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Wasabi - Japanese Horseradish

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Abstract

Wasabi, Japanese Horseradish (*Wasabia japonica* (Miq.) Matsum) is a perennial plant native to Japan. It has been cultivated in Japan for more than a thousand years and is now being grown in many countries as interest in Japanese cuisine expands. Wasabi can be grown in two main ways, either in flooded fields or in soil based mediums. The unique flavour of wasabi comes from isothiocyanates (ITCs) which are evolved from precursor glucosinolates by the enzyme myrosinase when the tissue is disrupted. ITCs found in wasabi are volatile, possess strong pungent smells and are toxic at high intakes. The overall flavour of wasabi depends on individual ITC content. Allyl ITC is found in the highest concentration in all tissues, ranging from 86-92% of the total ITC content. Apart from flavouring sauces and foods wasabi isothiocyanates have interesting anticancer effects. ITCs can also counter inflammatory conditions like asthma and anaphylaxis. ITCs have also been shown to inhibit platelet aggregation in the blood. Wasabi is a valuable crop that can be processed into a tasty condiment. Its production and consumption will increase as it becomes more appreciated in Western cuisine.

Keywords: *Wasabia japonica*, Horseradish, Flavour compounds, Isothiocyanate (ITC), Glucosinolate, Allyl ITC, 3-butenyl ITC, 4-pentenyl ITC, 5-hexenyl ITC, 2-pheneylethyl ITC, Isopropyl ITC, Secbutyl ITC, Rhizome, Anticancer, Anti-asthmatic, Anti-inflammatory, Industrial application

Introduction

History

Wasabi, known as Japanese Horse-radish (*Wasabia japonica* (Miq.) Matsum) is a native condiment crop of Japan. It is not known when wasabi was first brought into cultivation but Japanese historical records indicate that wasabi, known originally as wild ginger, was introduced as a medicinal plant by Sukahito Fukae. The first Japanese

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medical encyclopaedia called “Honzo-wamyo” was published in A.D. 918 and it states that “wild ginger” (wasabi) had been grown in Japan for at least a thousand years (Hodge, 1974). During 1596-1615 A.D. wasabi cultivation began on the upper reaches of the Abe River in Shizuoka prefecture. Its use, however, was reserved to the ruling class by order of the Shogun Iieyasu Tokugawa (Kojima,1981). At present, the natural distribution of wasabi in Japan ranges from Russia's Sakhalin island, north of Hokkaido (the most northern Japanese island) to Kyushu (the southernmost major Japanese island) (Chadwick *et al,* 1993). However, the Shimane region is the largest area of wasabi production and breeding research in Japan at present.

Wasabi is now being grown in many countries in the world including New Zealand, Taiwan, Korea, Israel, Brazil, Thailand, Columbia, near Vancouver, Canada and Oregon, USA. In New Zealand, the Ministry of Agriculture and Fisheries introduced wasabi for experimental cultivation in 1982 (Forde,1982). Agronomic investigation of this crop was stimulated by commercial interest in 1986 (Palmer, 1990; Douglas and Follett, 1992). Preliminary assessment of the growth and plant yield of soil-grown wasabi was carried out at Lincoln in 1995 (Martin and Deo, 2000). Yields of flavour compounds, as affected by fertilizer treat-ment, were carried out in 1997 (Sultana *et al,* 2000; Sultana *et al*, 2002). Further research has been performed at Lincoln University to develop an under-standing of wasabi growing in New Zealand, especially the agronomy, cultivation methods, ITC variation and stability (Sultana *et al*, 2003a; Sultana *et al*, 2003b). Wasabi is now grown in New Zealand for export of frozen rhizomes to Japan and it is also processed into a number of different wasabi flavoured food products.

Botany of wasabi

Wasabi is a member of the *Cruciferae* family which also includes cabbage, cauliflower, broccoli, sprouts, water cress, radish, mustard and horseradish. The European horseradish (*Armoracia rusticana*) is known as a distant cousin of wasabi and is sometimes preferred by chefs, as a substitute for wasabi. The genus *Wasabia* consists of two species, *Wasabia tenuis* (an uncultivated species) and *Wasabia japonica* (the cultivated species). These two species are distinguished primarily by their cytology, stem size and colour and leaf size and shape (Chadwick *et al,* 1993). *Wasabia japonic*a is a glabrous, perennial aromatic herb that grows about 450 mm high, producing leaves on long petioles from the crown of the plant. As the plant ages the rhizomes start to form and, at maturity after 18 months, the wasabi plant has a distinctive thickened stem (or rhizome) connected to the heart shaped leaves by long, thin petioles (Fig. 1). Rhizomes are the most favoured plant part of wasabi. Most plants have one or two main rhizomes and a number

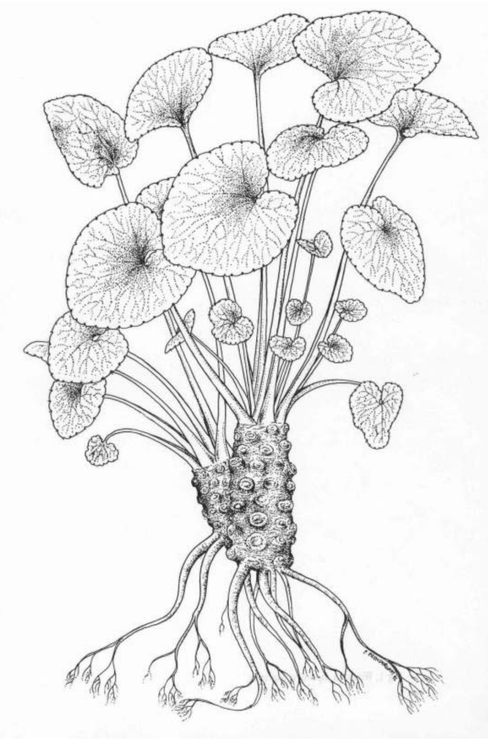

Fig. 1: Wasabi japonica (Depree *et al,* 1999)

of secondary stems (Martin and Deo, 2000). The lengths and weights of rhizomes vary widely between species e.g. for *Wasabia japonica* the length ranges from 50 to 200 mm long and weighs 4 to 120 g. *Wasabia japonica* leaves are simple, cordate-reniform, undulate-toothed and 80-250 mm in diameter. Petioles are vertical to oblique, 300-500 mm long, basally flattened and surround the rhizome. Whole fresh plants can weight up to 3.4 kg (Chadwick *et al,* 1993).

Wasabi flowers are white, bracteate, arranged on racemes, with ascending sepal, cruciform and obovate petals, perfect septum, elongate styles and simple stigma (Chadwick *et al*, 1993). Fertilisation is mainly by cross pollination. Seeds must be stored in a cool moist environment, since dry storage will result in desiccation and loss of viability of the seed. Fresh seed is naturally dormant and until it is vernalised by storing at a low temperature (Palmer, 1990).

Wasabi cultivars

In Japan a cultivar is usually named after its region of cultivation and, thus, wasabi cultivars are considered regionally specific in Japan. Seventeen wasabi cultivars have been developed and each has a strict cultivation and climate requirement that limits major cultivation to distinct areas (Chadwick *et al,* 1993). Specific regions and individual farmers produce their own unique cultivars as a result of persistent inbreeding and selection. According to some Japanese farmers wasabi has eight well-known cultivars which are Mazuma, Daruma, Takai, Shimane, Midori, Sanpoo, Izawa Daruma and Medeka. These cultivars were developed in the Shizuoka and Shimane prefectures. Another important cultivar 'Hangen' comes from the Kanagawa prefecture. Daruma is the most popular variety, known to grow well under marginal environmental conditions, such as warmer temperatures. It was developed by plant breeders based in the Shimane Research Station. For poor quality locations they developed Fuji Daruma, Izawa Daruma, Ozawa Daruma and Sanpoo in Shimane. However, all Shimane cultivars produce high quality rhizomes. Mazuma was developed in Shizuoka (but was originally grown in Wakayama and Okutama) and its production in Pacific Coast areas suggests that it has more heat tolerance than the Daruma cultivars although no published data can be found to verify this. In New Zealand, Daruma is the commercial cultivar of wasabi and preliminary studies using Shingen have just commenced.

Cultivation of wasabi

In Japan, wasabi sometimes grows naturally in the gravel beds of mountain streams and is highly adapted to this environment. For commercial wasabi growing two types of cultivation methods are used. These are upland or soil grown wasabi and flooded field cultivation or water grown wasabi. Japanese growers select the method depending on the particular end use of the plants after harvest. Wasabi plants grown using the upland soil production method are harvested primarily for producing leaf and petiole products while wasabi plants grown using stream cultivation are harvested mainly for their enlarged rhizome, and only this plant part is used to make food products (Chadwick *et al*, 1993). Thus, it is believed in Japan that flooded systems can produce superior high quality enlarged stems. These are highly sought after and command higher prices.

Soil grown wasabi

Wasabi requires specific environmental conditions to thrive. Upland wasabi requires an air temperature from 6-20^{O}C with 8-18^{O}C considered optimal. Soil of pH 6-7 are considered best. It is most often grown on well-drained soil under mulberry or plum trees in Japan, whereas in New Zealand wasabi is usually grown in soil and in shade houses rather than under trees.

Water grown wasabi

Stream grown wasabi requires air temperatures ranging from 8-18^{O}C. However, a narrower range of temperatures (12-15^{O}C) is considered ideal. An air temperature of less than 8^{O}C inhibits plant growth and at less then 5^{O}C plant growth ceases. Other factors can have an effect on the growth of wasabi and need to be considered carefully e.g. stable water temperature, good nutrient status in the water and well aerated, neutral or slightly acidic pH a high dissolved oxygen level and a large supply of water to maintain consistent flow (this particularly depends upon the field system being used). Rainfall accumulation is also important, with an even distribution desirable to stabilize the water supply and temperature (Chadwick *et al*, 1993). Spring water is considered best because of its clarity, stable temperatures and high level of oxygen. At warmer temperatures the dissolved oxygen in the water decreases, which inhibits the growth of plants. Silty or muddy water is undesirable as it may contain insufficient oxygen, but some silt in the water is considered beneficial as a source of nutrients. In Japan, wasabi grows on the wet banks of cool mountain streams and springs. Overall, construction and establish-ment of a flooded field is expensive and labour intensive. Water grown wasabi is produced in 42 prefectures, and soil grown wasabi in 21, out of 47 prefectures in Japan, which indicates that flooded cultivation is popular and is considered to produce a high quality product.

The unique environmental requirement and shortage of cultivatable lands limit wasabi production areas to 880 hectares in Japan (Adachi, 1987) and 400 hectares in Taiwan, but demand for wasabi condiments is spreading from Japanese cuisine to modern western food. The increasing interest in wasabi and the inability to expand production in Japan has seen prices rise steadily since 1970 (Chadwick *et al*, 1993). High prices have stimulated research into soil production methods and the investigation of production areas outside Japan. Since 1982, the cultivation of wasabi has been trialled in New Zealand (Douglas and Follett, 1992) because of New Zealand's climate (appropriate air temperature range, high quality water, long sunlight hours), which meets the ideal requirements for growing quality wasabi outside Japan. However, the area of soil grown wasabi is increasing not only in New Zealand but also in Taiwan, Colombia, Canada, Korea, Thailand and USA. The expansion in soil grown wasabi is mainly to reduce the high cost of flooded field establishment and associated high labour costs.

Uses of wasabi

Wasabi adds a unique flavour, heat and greenish colour to foods and, thus, it is a highly valued plant in Japanese cuisine. Wasabi is described as having 'a sharp hot taste with pungent smell' but the heat component in wasabi is different from chillies, and the hotness quickly dissipates in the mouth leaving an extremely pleasant mild vegetable taste, with no burning sensation at all. Wasabi adds aesthetic and culinary appeal to many foods and is considered a staple condiment in the Japanese diet. Recently, it has found widespread appeal in western cuisine due to its ability to change an ordinary dish to an extra special one by improving the taste (with addition of a spicy flavour) and eye appeal i.e. by decorative contrast of the light green colour. As a result, it is becoming a new flavour for the rest of the world.

All the plant parts of wasabi possess some flavour but vary in the sharpness they deliver (Sultana *et al*, 2000; Sultana *et al*, 2003c) and are, therefore, used for different purposes. Basically, wasabi can be served in three ways. These are as a condiment on the side of a dish, as a spice or herb in a dish and as wasabi flavour in processed foods. Rhizomes are the most popular tissues used to prepare fresh paste to be placed in a mound on a dish next to sliced raw fish (sashimi), spread on the raw fish in sushi preparations, or served on a small dish to accompany a bowl of cooked noodles (Chadwick *et al,* 1993). Sometimes grated wasabi is mixed with other ingredients like soya sauce and vinegar to prepare a dip for use with raw fish or other dishes, according to individuals' choice. Tofu (soybean curd) is often decorated with grated wasabi.

Wasabi petioles and leaves are pickled in sake brine or soya sauce and are popular accompaniments for white rice. Sometimes fresh leaves are used in salads and dried leaves are used to flavour cheese, salad dressings or crackers. A wasabi wine is sold (mainly as a novelty) in some Japanese specialty stores as well as a high alcohol content wasabi liqueur.

Lower quality wasabi stems are commonly mixed with European horseradish (Armoracia rusticana) powder, mustard and food colour to produce 'wasabi' paste in tubes or to sell as wasabi powder. An alerting message is sometimes included with this wasabi paste like, “don’t be fooled with the green (smooth textured) clump on the side of your sushi dish, it is rarely real wasabi.” In New Zealand, a variety of genuine wasabi flavoured quality products e.g. sauces and mayonnaise are being developed to add to snacks and foods.

Wasabi paste preparation

In traditional Japanese cuisine, wasabi is prepared by grating the fresh stem against a rough surface, such as a ginger grater, in much the same way as horseradish is prepared (Chadwick *et al*, 1993). But it is also noted that using sharkskin or "oroshi" as a tool for grating wasabi has been a practice in Japan since the earliest times and is still regarded as the preferred method of obtaining the best flavour, texture and consistency in freshly ground wasabi. Using a sharkskin grater and keeping the rhizome at a 90^{O} angle to the grating surface is reported to minimize the volatiles' exposure to the air. It is also stated that, in this way, the volatile compounds are allowed to develop with minimal dissipation. In New Zealand, wasabi paste is commercially prepared using mincer to finely grind the rhizomes and then it is mixed with other ingredients depending on the end use of the paste.

Flavour constituents of wasabi

Isothiocyanates (ITCs) are a group of naturally occurring sulphur compounds responsible for the characteristic flavour of wasabi (McGregor *et al*, 1983; Delaquis & Mazza, 1995; Masuda *et al,* 1996). The compounds are volatile in nature and are evolved from plant tissues when they are disrupted eg. in the preparation of food, grating, cutting, chewing etc. However, plant tissues do not contain ITCs, but contain glucosinolates (GSLs) which are the precursors of ITCs.

GSLs are a group of glucosides, stored within the cell vacuoles of all Crucifereae plants (Delaquis and Mazza, 1995). GSLs are biosynthesised from amino acids by three major steps (Sultana *et al*, 2000). The GSLs consist of a ß-D thioglucose moiety, a sulphate attached through a C=N bond and a side group (R) that distinguishes one GSL from another (Fig. 2). Based on the structure of different amino acid precursors a wide variety of side groups (R) produce different GSLs (aliphatic, aromatic, indolyl types) and, therefore, different ITCs. Due to the low pKa value (Prestera *et al*, 1996) of the sulphonic acid group GSLs invariably occur in nature in the anionic form (Larsen, 1981) and usually as the potassium or sodium salt (Warton *et al*, 2001). Due to the presence of the glucose moiety they are hydrophilic, non volatile compounds (Larsen, 1981).

When plant tissues are mechanically disrupted or injured (eg. by chewing, crushing or grating in the preparation of food), the myrosinase is released from the cell wall and in the presence of adequate moisture myrosinase rapidly hydrolyses the GSLs (Fig. 3) to yield glucose and an aglucone. Some of the intermediate steps have not been fully

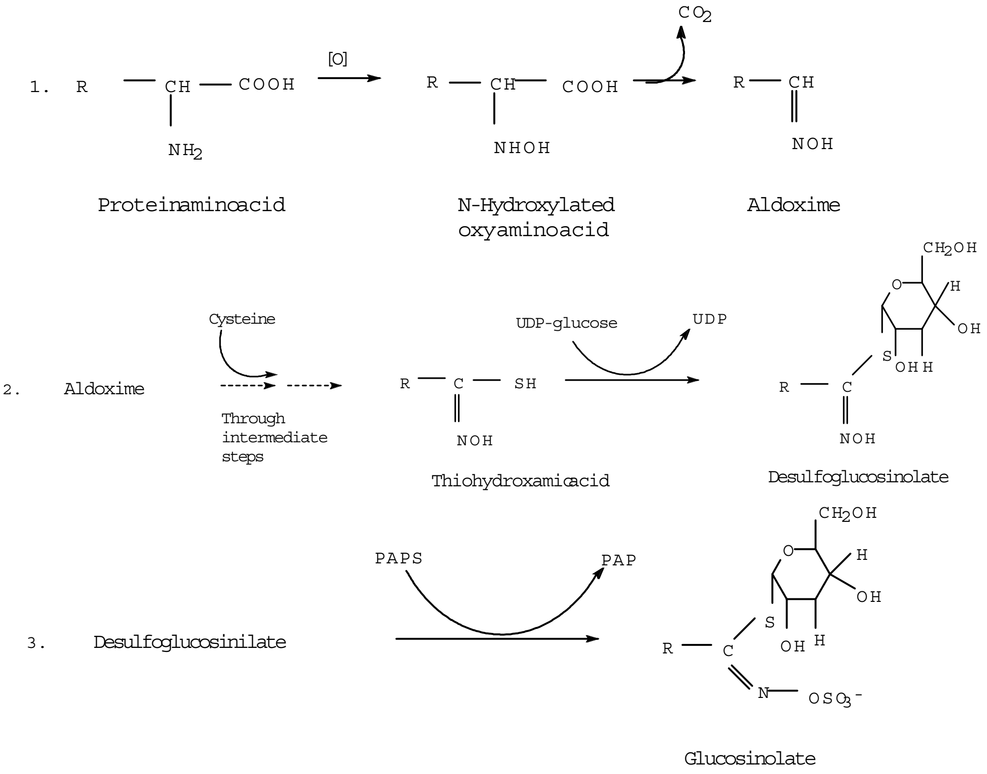

Fig. 2: Biosynthesis of glucosinolates (Sultana *et al,* 2000)

described (Fahey *et al*, 2001; McGregor, 1993). The organic aglucone is unstable and undergoes Lossen Rearrangement (Fenwick *et al*,1983) to produce sulphate and a variety of other products.

The nature of the products is dependent on the number of factors, including the structure of the GSL side chain, the reaction conditions (eg. pH), the presence of cofactors (eg. metal ions, specific proteins), temperature and duration as well as the age and condition of the plant tissues. Isothiocyanates (ITCs) are formed from GSLs under neutral and alkaline conditions. However, GSLs that contain a ß-hydroxyl group (I. in Fig. 3) in their side chain, give rise to ITCs that spontaneously cyclize to form oxazolidinethiones. Some aromatic and heterocyclic GSLs (II in Fig. 3) produce ITCs which are unstable at pH 7 or higher and break down to release the corresponding alcohol and inorganic thiocyanate ions.

However, once formed, ITCs are more stable under acidic conditions. In weakly acidic pH or in the presence of Fe^{+2} and/or endogenous nitrile factor, nitriles are produced from aglucone by autolysis instead of ITC, with the liberation of elemental sulphur (McGregor,1993). The relative pro-portion of ITC to nitriles can vary widely depending upon the conditions of autolysis (McGregor,1993). Thiocyanate formation is believed to involve a cofactor, which may also be a protein, since it has been shown to be labile to both heat and polar organic solvents. Most of the sulphur containing end products formed by the enzymatic and non-enzymatic reactions of GSLs are volatile (Delaquis and Mazza, 1995).

Several ITCs have been reported from previous investigations into wasabi and each ITC has a specific flavour profile (Sultana *et al,* 2000; Masuda *et al,* 1996) with the complete taste of wasabi being derived from the combined tastes and odours of all the ITCs present. A summary of different ITCs reported from previous investigations into the ITC content of wasabi tissue is listed in Table I.

Allyl ITC has the main effect on the overall taste of wasabi because it is the ITC found in highest concentration in the rhizomes and other plant tissues (Sultana *et al,* 2002). Allyl ITC is also found in the highest concentration in horseradish (Sultana *et al,* 2003c). While allyl ITC is the main flavour component of wasabi due to its pungency other ITCs e.g. 6-methylthiohexyl ITC and 7-methylthioheptyl ITC, by giving their characteristic fresh greenish flavour, may contribute significantly to the total taste profile of wasabi (Masuda *et al,* 1996; Ina *et al,* 1981).

Medicinal properties of isothiocyanates

The medicinal value of chemicals extracted from wasabi were first docu-mented in the Japanese medicinal encyclo-paedia during the 10th century (Ina *et al*, 1981). Recently, research interest in ITCs has become more

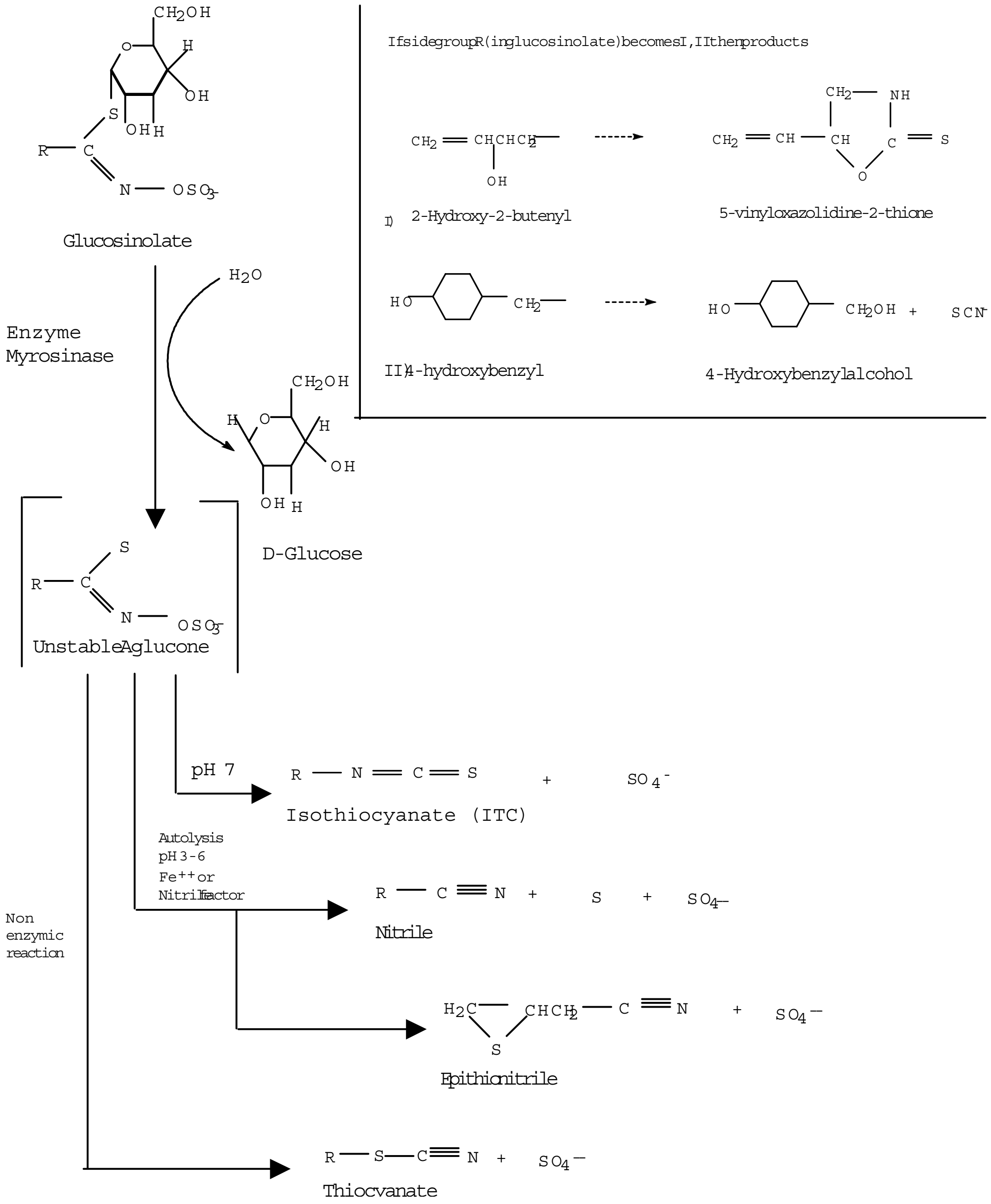

Fig. 3: Conversion of glucosinolates to different products by enzymic and nonenzymic reactions (Sultana *et al*, 2000)

intense because of their potential to have a wide variety of medicinal, pharmacological or industrial applications. These exciting applications are at an early stage of investigation, most likely because of wasabi's high present commercial value and scarcity.

Table I. Isothiocyanates in wasabi (mg/kg fresh weight) and a description of the odour of each individual ITC (Sultana *et al*, 2000)

Isothiocyanates (ITCs)	Wasabi rhizome (22)	Wasabi rhizome (15)	Wasabi root[a]	Mean published values	Odour description (15, 21, 24)
Isopropyl ITC	-	7.6	-	7.6	Weak mustard-like
Allyl ITC	1282	1880	1110	1424	Strongly pungent, mustard like, lachrymatory, bitter
n-butyl ITC	-	-	17.4	17.4	-
Sec-butyl ITC	11.4	13	-	12.2	Weak mustard-like
Isobutyl ITC	0.6	3.9	-	2.3	Sweet, chemical
3-butenyl ITC	123.5	25	18.3	55.6	Green, pungent, aroma
4-pentenyl ITC	65.2	31	39.0	45.1	Green, pungent, acrid
5-hexenyl ITC	16.9	8.0	10.2	11.7	Green, pungent, fatty
6-heptenyl ITC	1.0	0.6	-	0.8	Green, pungent, fatty
3-methylthio-propyl ITC	2.4	Tr	-	2.4	Strongly raddish-like, pungent
Benzyl ITC	-	-	-	-	Chemical, pungent
2-phenylethyl ITC	-	Tr	-	-	Strongly radish-like
4-methylthio-butyl ITC	0.2	-	-	0.2	-
5-methylthio-pentyl ITC	9.9	1.5	4.8	5.4	Radish-like, pickle-like
6-methylthio-hexyl ITC	35.0	4.8	18.9	19.6	Radish-like, sweet, fatty
7-methylthio-heptyl ITC	3.2	0.9	14.4	6.2	Sweet, fatty, radish-like, pickle-like
5-methyl-sulphinylpentyl ITC	-	-	21.7	21.7	-
6-methyl-sulphinylhexyl ITC	-	-	78.0	78	-
7-methyl-sulphinylheptyl ITC	-	-	14.1	14.1	-
Total ITC	1653.9	1976.3	1346.8	1659.0	

[a] Wasabi root in this reference presumably refers to either the rhizome or the total root plus rhizome mass, Tr, less than 0.5mg/kg; -, not reported

Anticancer effects

Medicinally, the most important feature of ITCs is evidence that they have a chemo-preventive effect on cancer at a variety of organ sites including lung, mammary glands, liver, oesophagus, bladder, pancreas, colon and prostrate (Chung, 2002). A recent case-control study in Los Angeles (Lin *et al,* 1998) showed that high consumption of cruciferae vegetables containing ITCs reduced the risk of developing colon cancer (Verhoeven *et al,* 1996; Steinmetz and Potter, 1991; Tanida *et al,* 1991; Fuke *et al,* 1997; Fuke *et al,* 1994). Tests have been carried out on tumours in rats and it has been reported that some ITCs have a protective role against breast, stomach and colon cancers in rats (Wattenberg, 1977; Wattenburg, 1981). Several mechanisms have been proposed and investigated for tumour inhibition by ITCs, for instance sulfoforane (SFN) and phenylethyl ITC (PEITC) are reported as potent inducers of the phase II enzymes involved in detoxification of carcinogens (Zhang and Talalay, 1994). The inhibition of chemically induced lung tumorigenesis by PEITC was mediated primarily by the inhibition of metabolism which resulted in a decrease in O6 methylguanine in lung DNA, indicating that ITC targets cytochrome P450s (Morse *et al,* 1989; Morse *et al,* 1991). Results from recent bioassays in A/J mice appear to support the mechanism of induction of apoptosis in lung by PEITC and butyl ITC (BITC) (Yang *et al,* 2002). Weil *et al*, (2005) reported that mono galactosyl dia-cylglycerides from wasabi rhizomes showed upto 47% inhibition of cyclooxygenase enzyme at a concentration of 250ug/ml and 44% inhibition of stomach cancer at dose of 60ug/ml. Therefore, the authors suggested that functional compounds in wasabi may play important role in reducing cancer risks and the occurance of cardiovascular disease. Extensive research on ITCs commonly found in cruciferous vegetables such as watercress, broccoli, radish and cabbage have been linked to the reduced risk of certain human cancers (Verhoeven *et al,* 1996; Steinmetz and Potter, 1991). From the chemoprevention point of view it is important to know whether the beneficial effects come, at least in part, from ITCs in the diet. In a cohort study it was clearly shown that individuals with detectable levels of ITCs in the urine were less likely to develop lung cancer (Seow *et al,* 1998). It has been suggested that normal dietary levels of ITCs derived from wasabi or other fresh cruciferous vegetables eaten regularly can protect against the low levels of carcinogens encountered in everyday life (Chung, 2002). As a result, the American Cancer Society recommends that cruciferous vegetables should be part of every person's daily diet to reduce the risk of several cancers.

Anticoagulant effects

The ITCs in wasabi have been tested for inhibition of platelet aggregation mediated by arachidonic acid (Kumagai *et al,* 1994), and for deaggregation. ITCs showed a ten times higher response than is reported for aspirin. In the case of heart attacks, where aspirin is commonly prescribed, ITCs have been shown to have a more rapid action at low levels than the thirty minutes for aspirin. In this regard, the most potent ITCs reported are ω-methylthioalkyl ITCs, especially 6-methylthiohexyl followed by 7-methyl-thio-heptyl and 5-methylthiopentyl ITCs. The anticoagulant property of ITCs could be used in the treatment of elderly people and during surgery where preventing platelet aggregation is vital for the well being of the patient. The mechanism by which the ITCs inhibit platelet aggregation from occurring has not been precisely determined but may be through a specific inhibition of the arachidonic acid cascade (Depree *et al,* 1999). Whereas, Morimitshu *et al,* (2000) reported that the antiplatelet role of ITC moiety is because of its high reactivity with sulphydryl groups in biomolecule. This therefore raises the possibility of using ITCs to limit inflammation in tissues.

Anti-asthmatic and anti-inflammatory properties

Benzyl and allyl ITCs from onion extracts showed anti-asthmatic effects when studied by Dorsch *et al.* 1985. Throm-boxanes (generated by lung tissue and by aggregating platelets during lung anaphy-laxis) and prostaglandins (generated by mast cells during activation) are known to cause bronchial obstruction and generally play a role in the pathogenesis of bronchial asthma. The isothiocyanates prevented bronchial obstruction caused by subsequent inhalation of ovalbumin but did not prevent obstruction caused by inhalation of histamine acetylcholine. This indicates that the anti-asthmatic effect of ITCs are not due to an anti-histamine effect but act by inhibiting the inflammatory process at an earlier stage, possibly the production or action of other inflammatory molecules such as thromboxanes or prostaglandins. Thus, ITCs could potentially be used to counter inflammatory conditions such as asthma or even anaphylaxis. Traditionally, horseradish and mustard have been used as a remedy for clogged sinuses, relief of congestion, muscular pain and inflamed joints (Depree *et al,* 1999).

Antibiotic effect

Masuda (2000) has suggested that wasabi could contribute to a healthy smile by inhibiting the growth of the bacteria on teeth and gums in the mouth. Streptococcus mutans is known to cause dental caries and the consumption of wasabi can reduce bacterial activity. This was explained by wasabi's ability to interfere with the sucrose-dependent adherence of cells to the surface of teeth and gums. Shin *et al,* (2004) reported that allyl ITC in roots, stems and leaves of wasabi showed bactericidal activities against Helicobacter pylori. The bactericidal activity of leaves found highest than that of roots though the contents of allyl ITC in leaves found lower than roots. Therefore, they suggested that certain bioactive compounds besides allyl ITC in wasabi are also effective in killing H. pylori which causes stomach ulcer.

Other industrial applications

ITCs extracted from wasabi can be used to make antibiotics, fungicides, insecticides, nematocides and as wood preservatives (Brown and Morra, 1997). ITCs are said to act as an antidote to food poisoning bacteria, one factor that has led to the use of wasabi with raw fish dishes in Japan (Ono *et al*, 1998; Shin and Lee, 1998; Hasegawa *et al*, 1999). It is also reported that ITCs may have a role in protecting against diarrhoea (Nakayama *et al*, 1998). ITCs have also been used as antifouling compounds to stop seaweed growing on ships' hulls. Recently it has been shown that wasabi contains anti-fungal metabolites that can render plants resistant to virulent isolates of the blackleg fungus (Soledade *et al*, 1998). This fungus can devastate commercially important crops such as the oilseed plants rapeseed and canola. Transgenic rice plants showed enhanced field resistance against rice blast fungus when genetically modified with wasabi defensin gene (Kanzaki *et al*, 2002). It seems that there is a potential to develop a natural fungicide using wasabi extracts. Wasabi also showed peroxidase activity (Kinae *et al*, 2000) and exhibited antioxidative and superoxide scavenging potency. Thus wasabi extract may be used as natural antioxidant.

Conclusions

Wasabi is a valuable crop that can be made into a tasty condiment. In Japanese cuisine freshly ground wasabi is used to add a spicy flavour directly to foods. Wasabi also made into a paste which is stabilised by the addition of a number of other ingredients. In Western cuisine where hot spicy tastes are a recent addition to the diet, milder sauces and mayonnaises containing wasabi are more often appreciated. While the main reason for consuming wasabi is the unique taste, it is interesting to note that the active components, the isothiocyanates appear to have some positive anti-cancer effects in the body. This will lead to increased production and consumption of this interesting perennial crop. Wasabi might be potent functional food for keeping human health.

References

Adachi, S. (1987). Wasabi cultivation. Shujyunsya Co. LTd., Tokyo, Japan. P 199. (Translated).

Brown, P.D. Morra, MJ. (1997). *Adv Agron* **61:** 167-231.

Chadwick, C.I. Lumpkin, T.A. Elberson, L.R. (1993). *Econ Bot* **47:** 113-135.

Chung, F.L. (2002). Chapter 7 in Phytochemicals in Nutrition and Health edited by Meskin MS, Bidlack WR, Davies AJ and Omaye ST, CRC Press USA.

Delaquis, P.J. Mazza, G. (1995). *Food Technol* 73-84.

Depree, J.A. Howard, T.M. Savage, GP. (1999). *Food Res Inter* **31:** 329-337.

Dorsch, W. Adam, O. Weber, J. Ziegeltrum, T. (1985). *Euro J Pharmacol* **107**: 17-25.

Douglas, J.A. Follett, J.M. (1992). *Proc Agron Soc* **22:** 57-60.

Etoh, H. Nishimura, A. Takasawa, R. Yagi, A. Satio, K. Sakata, K. Kishima, I. Ina, K. (1990). *Agric Biol Chem* **54:** 1578-1589.

Fahey, J.W. Zalcmann, A.T. Talalay, P. (2001). *Phytochem* **56:** 5-51.

Fenwick, R. Heaney, R.K. Mullin, W.J. (1983). CRC Crit Rev *Food Sci Nutr* **18:** 123-201.

Forde, B. (1982). Department of scientific and Industrial research discussion paper no. 7. Wellington, NZ, 25p.

Fuke, Y. Haga, Y. Ono, H. Nomura, T. Ryoyama, K. (1997). *Cytotech* **25:** 197-203.

Fuke, Y. Ohishi, Y. Iwashita, K. Ono H. Shinohara, K. 1994. *J Japanese Soc Food Sci Technol* **41:** 709-711 (In Japanese with English summary).

Hasegawa, N. Matsumoto, Y. Hoshino, A. Iwashita, K. (1999). *Internat J Food Microbiol* **49:** 27-34.

Hodge WH. (1974). *Econ Bot* **28:** 118-129.

Ina K, Sano A, Nobukuni M, Kishima I. (1981). *Nippon Shokuhin Kogyo Gakkaishi* **28:** 365-370.

Kanzaki, H. Nirasawa, S. Saitoh, H. Ito, M. Nishihara, M. Terauchi, R. nakamura I. (2002). Theo and App Genet. **105 (6/7)**: 809-881.

Kinae, N. Masuda, H. Shin, IS. Furugori, M. Shimoi. K. (2000). *Biofactors* **13 (1-4):** 265-269.

Kojima M. (1981). *Nogyo Oyobi Engei*, **56(5):** 113-118.

Kumagai, H. Kashima, N. Seki, T. Sakurai, H. Ishii, K. Ariga T. (1994). *Biosci Biotech Biochem* **58 (12):** 2131-2135.

Kumagai H, Kishima N, Seki T, Sakurai, H., Ishii K, Ariga T. (1994). *Biosci Biotechnol Biochem* **58:** 2131-2135.

Larsen PO. 1981. Glucosinolates in the biochemistry of Plants. A comprehensive Teatise, Stumpf PK and Conn, EE Eds, Vol 5, pp 502-525, Academic press, N Y.

Lin HJ, Probst-Hensch NM, Louie AD, Kau IH, Witte JS, Ingles SA, Frankl HD, Lee ER, Haile RW. (1998). *Cancer Epid Biomark Prev* **7:** 647-652.

Martin RJ, Deo B. (2000). *N Z J Crop hort Sci* **28:** 45-51.

Masuda, H. Harada, Y. Tanaka, K. Nakajima, M. Tebeta, H. Takeoka, GR. Teranishi, R. Williams, PJ. Kobayash, IA. (1996). *Biotech improved foods flavours*. ACS Symposium Series No. 637 **25:** 67-78.

Matsuda H. 2000. *Sci News* (159): **29.**

McGregor DI, Mullin WJ and Fenwick GR (1983). *J Ass off Anal Chem* **66 :** 825-849.

McGregor DI (1993). In: Encyclopaedia of Food Science Food Technology, Nutrition, Macrae R, Robinson RK and Sadler MJ. Eds, Vol 4, Academic press, Harcourt Brace Jovanovich publishers.

Morimitsu, Y. Hayashi, K. Nakagawa, Y. Fujii, H. Horio, F. Uchida, K. Osawa, T. (2000). *Mech Ageing Dev* **116 (2-3):** 125-134.

Morse, M.A. Amin, S.G. Hecht, S.S. Chung, F.L. (1989). *Cancer Res* **49:** 2894-2897.

Morse, M.A. Eklind, K.L. Hecht, S.S. Jordan, K.G. Choi, C.I. Desai DH, Amin, S.G. Chung, F.L. (1991). *Cancer Res* **51:** 1846-1850.

Nakayama, H. Suzuki, T. Suzuki, Y. (1998). Nippon Nogeikagaku Kaishi **72:** 499-507.

Ono, H. Tesaki, S. Tanabe, S. Watanabe, M. (1998). Biosci Biotech Biochem **62(2):** 363-365.

Palmer, J. (1990). *N Z J Crop Hort Sci* **18:** 161-164.

Prestera, T. Fahey, J.W. Holtzclaw, W.D. Abeygunawardana, C. Kalchinski, J.L. Talalay, P. (1996). *Anal Biochem* **239:** 168-179.

Seow, A. Shi C-Y, Jiao, D. Hankin, J.H. Lee, H-P. Coetzee, G.A. Yu, M. (1998). *Cancer Epid Biomark Prev* **7:**775-781.

Shin, I.S. Lee, J.M. (1998). *Bull Korean Fish Soc* **31:** 835-841.

Shin, I.S. Masuda, H. Naohide, K. (2004). *Int J Food Microbiol* **94 (3):** 255-261

Soledade, M. Pedras, C. Sorensen, J.L. (1998). *Phytochem* **49:** 1959-1965.

Steinmetz, K.A. Potte, J.D. (1991). Vegetables, fruit, and cancer. II: Mechanisms. *Cancer Causes Control* **2:** 427-442.

Sultana, T. Savage, G.P. McNeil, D.L. Porter, N. Martin, R.J. (2000). *Proc Nutr Soc NZ* **25:** 95-106.

Sultana, T. Savage, G.P. McNeil, D.L. Porter, N. Martin, R.J. Deo, B. (2002). *J Sci Food Agric* **82:**1477-1482.

Sultana, T. Porter, N.G. Savage, G.P. McNeil, D.L. (2003a). *J Agrc Food Chem* **51:** 3586-3591.

Sultana, T. McNeil, D.L. Porter, N.G. Savage, G.P. (2003b). *J Food Composition & Analysis* **16:** 637-646.

Sultana, T. Savage, G.P. McNeil, D.L. Porter, N. Clark, B. (2003c). *J Food Agric & Environment* **1(2):** 117-121.

Tanida, N. Kawaura, A. Takahashi, A. Sawada, K. Shimoyama, T. (1991). *Nutr Cancer* **16:** 53-58.

Verhoeven, D.T.H. Goldbohm, R.A. van Poppel , V. erhagen, H. van den Brandt, P.A. (1996). *Cancer Epid Biomark Prev* **5:** 733-748.

Warton, B. Matthiessen, J.N. Shackleton, M.A. (2001). *J Agric Food Chem* **49:** 5244-5250.

Wattenberg, L.W. (1977). *J Nat Cancer Inst* **58:** 359-398.

Wattenburg, L.W. (1981). *Cancer Res* **41:** 2991-2994.

Weil, M.J. Zhang, Y. Nair, M.G. (2005). *J Agric Food Chem*. **53:** 1440-1444.

Yang, Y.M. Conaway, C.C. Wang, C.X. Dai, W, Chiao, J.W. Albino, A.P. Chung, F.L. (2002). Cancer Res, In press.

Zhang, Y. Talalay, P. (1994). *Cancer Res* **9** (suppl.), **54:** 1976-1981.

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