Review Article

Tempe, a nutritious and healthy food from Indonesia

Mary Astuti[1] Bachelor Eng, MSc, PhD, Andreanyta Meliala[2] Bachelor Med, MD,
Fabien S Dalais[2] BSc Hons, PhD and Mark L Wahlqvist[2] BMedSc, MBBS, MD, FRACP, FACN

[1]*Centre of Women's Studies, Gadjah Mada University, Yogyakarta, Indonesia*
[2]*International Health and Development Unit, Faculty of Medicine, Monash University, Melbourne, Victoria, Australia*

Tempe is a fermented soy bean product originally made by Central Javanese people through fermentation with *Rhizopus* species. Although there is evidence of earlier fermentation of soy, tempe had appeared in the Central Javanese food pattern in the 1700s. Through its extensive use in main meals and snacks, it has led to people in the Jakarta prectinct having the highest known soy intake in the world and accordingly of the isoflavones contained. This provides an unique opportunity to consider the health effects of tempe (and soy), both beneficial and potentially toxic. Apparent health benefits are bowel health, protection against cardiovascular disease, certain cancers (e.g. breast and prostate) and menopausal health (including bone health). The long use of tempe at all stages of life, without recognised adverse effects, suggests it is relatively safe at the levels of intake seen in Central Java. However, further research on soy, both fermented and non-fermented, in Central Java should yield more insight into the mechanisms of action and the safe ranges of intake.

Key words: bone health, bowel health, cancer, cardiovascular disease, Central Java, Indonesia, isoflavones, oligosaccharides, phytic acid, tempe.

Introduction

History

Tempe is a widely consumed Indonesian traditional fermented food, which is principally made with soybeans, but can also be made from a variety of legumes and seeds. In Indonesia, soybeans are consumed mostly in the form of traditional foods, consisting of fermented and non-fermented products. Commercially fermented soybeans include tempe, soy sauce and soy paste. Historical evidence shows that soybean tempe is a fermented product originally made by Central Javanese people and appeared in their food pattern around the 1700s.[1,2] In addition, this finding is supported by the presence of non-salted fermented soybeans in Asian countries, for example, *natto* in Japan, *dau chi* in China and *kinema* in Nepal and India, which are products fermented by bacteria *Bacillus* sp.[1] Tempe, however, is fermented by the *Rhizopus* sp (Fig. 1).

How is it made?

There are four steps in the tempe manufacturing process, soaking, boiling, inoculating with microbia and incubating at room temperature. Tempe in Indonesia is fermented with *Rhizopus* sp. mould, especially *Rhizopus oligosporus*, *R. oryzae*, *R. arhizus*, *R. stolonifer* and *R. microsporus* (I Ganjar, unpubl. data, 1995). Traditional inoculum is prepared in Hibiscus or teak leaf and inoculum powder is prepared from cooked rice. Tempe producers in Indonesia do not use the pure culture of *R. oligosporus*, but they use a mixed culture of *Rhizopus* sp. There is no standard process for tempe making, which is one of the reasons why there is a lot of variation in tempe making from one region and one producer to another.

Tempe in Indonesia

Apart from soybean-based tempe, there are many other kinds of tempe in Indonesia and their name is derived from the raw material in the tempe. They include sword beans, velvet beans, pigeon peas, *leucaena lecocephala* and tofu waste material (left over soy-pulp after tofu preparation). As soybean tempe is the most popular, the word tempe usually refers to soybean-tempe. The local name of tempe can be used for international and regional publications, as there are no common English names available.[3] Tempe is produced mostly by small household industries with a production range of 10 kg–4 metric tons of tempe per day.[4] It is estimated that there are more than 100 000 tempe producers spread out in the provinces of Indonesia. Urban and rural populations, especially in Java, generally consume tempe as a part of their food pattern. As a source of protein, tempe is consumed in greater quantities than other protein sources. Tempe supplies at least 10% of the current protein consumption, while chicken egg supplies 1.25%, meat supplies 3.15% and cereals supply around 60%.[4] Tempe is not consumed as a raw food but in the form of cooked tempe and served as a delicacy or a side dish, often fried, boiled, steamed or roasted.

Correspondence address: Dr Andreanyta Meliala, International Health and Development Unit, c/o Department of Epidemiology and Preventive Medicine, Monash Medical School, Alfred Hospital, Prahran VIC 3181, Australia.
Tel: 61 3 9903 924; Fax: 61 3 9903 0576
Email: meliala.andreanyta@med.monash.edu.au
Accepted 1 May 2000

All references to papers presented and unpublished data can be obtained from the corresponding author via email.

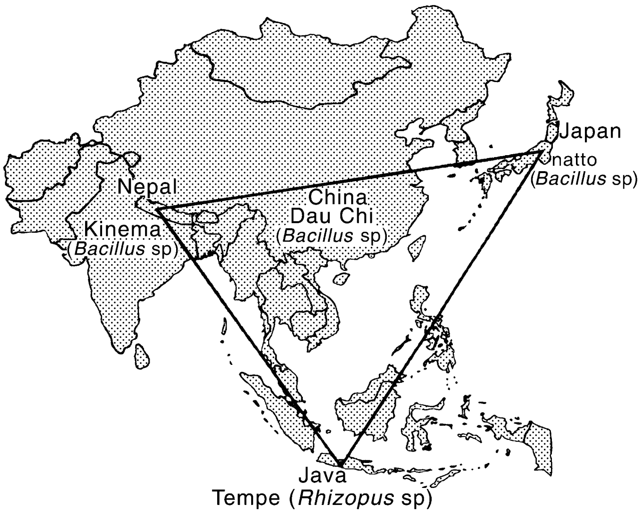

Figure 1. Map 'Natto triangle' describing only tempe from Central Java using *Rhizopus* sp. for soybean fermentation. Jepang, Japan; Jawa, Java.

Tempe is categorised as a low social value food, which means that tempe is only served at home as domestic food and through stall food-vendors, although tempe is consumed by people of various ages of different socioeconomic status.

Biochemical changes from soybean to tempe

Research in the tempe field has shown its potential health benefit, possibly due to biochemical changes during soybean fermentation. During tempe processing, there are valuable changes not only in the increase of nutritional values of some nutrients in soybeans, but also in the development of vitamins, phytochemicals and antioxidative constituents.

Protein

Although the protein content of tempe and unfermented soybeans is almost the same, the soluble protein content increases sharply due to the action of protease enzyme produced by mould during fermentation. Furthermore, the quality of protein in tempe is slightly higher than in unfermented soybean.[5] The soluble nitrogen content in unfermented soybeans is 3.5 mg/g, compared to 8.7 mg/g in tempe. Additionally, following 48 h of fermentation, most amino acids decrease in the range of 3.62–27.9%. According to Murata *et al.* total amino acids content decrease but the free amino acids increase sharply, possibly due to strains of *Rhizopus* using amino acids as a source of nitrogen for growth (AJ Graham *et al.*, unpubl. data, 1995).[6]

Lipid

The lipid content of tempe is lower than that of unfermented soybeans. It has been shown that during soybean fermentation the lipase enzyme hydrolyses triacylglycerol into free fatty acids. These fatty acids are used as a source of energy for the mould resulting in lower lipid content in tempe. During soybean fermentation the lipid contents decrease about 26%. A study by Graham *et al.* shows that the mould of *R. oligosporus* and *R. stolonifer* use linoleic acid, oleic acid, palmitic acid as energy sources, therefore during fermentation, palmitic acid, stearic acid, and linoleic acid rapidly decrease 63.4, 59.25 and 55.78, respectively (AJ Graham *et al.*, unpubl. data, 1995).[5]

Minerals

Trace mineral (iron, calcium and cuprum) levels were not influenced by the fermentation process; even so, their solubility increased sharply. Most of the iron in soybean is present as organic iron, which is bound to protein and other organic compounds. Total soluble iron increases from 24.29% in unfermented soybean to 40.52% in tempe and during fermentation soluble iron increases 66.51%.[5] Protein is broken down resulting in free amino acids, peptide or simple proteins. As a result, the iron is liberated from the iron-protein complex, thus increasing soluble iron. Astuti *et al.* have shown that tempe is a good source of available iron.[5] Calcium content decreases during the fermentation, but is not clearly understood. Calcium is possibly released from the bridge of phytate–protein during digestion of complex compound and lost together with bound water, which may be released during fermentation.

Vitamin B, B12 and tocopherol

The levels of vitamin B-complexes increase except for thiamine. Okada reported that vitamin B12 content of fresh tempe bought from Indonesia was 4.6 µg/100 g, the range from tempe prepared with *R. oligosporus* NRRL 2710 in Japan was 0.03–0.06 µg/100 g[8]. It seems that vitamin B12 is mainly produced by bacteria other than mould. During the soaking of soybeans, *Klebsiella pneumonia* is developed and produces vitamin B12.[8] Tocopherol composition changes during fermentation. Except for α-tocopherol, the levels of beta, gamma and delta tocopherol increases. Even though β-tocopherol has only 40% of the biological activity of α-tocopherol, an increase of 222.5% in beta tocopherol adds value to the natural antioxidant activity of tempe.

Phytic acid

Phytic acid is reduced by about 65% as a result of the action of phytase enzyme produced by *R. oligosporus*.[9] Phytic acid is known as an antinutrient factor which is able to bind divalent minerals, thus lowering the mineral bioavailability. Therefore, the decrease in phytic acid has a beneficial effect on mineral bioavailability.[5]

Oligosaccharide

The level of glucose increases sharply during tempe fermentation, possibly a product of the digestion of complex to simple carbohydrate. Starch, stacchyose, raffinose and sucrose in soybean are all decreased during tempe processing.[10]

Isoflavones

Isoflavones are oestrogenic compounds which have been reported to have many health beneficial effects. György *et al.*, Zilliken and Murakami *et al.* reported that tempe contains isoflavones.[11–13] Hutchins *et al.* compared the urinary isoflavonoid recovery between groups fed with fermented soybeans in the form of tempe and unfermented soybean in the form of tofu. A greater increase in urinary isoflavonoid recovery in the fermented-soybean group suggests that fermentation increases the availability of isoflavones in soy.[14] Dalais (FS Dalais pers. comm., 1998), Wuryani, Wang and Murphy, Dwyer *et al.* and Pillow *et al.*, have measured the isoflavone levels in tempe and found that the values are relatively high compared to other soybean products such as tofu and soy beverages.[15–18]

Superoxide dismutase

Superoxide dismutase (SOD) is a new enzyme, found in 1969. All biochemical living cell systems produce superoxide radicals, which cause a toxic effect to cells, thus every normal cell will have a defence system to protect the cells against the action of free radicals, such as superoxide anions.[19,20] The free radical scavenger, SOD, is present during the fermentation process (M Astuti *et al.*, unpubl. data, 1996). At the early state of fermentation, no SOD is present, but after 24 h of fermentation it gradually increases until up to 60 h of fermentation then starts to decrease, possibly due to a decrease in mould growth which is influenced by environmental conditions, such as pH. The presence of SOD in tempe is concomitant with the mould growth.

Health aspects of tempe

Flatulence and diarrhoea

A decrease in oligosaccharide, especially raffinose and content during tempe processing eliminates the flatulence problems observed when consuming soybeans. Tempe is essentially non-flatulent when it is fed to human subjects.[20] Van Veen and Schaffer observed the health benefits of tempe in preventing diarrheal problems in prisoners in Java. Individuals who did not consume tempe in their diet suffered from diarrhoea due to the bad sanitation of the prison.[21] A relevant thesis paper studied the effect of tempe on *E. coli* infection in a rabbit model. One group was given a diet containing tempe, the other were fed on a diet without tempe. After 4 weeks of feeding, both groups were infected with *E. coli* and observed for 14 days. Diarrheal symptoms occurred in 36% of the rabbits in the tempe group and 64% in the group without tempe.[22]

Lipid-related health matters

Lipid-lowering effect

The effect of a tempe-rich diet on cholesterol levels was reported by Mangkuwidjoyo *et al.* Tempe had a positive effect on cholesterol level and histopathological changes in liver and arteries of rats after a 4-month feeding trial.[23] Tempe constituents inhibit the enzyme which is responsible for biosynthesis of cholesterol and prevent the oxidation of low-density lipoprotein (LDL) thus minimise the production of plaque in arteries (M Astuti, unpubl. data, 1997).[1] The role of tempe on lipid profiles and lipid peroxidation has been studied by Astuti, using three groups of anaemic rats fed with casein, unfermented soybean and tempe as a source of protein and iron.[5] Protein source affected the serum lipids. Unfermented soybean and tempe groups tended to have lower levels of total cholesterol and triacylglycerol. Tempe feeding depressed lipid peroxides in the serum and liver, which could be correlated with the action of natural antioxidants in tempe. Isoflavonoids are able to form chelate complexes with iron which are efficient in inhibiting ferrous-iron induced lipid peroxidation (HC Jha *et al.*, unpubl. data, 1990). The hypocholesterolaemic effect of tempe was investigated by Astuti *et al.* using hyperlipidaemic rats, fed with tempe as a source of protein at varying concentrations (0, 25, 50, 75 and 100%) for 2 months. Lipid profile, lipid peroxide and superoxide dismutase activity were evaluated in rats' serum. Bile was then collected to evaluate a potential mechanism for cholesterol reduction. The result showed that tempe feeding lowered the cholesterol level in the tempe group, possibly due to the high content of cholesterol released from the liver through the bile (M Astuti, unpubl. data, 1997). According to Gorcia Hermosilla *et al.* free fatty acids in tempe inhibited the action of hydroxymethyl glutaryl CoA reductase, an enzyme which is responsible for cholesterol synthesis in the liver.[25] Hypocholesterolaemic properties of tempe in human subjects were studied by Astuti *et al.* in a feeding-trial of instant tempe-formula on 24 (8 male, 16 female) volunteers. Each respondent drank the formula daily for 3 months. The lipid profile, malondyaldehyde (MDA) and uric acid levels were measured in serum of each respondent as baseline before the feeding trial, every month during the feeding and 2 months after the feeding trial. (Malondyaldehyde is one of the products from the decomposition of fatty acid in lipid peroxidation. It is able to reach cell and tissue, thus resulting in cell damage. It does not only damage lipid molecules, but also non-lipid biomolecules, such as protein and nucleic acid. Damaged nucleic acid, especially in the nucleus, may cause gene mutation, which is able to promote cancer.) It showed that during the feeding trial, total cholesterol decreased 8.6% and 10.25% in males and females, respectively, but then increased in the same level of initial stage for both male and female respondents after 2 months of not consuming tempe formula. The LDL cholesterol levels decreased 12% in male and 9.67% in female respondents and then increased 9% in males and 15.5% in females after 2 months of not consuming the tempe formula. Lipid peroxidation which is expressed as MDA decreased 23% for both male and female respondents and then increased 13% in males and 15% in females after 2 months of not consuming the tempe formula. Uric acid level did not differ from baseline in the male group, but decreased about 14% in the female group, then increased in the same level of initial stage after 2 months of not consuming the tempe formula. Even though this was an uncontrolled study, these results are encouraging. The effect of tempe on SOD modulation was studied by Astuti, by using 45 copper-deficient male Wistar rats which were divided into five groups of nine rats and were fed with diets of different tempe concentrations (0, 25, 50, 75 and 100%, respectively) for 45 days. Copper is known as an important trace mineral acting as a cofactor of SOD. The activity of SOD and lipid peroxidation were evaluated from the serum. The highest inhibition of SOD against lipid peroxidation and the lowest level of MDA were found in rats on the 100% tempe diet as a source of protein and copper.[28] Copper as a component of SOD plays a dual role in SOD activity, as a cofactor as well as regulator.[29,30]

Menopausal symptoms

There are studies reporting a lower incidence of menopausal symptoms in Asian populations consuming high levels of soy, such as Japan, China, Korea and Indonesia. These oestrogenic compounds may play an important role in the prevention of menopausal symptoms.[31,32] Trials to date have not been properly designed to determine whether these compounds act similarly to oestrogen in alleviating menopausal symptoms. There is no epidemiological data specifically on menopausal disorders in populations with a very high intake of tempe.

Possible role of tempe in cancer prevention

Recently, attention has also focused on the potential role of soybean products in reducing cancer risk. Asian countries have among the lowest rates of common cancers in Western society such as breast, prostate and colon cancer.[33] The protective effect of a diet high in soy may partly explain it. An epidemiological study on colorectal cancer in Japan found that frequent consumption of soybeans and tofu markedly decreased both rectal and colon cancer risk.[34] Kiriakidis *et al.* demonstrated that tempe, especially its glucolipids, inhibits the proliferation of tumour cell in mice.[35] Indonesians are known as the largest soybean-consumers, especially in the form of tempe and tofu, in the South-East Asian countries. However, epidemiological studies relating to tempe consumption and the prevalence of cancer, particularly in Indonesia, have not yet been conducted.[36]

Conclusion

Diet as a part of lifestyle plays an important role in maintaining nutrition and health. Tempe is considered as a good source of protein, vitamin B12, antioxidants, phytochemical and other bioactive substances. Numerous studies to date strongly indicate that soybean-based tempe offers positive nutritional and health benefits. However, the recommendation of tempe consumption should be based on and supported by scientific experiments which show that tempe has indeed specific beneficial effects in human health. Continued multidisciplinary scientific research will provide a better understanding and further knowledge on the identification of the beneficial components and mechanisms of action, function, nutritional and health aspects of tempe. Furthermore, contribution from nutrition and the food-science community from all over the world to develop tempe from a variety of legumes as a raw material that are nutritious, tasty, acceptable and affordable will help us meet the challenge of health for all towards the 21st century.

References

1. Ngabei Ranggasutrasno. Centhini Tambangraras-Amongraga [Ancient Javanese Manuscript].
2. Astuti M. The history of the development of tempe in Bunga Rampai Tempe Indonesia. Indonesia Tempe Foundation 1996 20–41.
3. Anon. Report of the regional expert consultation on soybean processing and utilization. Bangkok, Thailand, 1996.
4. Indonesian Bureau of Central Statistic. 1987.
5. Astuti M. Iron bioavailability of traditional Indonesian soybean tempe. Memoirs of Tokyo University of Agriculture, XXXV 1994.
6. Murata K, Ikehata H, Miyamoto T. Studies on the nutritional value of tempeh. J Food Sci 1967; 32: 580–586.
7. Okada N. Role of microorganism in tempe manufacture. Isolation vitamin B12 producing bacteria. JARQ 1989; 22, 310–316.
8. Sudarmadji S, Markakis P. The phytate and phytase of soybean tempe. J Sc Food Process Agric 1977; 50: 426–428.
9. Van der Riet WB, Wigt AW, Cilliers JJL, Datel JM. Food chemical analysis of tempeh prepared from South Africa. Food Chem 1987; 25: 197–208.
10. György P, Murata K, Ikehata H. Antioxidant isolated from fermented soybeans. Nature 1964; 203: 870–872.
11. Zilliken FW. Isoflavones and related compounds, method of preparing and using and antioxidant compositions containing same. US Patent; US 4390559.
12. Murakami H, Asakawa T, Terao J, Matsushita S. Antioxidative stability of tempeh and liberation of isoflavones by fermentation. Agric Biol Chem 1984; 48: 2971.
13. Hutchins AM, Slavin JL, Lampe JW. Urinary isoflavonoid phytoestrogen and lignan excretion after consumption of fermented and unfermented soy products. JADA 1995; 95: 545–551.
14. Wuryani W. Isoflavones in tempe. ASEAN Food Journal 1995; 10: 99–102.
15. Wang H, Murphy PA. Isoflavone content in commercial soybean foods. J Agric Food Chem 1994; 42: 1666–1673.
16. Dwyer JT, Goldin BR, Saul N, Gualtieri L, Barakat S, Adlercreutz H. Tofu and soy drinks contain phytoestrogens. JADA 1994; 84: 739–743.
17. Pillow PC, Duphorne CM, Chang S, Contois JH, Strom SS, Spitz MR, Hursting SD. Development of Database for assessing dietary phytoestrogen intake. Nutr Cancer 1999; 33: 3–19.
18. Fridovich I. Superoxide Dismutase. Ann Rev Bio-Chem 1985; 44: 147–159.
19. McCord JM, Fridovich I. Superoxide dismutase. An enzymic function for erythrocuprein (hemocuprein). J Biol Chem 1971; 244: 6049–6055.
20. Callowy DH, Hickey CA, Murphy EL. Reduction of intestinal gasforming properties of legumes by traditional and experimental food processing method. J Food Sci 1971; 36: 251–256.
21. Shurtlef W, Aoyagi A. The Book of Tempe. New York: Harper & Row 1979.
22. Karmini M. The effect of tempe on the control of enteropathogenic diarrhea. (PhD Thesis). Bogor University, Bogor, Indonesia, 1987.
23. Mangkuwidjoyo S, Pranowo D, Nitisuwirjo S, Noor Z. Observation on hypolipidemic activity of tempe. In Hermana H, Karyadi D, eds. Proceedings of the Symposium on the Utilization of Tempe in Health and Nutrition Development, Bogor. Nutrition Research and Development Center, Department of Health of Republic of Indonesia, 1985; 114–127.
24. Jha HC. Novel isoflavonoids and its derivatives, new antioxidant derived from fermented soybean (tempe). Asian Symposium Non-Salted Soybean Fermentation, Tsukuba, Japan, July 14–16, 1985.
25. Gorcia Hermosilla JA, Jha HM, Egge H, Mahmud M, Hermana S, Rao GS. Isolation and characterization of hydroxymethylglutaryl Coenzyme A reductase inhibitors from fermented soybean extracts. J Clin Biochem Nutr 1993; 122: 163–174.
26. Astuti M. Superoxide dismutase in tempe, an antioxidant enzyme and its implication on health and disease. Proceedings of the International Tempe Symposium, 1997; 146–156. Indonesia: Indonesian Tempe Foundation (Yayasan Tempe Indonesia).
27. Donnely JK, McLellan KM, Walker JL, Robinson DS. Superoxide Dismutase in foods. Rev Food Chemistry 1989; 33: 243–270.
28. Harris ED. Regulation of antioxidant enzyme. J Nutr 1992; 122: 625–626.
29. Wahlqvist ML, Dalais FS. Phytoestrogens: Emerging multifaceted plant compound. Med J Aust 1997; 167: 119–120.
30. Adlercreutz H. Dietary phyto-oestrogens and the menopause in Japan. The Lancet 1992; 339: 1233.
31. Adlercreutz H. Epidemiology of phytoestrogens. Bailliere's Clin Endocrinol Metabolism 1998; 12: 605–623.
32. Watanabe Y, Tada S, Kawamoto I, Uozumi G, Kajiwara J, Yanaguchi Y, Murakami K, Misaki F, Akasaka Y, Kawai K. Epidemiologic study of colorectal cancer in Japan. Case control study of background factors in rectal and colon cancers. Nippon Sokakilogo Gakkai Zasshi 1984; 81: 185–193.
33. Kiriakidis S, Stathi S, Jha HC, Hartman R, Egge H. Fatty acid ester of sitosterol 3 beta glicoside from soybeans and tempe (fermented soybeans) as antiproliferative substances, J Clin Biochem Nutr 1996; 22: 139–147.
34. Karyadi D, Lukito W. Functional characteristics of tempe in disease prevention and treatment. Proceedings International Tempe Symposium 1997; 99–204. Indonesia: Indonesian Tempe Foundation.