

# Growing Wasabi in the Pacific Northwest

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## INTRODUCTION

Wasabi (*Wasabia japonica* [Miq.] Matsum) is a perennial plant that is a member of the *Cruciferaeae* or *Brassicaceae* family (commonly called the mustard family) and native to Japan. Grown for its unique, enlarged stem (sometimes described as a rhizome or root), which is 2 to 4 inches in diameter and 6 to 12 inches long, wasabi has a hot, pungent flavor (Figure 1). Although this flavor is similar to horseradish (*Armoricia rusticana*), another perennial Brassica, it has a subtle difference in that it quickly dissipates in the mouth, leaving a lingering sweet taste with no burning sensation (Chadwick et al., 1993).



Figure 1. A hand-harvested mature wasabi plant (a) and market-ready stem after trimming and cleaning (b) (photos by C. Miles and C. Chadwick, respectively).

Because of its specific growing requirements, wasabi is an expensive product, and therefore often substituted with the more easily obtained horseradish. Many markets recognize “real” or “genuine” wasabi as superior and distinct from mislabeled “fake” wasabi that is a mix of American or western horseradish, mustard, soy sauce, and green food coloring (Conjecture Corporation, n.d.; Ransom, n.d.).

When grated, wasabi forms a thick green paste and is commonly served with sushi, sashimi, and noodles. Its leaves and petioles also can be pickled or dried. Small or imperfect wasabi stems are dried and made into a powder used in foods such as crackers or as a

processed condiment paste packaged in squeezable tubes (Chadwick, 1990). Though wasabi is a staple condiment in Japanese cuisine, it is used sparingly to enhance the flavor of European and North American foods such as specialty dips, salad dressings, nuts, and cheese.

Wasabi thrives in cool and moist temperate climates. It is poorly adapted to many regions of the United States, but does grow well in the coastal region of the Pacific Northwest. Wasabi is also very suitable for small-acreage production because it is a high-value crop. However, growers need to become familiar with the unique production requirements of wasabi.

This publication outlines all aspects of wasabi production, including cultivar selection, plant propagation, horticultural practices, soil fertility, harvest, storage, and pest management. Since wasabi is a new crop in the United States, information on its production here is limited. Japanese authors writing on native growing conditions and experiences are the source for much of the information in this publication. Growers in the Pacific Northwest are advised to experiment with this research and adapt the findings for their particular environment.

## CULTIVAR SELECTION

Approximately 20 known wasabi cultivars are grown in Japan; they differ from one another in their stem shape and size; leaf size, shape, number, and color; and plant tolerance to temperature. Cultivars are region-specific in Japan; that is, certain cultivars are grown only in certain areas. Table 1 summarizes the characteristics of 18 wasabi cultivars. Because of wasabi's recent introduction to the United States, it may be difficult to find sufficient quantities of plant material or seed for commercial production. Generally only 'Daruma' and 'Mazuma' cultivars are commonly available, with costs ranging from 60¢ to \$15 per plant. Wasabi plants are available from suppliers in the United States, Canada, Japan, Taiwan, and New Zealand. Readers are encouraged to search for suppliers via the Internet and to compare prices and supply conditions.

## PROPAGATION METHODS

Wasabi is commonly propagated from tissue culture, offshoots, and seeds. Plants produced by tissue culture are genetically identical to their mother plant and therefore have the same potential to produce a high quality stem. Tissue culture plants are also disease-free. Plantlets are produced around the crown of the wasabi plant and are also identical to the mother plant, but have the potential to carry disease. Propagation by seed is a method Japanese farmers use

to avoid disease spread and rejuvenate a wasabi crop (Chadwick, 1990).

## Tissue Culture

Tissue culture<sup>1</sup> or micro-propagation is the process of culturing a small piece of plant tissue (e.g., stem, root, leaf, or bud) in a test tube. The plant tissue, called an explant, will grow into a plantlet that can be planted in a greenhouse or field (Figure 2). Tissue culture allows for quick production of many potentially high-yielding disease-free plants. A major challenge of wasabi tissue culture is heavy bacterial contamination rates and the high costs of overcoming them. Losses of up to 60% in the laboratory are not uncommon in wasabi tissue culture. In Asia, wasabi has been propagated through tissue culture for several decades. In 1994, experimental micro-propagation of wasabi at Washington State University successfully produced 100% disease-free plantlets from peduncle (inflorescence stem) explant material (Potts, 1994). Shoot apices, embryo, pollen, callus, and protoplast culture are all possible sources for micro-propagating wasabi.

Tissue culture plants need to be acclimatized before transplanting. In greenhouses, young tissue culture plants are first transferred to seedling trays, then grown in potting mix under high humidity conditions. This step is necessary to ensure good root development. After several weeks or a few months, plants are ready to be transferred to pots or a nursery bed. Mail-order tissue-cultured wasabi plants are at this stage and need to be transferred into a nursery bed following the procedures outlined below for seedlings.



Figure 2. Wasabi plantlet grown from tissue culture (photo by C. Chadwick).

<sup>1</sup> The book *Plants from test tubes* (Kyte and Kleyn, 1996) is recommended for anyone interested in learning more about and experimenting with tissue culture.

Table 1. Eighteen cultivars of wasabi commonly grown in Japan (Chadwick, 1990).

Cultivar	Stem	Leaves and Petioles	Disease Notes	Growth Habit
Daruma	Thick, green, excellent flavor	Heart-shaped or round green leaves; green petioles	Tolerant of soft rot and black leg	Upright to spreading
Fuji Daruma	High grade within 1 year	Heart-shaped or round thick leaves; green to purple petioles	Unknown	Spreading
Izawa Daruma	Large size, high quality	Heart-shaped dark green leaves; thick light purple petioles	Unknown	Spreading
Mochi Daruma	Large, sticky, high quality	Long round leaves; thick green petioles	Susceptible to soft rot	Spreading
Ozawa Daruma	Medium, soft flesh, high quality	Heart-shaped leaves; green to light purple petioles	Unknown	Unknown
Hangen	Thin, long, low quality	Unknown	Tolerant of soft rot	Unknown
Iwami	Large, thick, good quality, late maturing	Heart-shaped or round green leaves; dark red petioles	Unknown	Unknown
Mazuma	Large, stiff, good storage, poor market quality	Spreading leaves; purple and green petioles	Susceptible to soft rot and black leg	Spreading
Midori	Quick growth	Heart-shaped brilliant green leaves; thin blue-green petioles	Unknown	Upright
Sabumi	Thin, long, light purple, high yielding, high quality	Heart-shaped long light green leaves; thin very light green petioles	Unknown	Unknown
Sanbe	Large, high quality	Heart-shaped light green leaves; green petioles with red vascular tissue	Unknown	Unknown
Sanpoo	Early, spindle-shaped, inferior quality	Heart-shaped green leaves	Tolerant of soft rot	Unknown
Shimane 3	Conical, good quality	Spreading round light green leaves; reddish or greenish white petioles that turn red at maturity	Tolerant of soft rot and black leg	Spreading
Shimane Zairai	Spindle-shaped, light brown, sticky, excellent quality	Leaves unknown; red petioles	Susceptible to soft rot and black leg	Spreading
Shizukei 12	Medium sized, high quality	Heart-shaped large green leaves; fat light green petioles	Tolerant of soft rot	Spreading
Shizukei 13	Thick, light green, strongly spicy and sweet	Many heart-shaped large green leaves; thick light purple to green petioles	Unknown	Spreading
Sugita 25	Medium-sized, green, high quality	Many heart-shaped green leaves; thick, light purple to green petioles	Tolerant of soft rot	Unknown
Kamogiko 13	High quality, sticky, spicy	Heart-shaped large green leaves; thick, light purple petioles	Tolerant of soft rot	Spreading

## Vegetative Propagation

Plantlets (offshoots) are produced around the crown of the mother plant and can be used to propagate wasabi vegetatively. Each mother plant can produce up to 20 plantlets depending on the cultivar. When wasabi plants are harvested for market, plantlets are cut from the plant and immediately replanted. Plantlets should be at least 1½ inches tall, with 4 to 5 leaves and a healthy appearance and color (i.e., dark green, not chlorotic, and no symptoms of disease such as spots on leaves). If plantlets are too small to plant directly into a field, they can first be grown in a nursery bed as described below for seedlings. It is best to harvest and replant wasabi in early spring or fall when rains provide adequate moisture for root establishment and temperatures are cool. This cycle of vegetative propagation can likely be repeated for 3 generations or as long as the plants are healthy and produce disease-free plantlets. When the mother plants become too diseased to produce viable offshoots, growers will need to start over with disease-free plants produced from tissue culture or seed.

Mature stems can also be used for vegetative propagation (Adachi, 1987). Each stem has the potential to produce up to 20 plantlets. Stems should be cut into 5 pieces, with each sterilized by rinsing 3 times in a 0.05% bleach solution (Chadwick, 1990). Stem pieces can then be placed in a 50:50 mix of sand and compost in planting boxes or trays in a greenhouse with a temperature range of 46 to 50°F and 90 to 95% humidity. In about 2 months, plantlets will begin to grow. Once plantlets have 4 to 5 leaves they can be removed from the stem and planted out as described below for seedlings.

## Seeds

Wasabi begins to flower in January, peaks in April, and ends in May (Figure 3); seed pods are mature and ready for harvest 50 to 60 days after flowering is complete. Vernalization, or cold temperature induction of flowering, appears to be a prerequisite; however, optimum temperature and duration are unknown. Flowers that bloom from late March to early April appear to produce the maximum number of viable seeds, which also have a lower dormancy and therefore germinate faster than seeds that develop in warm ( $\geq 73^{\circ}\text{F}$ ) or cold temperatures ( $\leq 46^{\circ}\text{F}$ ) (Adachi, 1987).

In general, wasabi seeds have a high dormancy and fail to germinate when freshly harvested. In nature, cold winter temperatures break the dormancy of wasabi seeds, and they begin to sprout in February. Alternatively, artificial cold treatment (stratification) can be used to break seed dormancy. In their studies



Figure 3. Potted wasabi in flower in a western Washington greenhouse (photo by C. Miles).

with 'Daruma' and 'Shimane' cultivars, Tatsuyama et al. (1983) found that 41°F for 2 months was optimal for wasabi seed germination. Optimal stratification time and temperature likely vary depending on the cultivar, but specifics are unknown at this time. It is advisable to store all varieties of wasabi seeds in an airtight refrigerated container to provide the cold temperatures needed for germination.

Wasabi seeds can be planted anytime in February through March when the outside temperature range is most likely from 50 to 57°F to achieve the best germination. In Japan, the seedling box method and seedling bed method are both used to start seedlings.

## Seedling Box Method

The seedling box method utilizes planting boxes that are approximately 4 inches deep with bottom drainage holes. A 1½-inch layer of a well-draining germination or rooting medium such as a vermiculite-perlite-peat mix will work as a base. Wasabi seeds should be sown approximately 2 inches apart in the planting box and covered with ½ inch of the germination mix (Suzuki, 1968). An unheated greenhouse is the best place to keep the boxes, which must be watered so the seeds stay moist. However, it is important not to saturate the potting mix. The seeds should germinate in 20 days.

After the first true leaves (not cotyledons) appear, a dilute liquid fertilizer (1 to 5 lbs N-P-K per acre) should be applied once a week. Black shade cloth will protect wasabi seedlings from sunburn. In 4 to 6 months when the wasabi plants are 2 inches tall and have at least 4 leaves, the seedlings can be transplanted into an outside nursery bed under 65%

shade. A 50:50 sand and compost mix will provide good drainage. The seedlings need to be 2 inches apart and covered so that their crowns are about ½ inch above the soil surface. A misting or micro-irrigation system is excellent for wasabi seedling production to maintain moist soil without saturation. In about 2 months, the seedlings should be 4 inches tall and ready for transplanting into the field where they will grow until harvested. September through October is the best time to transplant wasabi so that plants can become established before temperatures drop below freezing.

## Seedling Bed Method

Wasabi seeds are sown in a field hoophouse<sup>2</sup> in late winter with the seedling bed method. A sand and compost mix that provides good drainage works best for the bed fill. Seeds should be planted 2 inches apart and ½ inch deep. Once the seedlings reach a height of 2 inches they can be transplanted outside into a nursery bed as described above.

## GROWING ENVIRONMENT

In nature, wasabi is found growing on the shaded wet banks of cold mountain streams and springs. Under cultivation, wasabi appears to grow best in heavy shade and shallow, clear, cold running water. Sites that are naturally suited for wasabi production also have ferns, trout, salamanders, wild parsley, and/or butterbur (Adachi, 1987). It is unknown how long wasabi plants take to reach marketable size or whether stems reach high quality when grown in natural environments.

Wasabi is generally cultivated by either a semi-aquatic system or a field system. In Japan, most wasabi is produced in semi-aquatic systems, and the stems are of high value, sold in fresh markets, and used freshly grated. The field system is common in Taiwan, a major wasabi-producing country in which whole plants are harvested and shipped to Japan for processing.

## Semi-aquatic System

A traditional semi-aquatic system provides a continuous flow of cool, clean water. An alternating on-off flow system may also be effective. Water flow is balanced with proper air temperature, water temperature, pH, and electrical conductivity levels. Air temperature, measured 2 feet above the plants, should be 46 to 64°F, with 54 to 59°F as the ideal range. When the air temperature rises above 82°F, wasabi plants may become heat-damaged and infected by soft rot (*Erwinia aroideae*). Air temperatures below 46°F can slow or stop

plant growth; at 27°F, plants begin to freeze and may become damaged if temperatures decline further or remain low for extended periods of time (Chadwick, 1990; Adachi, 1987).

Water temperature is one of the most critical factors when growing wasabi in a semi-aquatic system. The ideal water temperature range is from 54 to 59°F, which should be the same as the air temperature surrounding the plants. When the water temperature rises above this point, oxygen levels in the water drop and plant growth is inhibited. Spring water generally has high levels of oxygen and therefore is considered optimal for semi-aquatic wasabi cultivation (Chadwick, 1990).

The pH of water in a semi-aquatic system should be near neutral or slightly acidic (6.0 to 7.0 pH). Low electrical conductivity<sup>3</sup> (between 0.03 and 0.2 millimho per cm) in the water is also needed to effectively grow wasabi. Other requirements for this growing method are less than 0.1 ppm ammonia-nitrogen in the water and no nitrite-nitrogen (Chadwick, 1990). Due to the fragile nature of the water system and regulations governing water quality, applying additional fertilizer is not allowed.

The quantity of water required for wasabi production is dependent on its growing environment (Adachi, 1987; Suzuki, 1968). In general, a constant and stable flow of about 19 gallons of water per second is required for a one-acre wasabi field.

## The Tatamishi System, or Rock Mat Semi-aquatic System

The Tatamishi system, or rock mat semi-aquatic system, is most commonly used in Japan for wasabi production because it is believed to produce the highest quality stems (Figure 4; Chadwick et al., 1993). Beds are generally 16 to 33 feet wide and 33 to 49 feet long. Each bed consists of a 2-inch layer of sand on top of a 3-inch layer of gravel (from 1/4 to 3/8 inch in diameter, referred to as “minus” or “chips”). Beneath the gravel is a 16 to 40-inch layer of small rocks (about 3 inches in diameter) that provides rapid water filtration.

The Tatamishi system requires gentle slopes of 1 to 4% and a water flow rate of 5 to 6 inches per second (Chadwick, 1990; Adachi, 1987; Toda, 1987). In this

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<sup>2</sup> For field hoophouse designs, see *Portable field hoophouse* (Miles and Labine, 1997) and *The hoophouse handbook* (Byczynski, 2003).

<sup>3</sup> Electrical conductivity is a measure of the total salt content of water based on the flow of electrical current through the sample. The higher the salt content, the greater the flow of electrical current.



Figure 4. Wasabi grown with the semi-aquatic Tatamishi system in the Shizuoka area near Mt. Fuji, Japan (photo by Yoshikazu Kiriwa, Shizuoka University, Japan).

system, two wasabi stems can be produced per square foot and be ready for harvest in 16 to 20 months. A series of terraces on a hillside provide the best water flow and most efficient use of water. Water flows through each terrace by filtering down through the sand, gravel, and rocks that make up the bed, and out to the ditch at the bottom (Adachi, 1987; Toda, 1987). Beds should be built so there is no leakage from the sides. On the side of the bed, plastic or large rocks mortared together with smaller rocks can be used to contain the water (Chadwick, 1990).

If the slope and water flow rate meet the Tatamishi system requirements, wasabi plants will grow without support and the stems will be straight and of the highest quality. Wasabi stems grown in beds that have a strong water flow will be shrimp-shaped, which is not desirable (Adachi, 1987). However, stones or plastic pipes can be used to hold plants steady against a current. A large flat stone at the base of each plant on the upstream side will cause the water to hit the stone and be diverted around the plant. Plastic pipes need to have a 3 to 3½-inch diameter and be 2½ to 3 inches long. If placed over the plant so that half the pipe is above the surface of the sand and half is below, the water flow will be directed under the pipe to keep the plant cool. This technique also reduces water bug and soft rot damage, but may increase aphid problems. In addition, stems and petioles may become smaller and less colorful.

## Greenhouse Production

Although hydroponic greenhouse systems are not used in Japan and no instructional literature exists, some growers in the United States have successfully used this system. A semi-aquatic system can be built



Figure 5. A wasabi-appropriate shade greenhouse in western Washington built on a slight slope with water entering from one end (a), water flowing through a gravel bed full of wasabi (b), and water exiting the other end of the greenhouse (c) (photos by C. Miles).

within a greenhouse on a slight slope to provide the correct shade and water flow needed to produce high quality wasabi (Figure 5). The general guidelines for semi-aquatic production should be followed, with adjustments to flow rate and nutrition as needed based on plant observations.



Figure 6. Wasabi grown in soil under an evergreen tree canopy in Taiwan (photo by C. Miles).



Figure 7. Wasabi grown in soil under an evergreen canopy in western Washington (photo by C. Miles).

## Field Soil System

Since wasabi is a shade-loving plant and is predominantly grown under shade trees or nets, air temperatures of 43 to 68°F are required for good production. If the environment is naturally overcast and cool, especially during summer months, shading may not be necessary (Adachi, 1987). When wasabi leaves are exposed to too much direct solar radiation or air temperature reaches 77°F, the likelihood of soft rot (*Erwinia aroideae*), black leg (*Phoma* spp.), and leaf burn increases. If temperatures are too cool (32 to 43°F), plant growth slows or stops; when the temperature falls below 27°F, frost damage can occur, but plants will likely survive and regrow when temperatures increase (Chadwick, 1990).

Planting trees such as black alder or poplar is recommended to provide summer shading for wasabi plants. In Taiwan, upland wasabi is grown under large evergreen trees that provide shade year-round, and the soil remains moist through rainfall and dew (Figure 6). In some places in Japan, wasabi is grown in persimmon orchards with one tree per 1,000 square feet. Some of these orchard systems are over 300 years old.

A small study in western Washington along the coast showed that wasabi can also be grown under an evergreen canopy in this environment (C. Miles, personal observation; Figure 7). Field trials at the Washington State University Long Beach Research and Extension Unit indicate that wasabi will grow without shade, though the quality of the stems is unknown (Kim Patten, WSU Long Beach, personal communication with C. Miles). Another option is to cover wasabi plants with straw to provide more shade (Chadwick, 1990). Potential growing sites should be assessed to determine if only summer shade is required or if year-round shade is necessary to keep temperature and moisture within the desirable range.

Wasabi grows best on soils that are high in organic matter; have an open, friable structure; and good drainage. In general, soils such as deep alluvial loam, sandy loam, or sandy clay loam are well suited for wasabi production. Sandy soils will need annual additions of organic matter and heavier soils need to have adequate drainage (Barber and Buntain, 1997).

## IRRIGATION

Irrigation is used in field production systems of wasabi to 1) maintain soil moisture levels, 2) provide humidity, and 3) cool the plants. Micro-irrigation systems are suited to wasabi production because they maintain good soil moisture and high humidity in the canopy. Irrigation practices should keep wasabi roots moist but not saturated and be based on plant observations (e.g., wilted plants require more irrigation, whereas root rot is a sign of over-irrigation).

## FERTILIZER

Optimum fertilizer recommendations for wasabi are unknown. In semi-aquatic systems in Japan, water comes from rice fields that lie above the wasabi terraces. Phosphorus levels in this water range from 0.06 to 2.2 ppm, and potassium levels average between 2.0 and 3.0 ppm. Since these levels appear to meet plant needs, no additional fertilizer is added. In other areas of Japan, a slow-release fertilizer such as 12-12-12 (N-P-K) is applied to the water at the rate of 0.02 pounds per square foot. A foliar application of sulfur is sometimes made 1–3 months before harvest to enhance the flavor of wasabi. However, adding fertilizers to semi-aquatic systems where water returns to a stream or other natural water source is illegal in the Pacific Northwest. Conducting both water and soil tests prior to planting wasabi is therefore advisable to

determine nutrient availability.

For wasabi field production, organic matter such as poultry, dairy and green manure, or 12-12-12 fertilizer at a rate of 100 lbs plant-available N per acre should be broadcast and incorporated into the soil before planting. Boron-deficient soils can be alleviated by broadcasting borax at the rate of 18 pounds per acre or banding (i.e., placing fertilizer in a band down the plant row) 9 pounds per acre at planting. Applying sodium molybdate at 0.9 pounds per acre or a foliar spray at 0.5 gallons per acre is advised for soils that are molybdenum-deficient (Barber and Buntain, 1997).

## PLANTING

Both semi-aquatic and field soil systems stipulate planting wasabi so that the crown of the plant is approximately ½ inch above the soil surface. Extra shade may be needed until the plants are established and throughout the summer thereafter depending upon the intensity of the sun in the growing area. If leaves appear limp or wilted, increasing the humidity around the plants with misting can help. However, inadequate root development and/or contact with the planting medium may be the source of the problem if wilting continues. In a field system, soil moisture levels should be checked. If there is no change in the color of leaves within a week and petioles remain wilted, the plants need to be removed and replanted in a different area.

## WEED CONTROL

Once plants are established, the planting area should be kept weed-free by hand-pulling or mechanical cultivation since no herbicides are registered for use on wasabi. In a semi-aquatic system, there will be very few weeds.

## HARVEST

Harvesting wasabi requires pulling up the plants by hand since there is no machinery available for this purpose. Removed plantlets can immediately be replanted if they appear healthy. Harvesting and replanting wasabi therefore often occur at the same time, in the fall or spring when growing conditions are best due to cool temperatures and high moisture. It is advisable to evaluate wasabi early in its second year of growth (when it should begin to reach its peak harvestable size) to develop a harvesting schedule that best meets the needs of the plant.

Wasabi stems are the most desirable part of the plant, and should be 6 inches long and 2 inches in diameter before harvest. The highest quality stems are evenly tapered, especially for the fresh market. Uneven

tapering indicates that growing conditions were variable. At harvest, the stems are pale to dark green inside. A medium green stem makes an excellent paste when grated, and will bring the highest price in Asian markets. Many buyers consider very dark or very light-colored stems unsuitable, which translates into a lower price. If wasabi stems are being dried and used for paste, a dark green internal color is acceptable. Wasabi leaves, which have a milder flavor than the stem, are also used, primarily as a garnish or in salads.

After the plants are harvested, the stems need to be washed thoroughly to remove any soil and debris. Any dead or dying leaves and diseased portions of the stem also need to be removed. Wasabi grown in soil-based systems often require trimming at the base of the stem to remove disease. However, it is important to note that knowledgeable buyers recognize this connection and therefore consider excessively trimmed stems to be of low quality.

Although plantlets are removed during wasabi harvest, the crown should remain intact. For the fresh market, buyers prefer a few leaves on the plant as an indicator of freshness, so it is best to retain the newest, healthiest, center leaves and remove the older, outside leaves. Leaf stems should be trimmed evenly to approximately one-third their original length, although this may vary among markets (Barber and Buntain, 1997).

## STORAGE

Wasabi stems need to be stored in cold, humid conditions such as a refrigerated cooler. Good quality can be maintained in this environment for up to 4 weeks. In grocery stores, wasabi should be displayed in the misting section with other fresh vegetables. Stems need to be kept moist and cool to prevent desiccation. At home, stems should be wrapped in a damp paper towel and placed in the refrigerator. These practices will keep wasabi fresh for several weeks (Barber and Buntain, 1997).

## PESTS AND DISEASES

As a member of the brassica or crucifer family, wasabi is subject to many pests and diseases that attack other crops in the same family. Many of these pests and diseases cause deterioration in wasabi stem quality and yield. Chemical controls should be avoided due to the delicate nature of wasabi production systems (stream habitats) and lack of approved pesticides. Since wasabi is

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<sup>4</sup> The Extension publication *Recognizing economically important caterpillar pests of Pacific Northwest row crops* (Antonelli et al., 2000) provides color photographs and lifecycle information for this key pest group.

infrequently grown in the Pacific Northwest, the severity of any of these problems here is unknown. The pest and disease discussion below is meant to help the reader identify potential problems and prevent their occurrence.

## Foliar Pests

### Aphids

Aphids are potentially serious pests of wasabi because of their ability to transmit viruses and cause discoloration and distortion of the leaves. *Myzus persicae* (Sulzer) is known to attack wasabi leaves, and root aphids have been found on wasabi roots (Adachi, 1987).

### Moths

Cabbage and alfalfa loopers (*Trichoplusia ni* and *Autographa californica*) are nocturnal, light-colored moths whose larvae damage wasabi roots and shoots in Japan's field-grown wasabi. The imported cabbageworm (*Pieris rapae*) has been found in wasabi nurseries and semi-aquatic wasabi fields; the caterpillar<sup>4</sup> form feeds on leaves and stems. Larvae of the diamond back moth (*Plutella xylostella*) damage wasabi leaves in field systems (Adachi, 1987).

### Crane flies

Adult European crane fly (*Tipula paludosa*) and common crane fly (*Tipula oleracea*) are mosquito-like in shape, and brown or gray with dark markings on their wings. Adult crane flies do not feed on wasabi but are an indicator of a potential problem. Crane fly larvae are gray to black, aquatic, live in moist soil, and feed on wasabi stems.

### Slugs

The gray field slug (*Deroceras reticulatum*) feeds on all parts of wasabi, damaging its market value and causing complete plant loss in some cases (Adachi, 1987). These pests are usually removed by hand.

## Bacterial Diseases

### Internal black rot syndrome

Internal black rot syndrome is caused by *Erwinia* sp. and *Pseudomonas* sp. in combination with the fungal pathogen *Phoma* sp. The veins of infected wasabi plants turn dark, dark spots then appear, and the spots later become milky with a putrid odor. Leaves turn yellow and die, and roots also turn yellow, but plants may recover and regrow (Adachi, 1987).

*Erwinia aroideae* and *E. carotovora* require moist conditions to thrive and usually infect wasabi plants

through wounds. *E. aroideae* can be spread over a wide range of air temperatures from 32 to 99°F, but is likely to peak during summer months when air temperatures reach 93°F and water temperatures are at 64°F. Internal black rot syndrome can be avoided by planting resistant cultivars such as 'Sanpoo,' 'Shimane 3,' and 'Daruma.' Providing shade of up to 70% and cool (55 to 59°F), silt-free water should minimize disease spread (Adachi, 1987).

### Vascular wilt

*Corynebacterium* causes vascular wilt, blight, and leaf spotting in wasabi grown in semi-aquatic systems. Leaves appear oil-soaked, leaf veins are broken, and stem and root vascular tissues are damaged. Though the pathogen remains year-round in semi-aquatic wasabi fields, this disease is infrequent in soil-based wasabi fields (Adachi, 1987). Using fresh plantlets and/or disease-free seedlings should minimize infection.

## Fungal Diseases

### Black leg

*Phoma wasabiae* and other *Phoma* species that cause black leg are the most destructive of all fungi affecting wasabi in both semi-aquatic and soil-based fields in Japan. These pathogens overwinter as mycelia in seeds or infected plant tissue (Roberts and Boothroyd, 1984).

Black leg often infects wasabi seedlings with the onset of warm weather ( $\geq 73^\circ\text{F}$ ). The first symptom of this disease on wasabi plants is black spotting on the leaves, petiole, and stem surfaces, which spreads inside to the vascular area. Leaves develop irregular and circular spots, which eventually result in holes. Leaf veins darken and leaves droop due to weakened vascular tissue, but remain on the plant since premature production of abscisic acid is absent (Adachi, 1987; Takuda and Hirose, 1975). The disease eventually destroys the whole vascular system by causing necrosis. Disease lesions can cause secondary infections to spread onto other plants.

Although black leg is difficult to prevent, some measures can be taken to minimize the spread and severity of infection, including limiting vegetative propagation to 3 consecutive years, using only disease-free seedlings as planting material, controlling water insects that wound wasabi plants, and harvesting wasabi early from infected fields (Adachi, 1987).

### White rust

White rust of wasabi is caused by the fungus *Albugo wasabiae* Hara. Symptoms include small, shiny spots that appear on the underside of leaves and grow larger

and turn milky white. Leaf veins, flowering stems, and pods can all become affected. The disease infects when air temperatures range from 45 to 46°F, spreads at 55 to 57°F, and stops at 66 to 68°F (Adachi, 1987).

### *Downy mildew*

Downy mildew on wasabi is caused by *Peronospora alliariae* Gaumann. Disease symptoms include leaves that turn yellowish-green to dark brown on top and have gray mildew on the underside. Affected leaves eventually dry up and die. The fungus grows faster in humid and warm conditions (77°F) and remains dormant through the winter (Adachi, 1987).

### *Damping off*

This disease, caused by the pathogen *Pellicularia filamentosa* (Pat.) Rogers, affects all stages of wasabi. In seeds, damping off decreases vigor or prevents germination, and in seedlings, stems become weak and plants fall over. Mature plants turn yellow and then black when affected by this pathogen. *P. filamentosa* has been found in both soil and plant tissues. Wasabi grown in semi-aquatic systems are generally unaffected by damping off.

### *White mold*

The fungus *Sclerotinia sclerotiorum* causes white mold on wasabi leaves. Symptoms of this disease include cottony or watery soft rot. Seed harvested from plants affected by white mold can have reduced germination rates and may cause reduced stand establishment in nursery bed production (Adachi, 1987).

### *Club root*

Wasabi roots can be attacked by the fungus *Plasmodiophora brassicae* Woronin that causes hypertrophy or swelling. The vascular system of infected wasabi roots becomes restricted and plants develop signs of nutritional and water stress (Roberts and Boothroyd, 1984). The club root pathogen is infectious from 48 to 81°F. Club root in wasabi production can be prevented by avoiding humid and infected areas during wasabi cultivation and raising the soil pH above 7.0 with agricultural lime (Adachi, 1987).

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