Comparison of flavour compounds in wasabi and horseradish

Tamanna Sultana and G. P. Savage. Food Group, Animal and Food Sciences Division, Lincoln University, Canterbury, New Zealand

The flavour of a dish determines the choice of spices used in cooking. Traditionally, condiments are used with cooked foods to turn an ordinary dish into an extra special one by using a freshly prepared paste from plant tissues that provides a hot taste with a pungent smell. Although spices and condiments have no nutritional value other than to offer flavour, some of the flavour compounds have effective chemopreventive roles with important pharmacological properties (Dorsch *et al*., 1985; Steinmetz and Potter, 1991; Isshiki *et al*., 1992; Fuke *et al*., 1994; Kumagai *et al*., 1994; Delaquis and Mazza 1995; Hecht, 1995; Verhoeven *et al*., 1996; Lin *et al*., 1998; Ono *et al*., 1998; Soledade *et al*., 1998 and Depree *et al*., 1999). A number of different plants are specially cultivated to supply a hot spicy flavour, for instance, the European horseradish (*Amoracia rusticana*) and the Japanese horseradish (*Wasabia japonica* (Miq) Matsum). Both of these plants belong to the *Cruciferae* family, which also includes cabbage, cauliflower, broccoli and mustard. Wasabi and horseradish both liberate isothiocyanates (ITCs) as flavour compounds and so possess a hot taste with a similar flavour (Palmer *et al*., 1990). However, Masuda *et al*. (1996) reported that the main difference between them is the green odour of wasabi as both of them possess a strong pungent flavour. Horseradish is a distant cousin of wasabi and is sometimes used as a substitute for wasabi with an added green food colour in it (Chadwick *et al*., 1993).

Horseradish is a taproot with many lateral roots that penetrates deeply into the soil. It is grown mainly for the white flesh of the roots, which is grated fresh or made into a sauce to use as a condiment with roast beef (Langer & Hill, 1991). However, wasabi is cultivated primarily for the rhizomes (stems) because they possess more flavour than other plant parts. The mature wasabi plants produce thickened rhizomes, which are used to make a hot green paste, eaten as a sauce with other foods or as an ingredient in a range of Japanese sauces. Wasabi is also used to decorate foods because of its bright green colour and also to flavour traditional and modern foods e.g. raw fish, noodles, sushi, and mayonnaise. Although rhizomes are the most valuable part of the wasabi plant, other parts such as petioles and leaves also contain ITCs and give these tissues some pungency (Sultana *et al*., 2002). Wasabi leaves and petioles are used to make a variety of food products including pickles in sake brine or soysauce, ice cream, cheese and crackers (Chadwick *et al*., 1993).

The flavour of both wasabi and horseradish comes from ITCs, the volatile sulphur compounds, which are liberated from the precursor glucosinolates (GSLs) when plant tissues become damaged (McGregor *et al.*, 1983). GSLs are a group of glucosides, stored within the cell vacuoles of all *Cruciferae* plants (Delaquis & Mazza, 1995) and are biosynthesised from protein amino acids (Fahey *et al*., 2001). GSLs coexist in plants, but are not in contact, with the hydrolytic enzyme myrosinase (thioglucoside glycohydrolase EC 3.2.2.1). When plant tissues are mechanically disrupted or injured (e.g. by chewing, crushing or grating in the preparation of food), myrosinase is released from the cell wall, and in the presence of adequate moisture it rapidly hydrolyses the GSLs to yield glucose and an aglucone (Fenwick *et al*., 1983; McGregor, 1993). The organic aglucone is unstable and undergoes lossen rearrangement to produce sulphate and a variety of other products. Under neutral and alkaline conditions ITCs are formed from GSLs. However, once formed ITCs are more stable under acidic conditions.

Most of the sulphur-containing end products formed by enzymatic and non-enzymatic reactions of GSLs are volatile (Delaquis & Mazza, 1995). Among these compounds, ITCs have been recognised as the characteristic flavour compounds of plants in the *Cruciferae* family because of their pungency (Masuda *et al*., 1996). Table 1 shows a summary of ITC content of wasabi and horseradish roots from previously reported investigations. Each ITC is found at different levels in the two plants. The taste or aroma of a paste made from each plant depends on the relative abundance of the ITCs in the original tissue, as each ITC has a different flavour profile. For instance, the more radish-like aroma of the horseradish roots may occur because of the higher content of 2-phenylethyl ITC. The typical wasabi flavour is derived from the high content of allyl ITC (2-propenyl ITC) but other ITCs contribute to the characteristic fresh 'green' notes (Ina *et al*., 1989; Masuda *et al*., 1996). However, allyl ITC (AITC) is the compound found at the greatest amounts in both of wasabi and horseradish (Kojima & Ichikawa, 1969; Ina *et al*., 1981; Masuda *et al*., 1996) while 2-phenylethyl ITC is only present in horseradish roots.

Seven isothiocyanates (ITCs) have been identified and measured as flavour compounds in New Zealand grown wasabi rhizomes and horseradish roots (Table 2). These are *iso*-propyl ITC, *sec*-butyl ITC, allyl ITC (AITC), 3-butenyl ITC (3-BITC), 4-pentenyl ITC (4-PITC), 5-hexenyl ITC (5-HITC) and 2-phenylethyl ITC (2-PEITC). The concentration of each ITC except 3-BITC was different in the two plant species and their relative values are given in Table 2.

The differences in the flavour between wasabi and horseradish depend on differences in the flavour compounds, which occur in the two plants. 2-phenylethyl ITC was the biggest component after AITC and was detected only in horseradish. It is likely to have a significant role in the overall aroma and taste profile of horseradish. Gilbert & Nursten, (1972) suggested that a small change in the proportions of ITCs would be sufficient to significantly alter the overall aroma. As a consequence, 2-phenylethyl ITC may play a major role in distinguishing the flavour profile of horseradish from wasabi. Masuda *et al*. (1996) and Gilbert & Nursten, (1972) reported that 2-PEITC imparted a strongly radish-like, fresh watercress aroma and gave a tingly sensation to the mouth. However, 2-PEITC had no pungency and lachrymatory role at all, like AITC, and therefore was distinctively different from AITC. Masuda *et al*. (1996) suggest that 2-PEITC was responsible for the obvious difference in odour between wasabi and horseradish. Hence the analytical and organoleptic data are consistent in attributing the radish-like aroma in horseradish to the contribution of 2-PEITC.

AITC in the main flavour compound because of its high concentration in both wasabi and horseradish and this is in agreement with previous investigations carried out by Ina *et al*. (1989); Kumagai *et al*. (1994) and Masuda *et al*. (1996). AITC is the primary contributor to the total ITC concentration of wasabi (94%) and horseradish (87%) and this suggests it will provide the most important character to the total flavour profile in both species. AITC is reported to be a lachrymatory compound, bitter in taste with a strong, pungent and mustard like smell (Masuda *et al*., 1996). Consequently, pungency is the common characteristic of both wasabi and horseradish flavours. However, this study found a 14% lower concentration of AITC in horseradish (significant at $P = 0.007$). As a major contributor this difference could be sufficient to easily differentiate the total flavour of wasabi and horseradish.

References

AOAC (1995): *Official Methods of Analysis*, 16th ed. Arlington, VA; Association of, Analytical chemists.

Chadwick CI, Lumpkin TA & Elberson LR (1993): The botany, uses and production of *Wasabia japonica* (Miq) (Cruciferae) Matsum. *Economic Botany* **47**, 113-135.

Delaquis PJ & Mazza G (1995): Antimicrobial properties of isothiocyanates in food preservation. *Food Technology* 73-84.

Depree JA, Howard TM & Savage GP (1999) Flavour and pharmaceutical properties of the volatile sulphur compounds of wasabi (*Wasabia japonica*). *Food Research International* **31**, 329-337.

Dorsch W, Adam O, Weber J & Ziegeltrum T (1985): Antiasthmatic effects of onion extracts-detection of benzyl and other isothiocyanates (mustard oil) as antiasthmatic compounds of plant origin. *European Journal of Pharmacology* **107**, 17-25.

Fahey JW, Zalcmann AT & Talalay P (2001)The chemical diversity and distribution of glucosinolates and isothiocyanates among plants. *Phytochemistry* **56**, 5-51.

Fenwick GR, Heaney RK & Mullin WJ (1983): Glucosinolates and their breakdown products in food and food Plants. *CRC Critical Reviews in Food Science and Nutrition* **18**, 123-201.

Gilbert J & Nursten HE (1972): Volatile Constituents of Horseradish Roots. *Journal of the Science of Food and Agriculture* **23**, 527-539.

Hecht SS (1995): Chemoprevention by Isothiocyanates. *Journal of cellular Biochemistry, Supplement* **22**, 195-209.

Ina K, Sano A, Nobukuni M & Kishima I (1981): Volatile components of wasabi (*Wasabia japonica*) and Horseradish (*Cocholeria aroracia*). *Nippon Shokuhin Kogyo Gakkaishi* **28**, 365-370.

Ina K, Ina H, Ueda M, Yagi A & Kishima I (1989) _- Methylthioalkyl Isothiocyanates in Wasabi. *Agricultural Biological Chemistry* **53**, 537-538.

Isshiki K., Tokuoka K., Mori R. and Chiba S. (1992). Priliminary examination of allyl isothiocyanate vapor for food preservation. *Bioscience Biotechnology and Biochemistry* **56**, 1476-1477.

Kojima M & Ichikawa I (1969): Gas Chromatographic studies on the Acrid Components of Japanese Horseradish (*Wasabia japonica*). *Journal of Fermentation Technology* **47**, 263-267.

Kumagai H, Kishima N, Seki T, Sakurai H, Ishii K & Ariga T (1994): Analysis of volatile components in essential oil of upland wasabi and their inhibitory effects on platelet aggregation. *Bioscience Biotechnology and Biochemistry* **58**, 2131-2135.

Langer RHM & Hill GD (1991): Agricultural plants second ed, Cambridge University Press.

Lin HJ, Probst-Hensch NM, Louie AD, Kau IH, Witte JS, Ingles SA, Frankl HD, Lee ER and Haile RW (1998). Glutathione transferase null genotype, broccoli, and lower prevalence of colorectal adenomas. Cancer Epid. Biomark. Prev. **7,** 647-652.

Masuda H, Harada Y, Nakajima M & Tabeta H (1996): Characteristic odorants of Wasabi (*Wasabia japonica* matum), Japanese Horseradish, in comparison with those of Horseradish (*Armoracia rusticana*). *Biotechnology for improved foods and flavours* **637**, 67-78.

McGregor DI (1993): Glucosinolates. Ed. Macrae R, Robinson RK & Sadler MJ *Encyclopaedia of Food Science Food Technology and Nutrition* **4**, 2221-2226.

McGregor DI, Mullin WJ & Fenwick GR (1983): Analytical methodology for determining glucosinolate composition and content: Review of analysis of glucosinolates. *Journal of the Association of Official Analytical Chemists* **66**, 825-849.

Ono H, Tesaki S, Tanabe S and Watanabe M (1998). 6-Methylsulphinylhexyl isothiocyanate and its homologues as food-originated compounds with antibacterial activity against *Escherichia coli* and *Staphylococcus aureus*. *Bioscience Biotechnology and Biochemistry*. **62 (2)**, 363-365.

Palmer J (1990): Germination and growth of wasabi (*Wasabia japonica* (Miq) matsumara). *New Zealand Journal of Crop and Horticultural Science* **18,** 161-164.

Soledade M, Pedras C and Sorensen JL (1998). Phytoalexin accumulation and antifungal compounds from the crucifer Wasabi. Phytochemistry, 49, 1959-1965.

Steinmetz KA and Potter JD (1991). Vegetables, fruit, and cancer. II Mechanisms. *Cancer causes and control.* **2**, 427-442.

Sultana T, Savage GP, McNeil DL, Porter N, Martin RJ & Deo B (2001): Effects of fertilisation on the allyl isothiocyanate profile of the above ground tissues in New Zealand grown wasabi. *Jounal of the Science of Food and Agriculture*. Submitted.

Verhoeven DTH, Goldbohm RA, van Poppel G, Verhagen H and van den Brandt PA (1996). Epidemiological studies on brassica vegetables and cancer risk. *Cancer Epid. Biomark. Prev.* **5**, 733-748.

Wang CH, Wang KM, Hu MF, Wang CH, Wang KM & Hu MF (1996): Effect of tunnel system, dolomite powder and rice hull on the yield and quality of wasabi (Wasabia Japonica Matsum), *Journal of Agricultural Research of China* **45**, 57-68 (In Chinese with English abstract).

Wang CH, Hu MF, Lo CT, Lin YW, Huang WT & Chiu LR (1999): Effect of lime and borax applications on the yield and quality of wasabi (*Wasabia Japonica* Matsum), *Journal of Agricultural Research of China* **48**(2), 100-127 (In Chinese with English abstract).

Table 1. Comparison of flavour compounds between wasabi and horseradish with a description of the odour of each compound

Isothiocyanates (ITCs)	*Concentration mg/kg fresh weight*					*Odour description*[b,d,e]
	Wasabi rhizome[a]	*Wasabi rhizome*[b]	*Wasabi root*[c]	*Horse radish root*[b]	*Horse radish root*[c]	
*Iso*propyl ITC	-	7.6	-	Tr	-	Chemical, weak mustard like
Allyl ITC	1282 ± 123	1880	1110	1570	966	Strongly pungent, mustard-like, lacrymatory, bitter
n- butyl ITC	-	-	17.4	-	4.2	---
Sec-butyl ITC	11.4 ± 1.2	13	-	27	-	Chemical, weak mustard like
Iso butyl ITC	0.6 ± 0.1	3.9	-	0.6	-	Sweet, chemical
3-butenyl ITC	123.5 ± 8.8	25	18.3	5.5	8.1	Green, pungent, aroma
4-pentenyl ITC	65.2 ± 3.8	31	39.0	1.7	1.0	Green, pungent, acrid, fragrant leaf
5-hexenyl ITC	16.9 ± 1.0	8.0	10.2	-	1.8	Green, pungent, fatty
6-heptenyl ITC	1.0 ± 0.1	0.6	-	-	-	Green, pungent, fatty
3-methylthio propyl ITC	2.4 ± 0.5	Tr	-	1.5	-	Strongly raddish-like, pungent
Benzyl ITC	-	0	-	1.6	-	Chemical, pungent
2-phenylethyl ITC	-	Tr	-	133	225	Strongly radish-like, pungent, strong watercress aroma, tingling sensation
4-methylthio butyl ITC	0.2 ± 0.0	-	-	-	-	-
5-methylthio pentyl ITC	9.9 ±1.2	1.5	4.8	Tr	-	Radish-like, pickle-like
6-methylthio hexyl ITC	35.0 ± 3.3	4.8	18.9	Tr	-	Radish-like, sweet, fatty
7-methylthio heptyl ITC	3.2 ± 0.2	0.9	14.4	Tr	-	Sweet, fatty, radish-like, pickle-like
5-methyl sulphinyl pentyl ITC	-	-	21.7	-	8.1	-
6-methylsulphinyl hexyl ITC	-	-	78.0	-	9.0	-
7-methylsulphinyl heptyl ITC	-	-	14.1	-	7.8	-
Total ITC	1653.9	1976.3	1346.8	1740.9	1231	

[a]Data from Kumagai *et al*., 1994; [b]Data from Masuda *et al*., 1996; [c]Wasabi root presumably refers to either the rhizome or the total root plus rhizome mass, data from Etoh *et al*., 1990; [d]Data from Fenwick *et al*., 1983; [e]Ina *et al*., 1981; Tr, less than 0.5mg/kg; -, not reported

Table 2. Isothiocyanates in wasabi and horseradish from New Zealand grown material

Isothiocyanates (ITCs)	*Concentration (mg of ITCs/kg fresh weight) Mean ± SEM*		*p-value*
	Wasabi	*Horseradish*	
*Iso*propyl ITC	12.81 ± 0.75	3.57 ± 0.01	0.000 ***
Sec-butyl ITC	18.78 ± 0.49	2.77 ± 0.24	0.000 ***
Allyl ITC	1937.80 ± 47.80	1658.10 ± 25.80	0.007 **
3-butenyl ITC	43.13 ± 0.92	39.43 ± 1.94	0.160 NS
4-pentenyl ITC	47.97 ± 0.84	8.99 ± 0.53	0.000 ***
5-hexenyl ITC	7.06 ± 0.09	2.64 ± 0.15	0.000 ***
2-phenylethyl ITC	†	185.20 ± 2.11	-
Total isothiocyanates	2067.55 ± 50.60	1900.70 ± 26.90	0.04 *

†, not detected, NS, not significant, *$P<0.05$, **$P<0.01$ and ***$P<0.001$