate given by Paul and Southgate (1978), were the following: soybeans, 1622; tofu, 2158; Okara, 893.

Results of the food chemical analyses are presented in Tables 1 and 2.

The conversion of soybeans into tofu and okara led to the following changes in the proximate composition, the trends being similar for all three soybean cultivars; whereas protein and oil were concentrated in tofu, total fibre, consisting of large amounts of both insoluble and soluble fibre, was concentrated in the okara; okara nonetheless contained appreciable amounts of protein and oil, as mentioned above, emphasizing the fact that it should not be regarded as a waste product. A large amount of soluble carbohydrate material, including monosaccharides and oligosaccharides,

TABLE 1
Food Chemical Analysis of Tofu, Okara and Soybeans of Three Cultivars used in their Preparation

Soybean cultivar	Sample analysed	Protein[a]	Oil	Carbohydrates[b]	Phytic acid	Insoluble fibre	Soluble fibre	Total fibre	Ash	Ca	Mg	Fe	Na	K	Cu	Zn	Mn	P	Thiamin	Riboflavin	Nicotinic acid
		(g/100 g)[c]								(mg/100 g)[c]											
Edgar	Whole soybeans	40·0	18·2	19·0	1·2	18·4	4·8	23·2	4·7	155	262	9·3	11·7	1 609	1·7	5·5	3·2	715	0·44	0·06	2·71
	Tofu	53·9	30·2	3·4	1·5	4·7	0·7	5·4	7·2	1 849	188	11·1	7·7	206	1·4	6·0	4·4	926	0·19	0·05	0·76
	Okara	28·4	9·6	5·3	0·5	42·0	14·6	56·6	3·2	260	163	6·2	16·2	1 046	1·1	3·8	2·5	396	0·59	0·04	1·01
Hutton	Whole soybeans	40·1	21·0	15·2	1·6	16·4	5·3	21·7	5·3	275	282	11·7	9·3	1 739	1·7	4·6	4·1	635	0·54	0·06	2·65
	Tofu	53·0	35·0	2·5	1·9	5·4	2·3	7·7	6·3	2 092	179	9·4	4·9	171	1·5	5·5	5·9	971	0·13	0·04	0·54
	Okara	25·4	10·9	3·8	1·2	43·6	14·5	58·1	3·7	428	158	7·2	19·1	1 094	1·1	3·5	3·1	444	0·49	0·03	0·82
Prima	Whole soybeans	39·5	20·4	17·7	1·7	15·5	5·6	21·1	5·4	187	247	11·6	3·5	1 693	1·8	6·0	2·8	830	0·45	0·06	2·90
	Tofu	52·4	32·4	3·7	2·5	4·8	2·8	7·6	6·8	1 939	207	9·5	6·1	256	1·4	6·9	3·8	1 014	0·23	0·05	0·86
	Okara	26·2	9·3	4·6	0·9	40·2	12·6	52·8	3·0	286	165	8·2	18·4	1 233	1·2	6·4	2·3	407	0·48	0·03	1·04

[a] Kjeldahl nitrogen × 5·71.
[b] Total starch, mono- and oligosaccharides—see Table 2.
[c] All values are given on a moisture-free, full fat basis.

TABLE 2
Carbohydrate Contents (g/100 g[a]) of Three Cultivars of Soybeans as well as Tofu and Okara made therefrom

Soybean cultivar	*Sample analysed*	*Monosaccharides (unspecified)*	*Oligosaccharides*			*Starch*
			Stachyose	*Raffinose*	*Sucrose*	
Edgar	Soybeans	2·5	6·3	1·2	8·0	0·95
	Tofu	0·4	0·9	0·2	1·5	0·44
	Okara	0·7	1·4	0·3	2·3	0·59
Hutton	Soybeans	2·3	4·9	1·7	5·6	0·74
	Tofu	0·4	0·5	0·2	0·8	0·58
	Okara	0·6	0·9	0·3	1·3	0·68
Prima	Soybeans	3·0	5·1	1·6	7·2	0·78
	Tofu	0·2	1·0	0·3	1·6	0·55
	Okara	0·7	0·9	0·4	1·8	0·79

[a] All values are given on a moisture-free, full fat basis.

was lost in the whey during tofu-making (Table 2); the okara in all cases contained slightly higher total carbohydrate levels than tofu. Starch is a minor constituent of soybeans (Bils & Howell, 1963; Wilson *et al.*, 1978) but relatively high levels were nonetheless recovered in tofu and okara, the latter having the higher concentration, indicating that amyloid material is largely retained in the solids during tofu-making. Soybean starch levels were found to be variable within different batches of the same cultivar—Prima and Hutton soybeans were previously found to contain lower levels of starch (Van der Riet *et al.*, 1987). Starch contents of soybean seeds have, however, been shown to vary with the degree of maturity; immature seeds contain appreciable amounts of starch but this is metabolised during maturation, leaving the fully matured seeds virtually free of this material (Bils & Howell, 1963). As pointed out in a previous investigation on soybean tempeh (Van der Riet *et al.*, 1987), protein-bound starch has been implicated in the poor digestibility of certain soybean proteins (Boonvisut & Whitaker, 1976).

Phytic acid, nutritionally significant because of its potential to chelate essential dietary minerals such as calcium and zinc (Cheryan, 1980; Liener, 1981; Forbes *et al.*, 1983) was found to be mainly concentrated in the tofu; it is precipitated together with the proteins upon addition of the coagulant mixture (Saio, 1979). The phytic acid content of soybeans has been shown to influence the physical properties of tofu; coagulation of the proteins occurs more slowly at higher phytic acid concentrations, and this was found to favour gel formation and resulted in increased tofu yields (Saio *et al.*, 1969*a*,*b*).

Soybeans are rich in potassium and phosphorus; the former element, together with sodium, was significantly concentrated in okara, indicating a probable association of these elements with fibre, and the latter in tofu, probably as a result of co-precipitation of phytic acid and protein (Saio *et al.*, 1969*a*,*b*; Saio, 1979).

Calcium levels were greatly increased in tofu as a result of the addition of the coagulant mixture. Taking the average dry weight value (1960 mg per 100 g) it may be calculated that amounts of approximately 294, 392, 490 and 588 mg of calcium would be present per 100 g serving of tofu at respective moisture contents of 85, 80, 75 and 70%. Calcium levels occurring in cheeses are presented here for comparative purposes: while the range on a wet weight basis is from 60 (Cottage cheese) to 1226 mg per 100 g (Parmesan), typical values for various cheeses are e.g. 360 (Stilton), 380 (Camembert), 534 (Limburger), 740 (Edam) and 800 mg per 100 g (Cheddar) (Paul & Southgate, 1978; Souci *et al.*, 1981). Depending on the moisture contents, tofu prepared by the present method would thus contain calcium levels comparable to those of many cheese types.

Significant levels of B group vitamins were recovered in tofu and okara, despite their water-solubility; thiamin and nicotinic acid were concentrated in okara.

Coagulation of the proteins is considered to be a critical step in making tofu and its variants such as silken tofu, and various coagulants, including mainly calcium and magnesium salts and acid-releasing substances such as glucono delta lactone, as well as the methods of application, have been investigated by several workers (Saio, 1979; Lu *et al.*, 1980; Skurray *et al.*, 1980; Tsai *et al.*, 1981; Wang & Hesseltine, 1982; Beddows & Wong, 1987). The present method, empirically derived, proved satisfactory in providing good tofu yields and elevated calcium contents.

Results obtained during the present investigation are largely in agreement with available published data concerning the proximate as well as mineral and vitamin composition of tofu, okara and also soybeans (Smith *et al.*, 1960; Liener, 1972; Smith & Circle, 1972; Shurtleff & Aoyagi, 1979*a*; Skurray *et al.*, 1980; Tsai *et al.*, 1981; Wang *et al.*, 1983).

Smith and Circle (1972) found an average of 42·9% protein (N × 6·25) and 19·7% oil in an investigation of 10 soybean varieties grown at five locations over a 5-year period; average levels of calcium, phosphorus and potassium were 275, 659 and 1670 mg per 100 g, respectively. The major sugars of soybeans were identified as sucrose, raffinose and stachyose; monosaccharides present in alcohol extracts of defatted soybean meal included fructose, rhamnose and arabinose; significant levels of glucose occurred only in immature seeds. Liener (1972) reported values comparable to those of the present investigation for thiamin and nicotinic acid in soybeans (1·4 and

2·3 mg per 100 g, respectively) and tofu (0·39 and 0·55 mg per 100 g, respectively); riboflavin levels were substantially higher, however, at 0·23 and 0·37 mg per 100 g for soybeans and tofu, respectively. The calcium content (dry weight basis) of mature beans ranged from 160 to 470 mg per 100 g and was 800 mg per 100 g in tofu; average phosphorus and iron levels were 620 and 12 (soybeans), and 900 and 10·5 mg per 100 g (tofu). Tsai *et al.* (1981) prepared tofu using various calcium salts at concentrations ranging from 0·01 to 0·08 N. The calcium contents, recalculated to a dry weight basis, of e.g. soft tofu, ranged from approximately 200 to 1940 mg per 100 g, the latter figure being comparable to the levels obtained during the present investigation. Previous studies (Adolph & Chen, 1932; Liener, 1972) have indicated a high bioavailability of calcium in tofu.

CONCLUSION

Tofu of consistent quality was produced from Edgar, Hutton and Prima soybeans by means of the present process. Similar trends were observed for all three cultivars in the changes in proximate as well as mineral and vitamin contents brought about during the conversion of soybeans into tofu and okara. Tofu should not be viewed in isolation of its byproduct, okara, which is itself rich in essential nutrients and dietary fibre. It was found possible to boost the calcium content of tofu to levels approximating those of many types of cheese. However, it is considered that the bioavailability of such added calcium requires detailed investigation.

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REFERENCES

Adolph, W. H & Chen, S.-C. (1932). The utilization of calcium in soy bean diets. *J. Nutr.*, **5**, 379–85.

Asp, N.-G., Johannsen, C.-G., Halmer, H. & Siljeström, M. (1983). Rapid enzymatic assay of insoluble and soluble dietary fibre. *J. Agric. Food Chem.*, **31**, 476–82.

Batey, I. L. (1982). Starch analysis using thermostable alpha amylases. *Starch/Stärke*, **34**, 125–8.

Beddows, C. G. & Wong, J. (1987). Optimization of yield and properties of silken tofu from soybeans. III. Coagulant concentration, mixing and filtration pressure. *Int. J. Food Sci. & Technol.*, **22**, 29–34.

Bils, R. F. & Howell, R. W. (1963). Biochemical and cytological changes in developing soybean cotyledons. *Crop Sci.*, **3**, 304–8.

Boonvisut, S. & Whitaker, J. R. (1976). Effect of heat, amylase and disulphide bond cleavage on the *in vitro* digestibility of soybean proteins. *J. Agric. Food Chem.*, **24**, 1130–5.

Cheryan, M. (1980). Phytic acid interactions in food systems. *Crit. Rev. Food Sci. and Nutr.*, **13**, 297–335.

Cilliers, J. J. L. & van Niekerk, P. J. (1986). LC determination of phytic acid in food by postcolumn colorimetric detection. *J. Agric. Food Chem.*, **34**, 680–3.

Forbes, R. M., Erdman, J. W., Parker, H. M., Kondo, H. & Ketelsen, S. M. (1983). Bioavailability of zinc in coagulated soy protein (tofu) to rats and effect of dietary calcium at a constant phytate:zinc ratio. *J. Nutr.*, **113**, 205–10.

Liener, I. E. (1972). Nutritional value of food protein products. In *Soybeans: Chemistry and technology. Vol. 1, Proteins*, ed. A. K. Smith & S. J. Circle. The AVI Publishing Company, Inc., Westport, CT, USA.

Liener, I. E. (1981). Factors affecting the nutritional quality of soya products. *J. Amer. Oil Chem. Soc.*, **58**, 406–15.

Lu, J. Y., Carter, E. & Chung, R. A. (1980). Use of calcium salts for soybean curd preparation. *J. Food Sci.*, **45**, 32–4.

Paul, A. A. & Southgate, D. A. T. (1978). *The Composition of Foods*. HMSO, London.

Rackis, J. J. (1981*a*). Significance of soya trypsin inhibitors in nutrition. *J. Amer. Oil Chem. Soc.*, **58**, 495–501.

Rackis, J. J. (1981*b*). Flatulence caused by soya and its control through processing. *J. Amer. Oil Chem. Soc.*, **58**, 503–9.

Saio, K. (1979). Tofu—Relationships between texture and fine structure. *Cereal Food World*, **24**, 342–54.

Saio, K., Koyama, E., Yamazaki, S. & Watanabe, T. (1969*a*). Protein–calcium–phytic acid relationships in soybean. Part III. Effect of phytic acid on coagulative reaction in tofu-making. *Agric. and Biol. Chem.*, **33**, 36–42.

Saio, K. Kamiya, M. & Watanabe, T. (1969*b*). Food processing characteristics of soybean 11S and 7S proteins. Part 1. Effect of difference of protein components among soybean varieties on formation of tofu-gel. *Agric. and Biol. Chem.*, **33**, 1301–8.

Shurtleff, W. & Aoyagi, A. (1979*a*). *The Book of Tofu*. Ballantine Books, New York, USA.

Shurtleff, W. & Aoyagi, A. (1979*b*). *Tofu and Soymilk Production*. New-Age Foods Study Centre, Lafayette, CA, USA.

Skurray, G., Cunich, J. & Carter, O. (1980). The effect of different varieties of soybean and calcium concentration on the quality of tofu. *Food Chem.*, **6**, 89–95.

Smith, A. K. & Circle, S. J. (1972). Chemical composition of the seed. In *Soybeans: Chemistry and Technology. Vol. 1, Proteins*, ed. A. K. Smith & S. J. Circle. The AVI Publishing Company, Inc., Westport, CT, USA.

Smith, A. K., Watanabe, T. & Nash, A. M. (1960). Tofu from Japanese and United States soybeans. *Food Technol.*, **14**, 332–6.

Souci, S. W., Fachmann, W. & Kraut, H. (1981). *Food composition and nutrition tables 1981/82*. Wissenschaftliche Verlagsgesellschaft mbH, Stuttgart, FRG.

Tsai, S.-J., Lan, C. Y., Kao, C. S. & Chen, S. C. (1981). Studies on the yield and quality characteristics of tofu. *J. Food Sci.*, **46**, 1734–40.

Van der Riet, W. B., Wight, A. W., Cilliers, J. J. L. & Datel, J. M. (1987). Food chemical analysis of tempeh prepared from South African-grown soybeans. *Food Chem.*, **25**, 197–206.

Van Niekerk, P. J. (1982). In *HPLC in Food Analysis*, ed. R. Macrae. Academic Press, New York, p. 210.

Wang, H. L. & Hesseltine, C. W. (1982). Coagulation conditions in tofu processing. *Process Biochem.*, **17**, 7–12.

Wang, H. L., Swain, E. W. & Kwolek, W. F. (1983). Effect of soybean varieties on the yield and quality of tofu. *Cereal Chem.*, **60**, 245–48.

Wight, A. W. & Datel, J. M. (1986). Evaluation of a reversed phase high performance liquid chromatographic column for estimation of legume seed oligosaccharides. *Food Chem.*, **21**, 167–81.

Wilson, I. A., Birmingham, V. A., Moon, D. P. & Snyder, H. E. (1978). Isolation and characterization of starch from mature soybeans. *Cereal Chem.*, **55**, 661–70.