

Tasting Terrific

Flavor improvement with hydroponics

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Second of a series

Hydroponic growers can control nutrient levels with precision so that strawberries need not lack sweetness or flavor, even if grown in mid winter.

In the previous article in this series on flavor improvement with hydroponics, the problem of the tasteless tomato was examined and some quality improvement methods detailed.

Tomatoes however, are not the only fruit to receive some criticism when it comes to taste – strawberry flavor can also become a victim of yield-orientated, large-scale commercial production, and hydroponic growers can help provide a solution, if armed with the right information.

Flavor or compositional quality of many hydroponic crops is coming under increasing scrutiny as consumers become more aware of where food comes from, how it is produced, its nutritional quality and overall flavor profile. We might think that the flavor aspect of quality really only applies to the hydroponic fruit crops of tomatoes and strawberries, but flavor, aroma and texture go much further. Aromatic herbs, peppery watercress, superheated chilies, crispy lettuce, pungent Wasabi and many other crops whose flavor depends not only on sugar and acid profiles but also on volatile compounds and texture are also crops we can improve using hydroponics.

Hydroponic strawberry flavor

Many of us who buy or sample strawberry fruit on a regular basis know the pleasure of finding that one berry with an intense aroma, sweet succulence and overall explosive “strawberryness” that is often missing. Strawberry quality from both outdoor and greenhouse crops can be highly variable – from the extremes of the rather woody and chewy berry to an overall soft and watery texture to a range of strange off flavors, uneven ripening and even a complete lack of taste.

As with tomatoes, much of the strawberry-like flavor in berries comes from volatile compounds, so a fruit that otherwise has sufficient sugar and acids but is lacking in volatiles can be a huge disappointment to any strawberry fan.

The other problem with strawberry fruit seems to be inconsistency in flavor even within the same crop, something growers can influence with careful control of growing conditions and harvest maturity.

Producers need to grow strawberry fruit that are of the correct size, shape and color for their particular market, but feedback from consumers suggests that flavor is now becoming as important as appearance. With modern strawberry cultivars consistently producing high yields of attractive, well sized, long shelf-life berries, growers can now focus more on compositional quality, and there are a number of production techniques that can be used to ensure those berries taste as good as they look.

The lack of flavor in greenhouse berries is a worldwide problem – these fruit are often produced out of season, or forced to provide fruit at times of the year when outdoor production is not possible. This means that the forced berries may lack flavor, particularly sweetness, due to the low light conditions they are grown under. Good light levels are essential for sugar production in the plant, and strawberry fruit suffer from a lack of sweetness under low winter light levels in most areas of the world.

Acids in strawberry fruit do not seem to be as affected by low light and temperature conditions as sugar levels, thus winter greenhouse fruit can be acidic or sharp without the required

sweetness to balance the flavor.

Strawberry fruit composition depends on a relatively small amount of dry matter. Since the average strawberry fruit is around 92-percent water, only eight-percent dry matter is responsible for the flavor quality of the berry. However strawberry fruit can range from seven to eleven and a half percent dry matter depending on growing conditions, cultivar, plant age and nutrition, with much of these soluble solids being attributable to sugars. Glucose and fructose are found in similar concentrations and these rise continuously during fruit development, from five percent in small green fruit to six to nine percent in mature berries.

Strawberry flavor, as determined by human tasters largely depends on sugar concentration. The most common complaint from consumers is a lack of sweetness. The average sugar level in most outdoor, summer-grown strawberry fruit is around a brix of eight to ten percent, which gives acceptable flavor. Fruit with a high degree of sweetness would have a brix of over eleven percent, balanced with a titratable acidity (citric or malic acids) of at least 1.35 grams per 100 grams of fruit. To give a good flavor balance, fruit are recommended to have soluble solids (brix) to acid ratio of nine to 13.5 for a sweet-tart flavor.

Improving fruit composition

The strawberry is a small plant, which if grown correctly develops a heavy sink demand with many large fruit developing over a relatively short period of time – usually 30 days from set to harvest. For a small plant to support such a large volume of fruit, it must maintain highly efficient rates of photosynthesis and

water/nutrient uptake while at the same time not overly depleting assimilate reserves in the crown of the plant.

For this reason, one of the main contributing factors to strawberry flavor apart from light levels, is the amount of healthy leaf area available per plant to produce assimilate for importation into the berries. It is this assimilate that ultimately determines the soluble solids content of the berries at maturity and the overall sweetness of the fruit as detected by consumers.

Commercially grown strawberry crops should aim to maximize leaf production, expansion and leaf area per plant in the early stages soon after planting out, before any flowers open. Optimizing nutrition, nutrient formulation and EC levels in hydroponic strawberries for vegetative-only growth in these first few weeks assists with process. Generally this means a nutrient formula with higher nitrogen (N) levels and a moderate EC, which is switched to higher potassium (K), higher EC formulation as soon as the plants enter the rapid berry development phase after fruit set.

The correct N:K ratio for hydroponic strawberry crops at the vegetative and fruiting phases is not well defined in the way it might be for other fruiting crops. It appears that climate, season, cultivar and growing system have a major influence on the N and K uptake rates of vegetative and reproductive strawberry plants. Individual growers must monitor these elements closely to determine exact ratios.

Sucrose is the major assimilate transported to the strawberry fruit. Transport of sucrose peaks at the time of color development. Immature berries are green in color and should have photosynthetic capacity: the contribution of fruit photosynthesis to carbohydrate accumulation is unknown, but suggests berries produced in full light have the potential to attain more sugars than those that are shaded for much of the day. Pre harvest shading of strawberry fruit appears to increase titratable acidity in berries, probably through its effect on the rate of respiration.

As with most crops, strawberries have large genetic differences when it comes to both yields and fruit composition. These genetic differences appear to interact with growing conditions. The best-flavored cultivar in one area may not be the ideal in another system and region. Overall strawberry flavor can be improved in most modern cultivars under hydroponic or greenhouse production with the use of environmental and nutritional modification. However, there is often a trade-off between flavor improvement and yield. In many cases, the greater the flavor profile in a strawberry fruit, the lower the fresh weight.

Another vital component of strawberry flavor is the fruit's aroma. Esters, which are responsible for strawberry fruit aroma, are only formed at the pink or red stages of fruit development. If fruit are held in controlled atmosphere storage with low oxygen or high CO₂ levels after harvesting to prolong shelf life, fruit flavor and aroma will suffer. As decreased alcohol transference activity occurs and acetate ester production becomes inhibited. Post harvest handling and storage also play a role in flavor development and retention. Although strawberry fruit can fully color in storage if harvested at the white or pink stage, changes in texture, sugars and acidity fail to develop fully.

Maximum flavor

Few studies have examined which nutrients play leading roles in the compositional quality of strawberry fruit. However it is well known that nitrogen (N) and calcium (Ca) play a major role in fruit firmness, and it appears that phosphorus (P), potassium (K), magnesium (Mg), zinc (Zn), molybdenum (Mo) and boron (B) are also important for fruit quality. B and Mo have been shown to be important for the good rates of Vitamin C (ascorbic acid) and sugars in strawberry fruit. B, Ca and Zn have direct effects on fruit quality; plants deficient in those minerals show poor pollen germination and reduced fruit set and size.

There is some evidence to suggest that hydroponically grown strawberry crops benefit from the application of silica to the nutrient solution. Silica has been found in studies on soilless strawberry crops to assist with mineral uptake, resistance to salinity and to boost overall growth and yield. It is likely that through increases in leaf area and mineral uptake, silica would also improve fruit compositional quality, sugar levels and firmness.

As with many fruit species, potassium is the one element that has the most effect on compositional quality in strawberry fruit, possibly because such high levels of this element end up in the fruit tissue. Potassium deficiency caused by rapid stripping of this element from recirculating nutrient solutions has been found in hydroponic crops and few growers realize



Certain flavor compounds in onions have been shown to increase with increasing levels of nitrogen in the hydroponic nutrient solution.

the amount of potassium a heavily fruiting crop requires to maintain the high uptake rates associated with rapid fruit swell. While many studies have been carried out to determine the optimal potassium to nitrogen ratios for strawberry crops, most fall within the range 1.7:1.0 to 2.0:1.0 potassium to nitrogen. However it is possible to grow strawberry crops on a vegetative formula with a potassium to nitrogen ratio of 1.0:1.0 to 1.2:1.0 until the time of fruit set on the first inflorescence and then gradually increasing the amount of potassium to a higher ratio when the plants are carrying a heavy fruit load.

Electrical conductivity (EC) levels recommended for hydroponic strawberries vary depending on environmental conditions and the growing system. Levels in NFT (nutrient film technique) are recommended to be 1.4 to 1.8 mScm⁻¹ (Millisiemens per centimeter) while levels of 1.4 to 2.4 are more common in media based systems. A minimum EC of 1.2 is necessary during the early vegetative stage, while under low winter-light conditions, EC levels should be run at higher levels of 2.0 - 3.2 to maintain fruit flavor. Lower levels can be maintained under warmer, higher light conditions to prevent excessive plant stress and facilitate water uptake under high evaporative demand.

Sugar levels

Sugar levels in hydroponic strawberry fruit have been shown to be increased by either deficit irrigation, salinity or high EC levels, all of which result in slight moisture stress in the root zone. In a study carried out in the UK, it was found that raising salinity level (sodium chloride) in the nutrient solution of rockwool-grown greenhouse strawberries altered fruit composition by enhancing sugar and acidity content mainly through a reduction in the fruit moisture content (Awang et al, 1993). However, while the increase in sugar levels were generally preferred by consumers, there was a loss in yield due to the salinity treatments that ranged from 2.5 - 8.5 mScm-1.

A Japanese study found that reduced irrigation of rockwool-grown greenhouse strawberries resulted in the EC in the root zone increasing to over 10 mS cm-1. This significantly increased the fruit sugar levels, resulting in higher flavored fruit. At the same time, however, fruit fresh weight was reduced even though total yield was slightly increased. A similar study carried out in Australia found that, although fruit yield declined with increases in nutrient EC from 2.0 to 4.0, sweeter fruit could be produced when the EC was increased from 2.0 to 3.0 or decreased from 3.0 to 2.0 at the early fruit set stage (Sarooshi and Cresswell, 1994). Finding the correct EC level to maintain high sugar levels in the fruit without compromising too much in the way of yield is something all growers need to evaluate for their particular growing system and environmental conditions.

Foliar sprays for strawberries

Strawberries are one crop that seem to benefit from foliar applications of certain nutrients. Studies have found that foliar application of trace elements, including iron, are beneficial to early plant growth and establishment of chilled runners into soilless production systems. Further, foliar fertilization increased berry yields and brix levels during early and mid season harvests, possibly due to improved rates of establishment and a larger leaf area.

Since young strawberry plants established from runners need to divert energy into the production of a new root system as well as foliage, followed closely by flowers and fruit, the plant appears to benefit from foliar mineral application particularly while the root system is still under formation and small in size.

Flavor enhancement in other crops

Capsicum – chilies and peppers

Hot chili peppers are a passion for many hydroponic growers, some of whom aim to produce the hottest, most explosive chilies imaginable. Commercial producers need to grow fruit that have a uniform and attractive appearance as well as the characteristic heat and flavor.

The main influence on chili fruit heat is genetics – within the capsicum species, fruit range from virtually no heat or pungency as with the large sweet bell peppers, to super hot, as with the habanero and other types.

The heat producing or burning compound contained in chili peppers is *capsaicin*, which was first isolated from plant tissue in 1877. The three main capsaicinoids detected in most chili fruit are capsaicin, dihydrocapsaicin and nordihydrocapsaicin. During recent years there has been the identification of other pungent compounds in capsicum fruit.

Capsaicin is an extremely concentrated and powerful compound and even back in 1910 it was reported that “a drop of a solution containing one part in 100,000 of capsaicin cause a persistent burning on the tongue. A drop of a solution of one part to a million imparts ‘perceptible warmth.’”

Capsaicin has no flavor or odor, the ability to sense it depends entirely on the physiological action of the compound (i.e burning) on the tongue. Most of the capsaicin concentration (90 percent) is reported to be found within the placental partition (cross wall) of the fruit, little is found in the seed or outer wall. The glands that manufacture the capsaicin are found at the juncture of the pod wall, but the amount of this compound present varies considerably among cultivars and even within the fruit of a single cultivar.

The pungency of the fruit of any chili plant is influenced greatly by environmental conditions with the concentrations of capsaicin increasing with plant stress factors such as lack of water and high temperatures. Capsaicin concentrations also increase through the development of the fruit and are always highest at maturity.

Underlying the heat of peppers are also some, rather delicate flavors that mostly arise from several aromatic compounds that make up the distinctive flavor of capsicum fruit. It is the outer fruit wall where most of the flavor compounds are located and these seem to be associated with the color or pigment levels in the fruit. There are many different compounds that impart distinctive flavor profiles in the many species of chili fruit. Jalapeno flavor is attributed to the compound 2-isobutyl-3-methoxy-pyrazine, for example, and this is distributed unevenly throughout the pepper pod.

With the large bell peppers, which have no pungency or heat, sweetness and texture become of the greatest importance in terms of flavor quality. Bell peppers, while not as high in sweetness as melons or tomatoes, are expected to have a pleasant, mild flavor, a lack of acidity and moderate brix levels, giving a distinctive but balanced taste that is combined with a crisp texture. Sweetness can be influenced slightly in bell peppers with careful use of slightly raised EC, however this tends to also reduce the size, shelf life and firmness of the fruit that is not



Other members of the pepper family can have considerable heat compounds in the fruit, as well as other background flavors which depend on the type of chili grown.

desirable.

The hydroponic production of sweet bell peppers and chili peppers is similar; however there are techniques that can be used to boost the pungency and flavor of the hot types that are best not used for growing a succulent, mild, bell pepper. Chili pepper fruit with their pungent compounds respond well to the application of controlled stress. Any factor that stresses the plant increases the concentration of the heat producing compounds in the fruit and at the same time reduces fresh weight or water content. This is great for those who are aiming to grow the hottest chili possible, but should be used with caution, as many chili cultivars are already genetically inclined to be scorching and intensifying these may not always be required.

Some varieties of chili are also grown not just for heat but for distinctive flavor profiles, which application of plant stress or high solution EC can certainly enhance. Plant stress can be applied in a number of ways – in the field this often occurs naturally as high summer light and naturally low soil water potential, combined with drying winds and other factors, force the plant into stressful conditions. In a hydroponic system we have more control over stress application for flavor improvement and can use careful control of the nutrient solution strength, deficit irrigation and temperature

control.

Increasing the EC in the nutrient solution is one of the best ways of inducing moderate stress on a tomato or chili plant to boost flavor. With chilies, the EC can actually be raised quite high without the problems that may develop in tomatoes, such as blossom end rot, although fruit size and fresh weight will be reduced. EC levels as high as 8.0 mScm⁻¹ have been applied to chilies to boost pungency levels with good result. However different chili cultivars will respond differently to increases in EC and growers should determine for themselves which EC level gives the biggest “kick” in the fruit.

When using a higher EC to favorably increase the pungency of chilies, it is best to do this by increasing only the macro nutrients in the solution (N, P, K, S and Ca) and maintain the trace elements (Fe, Mn, Zn, B, Cu and Mo) at normal EC strength levels.

Other factors also affect the level and development of capsaicin in chili fruit. Studies have found that concentrations of capsaicinoids are highest in fruits grown in full sun and in fruits that developed at night temperatures of 20 to 25 degrees C (68 to 77 F), rather than when fruit developed at lower night temperatures (15 C, 59 F). It has also been found that enrichment with carbon dioxide in chili greenhouses to levels of 1,000 ppm results in higher levels of capsaicinoids in the fruit than those that developed under ambient CO₂ levels.

So hydroponic growers who are able to both increase EC, keep night temperatures up and enrich with CO₂ have the potential to significantly improve the pungency of chili fruit.

Harvest timing also has an effect on the pungency of chili fruit. The heat producing compounds in chilies increase with maturity, reaching a maximum approximately 48 days

after fruit set. So while chili fruit can be harvested at the mature green stage and ripened off the plant, harvesting at full coloration will give the greatest degree of heat and flavor.

The Alliums – onions, garlic, shallots, chives and garlic chives

The Alliums, or onion family, are not a widely grown commercial hydroponic crop, although the herb members – chives and garlic chives – are a common hydroponic herb, one whose flavor can be manipulated via the composition of the nutrient solution.

Bulb onions have a strong pungent flavor and aroma originating from the presence of a range of organosulphur compounds. Onions accumulate large quantities of sulphur (S), and bulb concentrations of S have been reported to be in excess of one percent on a dry weight basis. Much of the sulphur taken up by onions is partitioned into organosulphur compounds as part of the flavor biosynthetic pathway (Coolong and Randle, 2003).

Onion pungency is known to increase in response to increased S fertility, but in addition to this, the form of nitrogen in hydroponic solutions is also shown to affect onion flavor. Hydroponic onion trials have shown that sulphate and nitrogen availability in the nutrient solution interacted to influence onion flavor compounds and can thus be used to manipulate onion compositional quality.

Certain flavor compounds in onions have been shown to increase linearly, with increasing N levels in hydroponic trials from 20 – 140 mg/l nitrogen. Garlic also responds in a similar way to increasing S and N concentrations in the nutrient solution when grown hydroponically.

Alliin is the specific flavor and quality trait related to the health value of garlic (Huchette et

al 2007,) which has been shown to increase with higher levels of S and N in many commercial garlic cultivars. Such manipulation of N and S in hydroponic nutrient solutions could not only produce higher flavored and more pungent garlic but also bulbs with a greater health value and thus a marketing advantage for growers.

Herbs – woody and succulent

Flavor quality of fresh herbs is an area of intense interest, as these crops are grown specifically for their flavor compounds or aromatics. However within the herb category there are plant species that range from soft succulent annuals to long-lived woody or herbaceous perennials, cool season to hot dry climate species and a wide range of essential oil compounds and concentrations.

Some very pungent, condiment hydroponic herbs such as Wasabi or horse radish contain mixtures of volatile compounds such as isothiocyanates, which give them their distinctive flavor and heat – these may respond to certain types of nutrition such as increased S in the nutrient solution, although there is very little information on this.

Other herbs such as basil have been more widely studied and the total amount of essential oil is known to significantly increase with light levels. The main flavor compounds in basil leaves are 1,8 cineol, linalool and eugenol, all of which respond to higher light by increasing the flavor intensity of the foliage. Some studies have also shown that the method of production of basil can influence the flavor or essential oil profile. One such study found that taste test panelists could discern the differences between organically and conventionally grown greenhouse basil, yet no preferences were shown.

Basil is an aromatic herb with a high percentage of essential oil in the foliage. This oil contained within the leaf tissue is also prone to oxidation and its pungency is easily lost. If the herb is grown in conditions that are too cool or the foliage is damaged there will be a loss in flavor and aroma. While basil oil content can be increased with moderate plant stress, high light and increased EC, this is usually not advisable for hydroponic crops grown to be consumed fresh as it tends to reduce leaf size and quality and it is possible for basil to become overly strong.

Basil destined for processing or drying, however, can benefit from being grown hard to increase the leaf fresh weight but increase the essential oil content.

Soft, cool season herbs such as parsley and mint should be grown differently than the more woody aromatic herbs such as rosemary, oregano and thyme, for maximum flavor and quality. Parsley can become overly strong, with bitter and unpleasant overtones in flavor, if grown with high light, temperatures and EC. Both mint and parsley can also develop tough and stringy foliage and stems that reduce their



Brassicaceae such as this cabbage owe their characteristic flavor to sulphur containing compounds called glucosinolates.



Some pungent herbs such as this Wasabi contain mixtures of volatile compounds such as isothiocyanates, which give them their distinctive flavor and heat.

eating quality, even though flavor may be more intense.

Lower EC values, summer shading and moderate temperatures produce the best flavor quality in these types of herbs.

The perennial herbs – many of which are referred to as the ‘Mediterranean herbs’ – have originated in hot, dry climates. These include thyme, oregano and rosemary and they respond well to being grown hard with a certain degree of stress. Under conditions of high light, reduced moisture, high EC, and warm temperatures these types of herbs respond by concentrating the levels of essential oils and aromatic compounds in the foliage.

Growth in winter under low light and temperatures can often be reduced. However weak, soft foliage also tends to have significantly reduced flavor compounds that can be many times less than those of a plant grown under full summer conditions. Hydroponic growers can adjust for this somewhat by increasing EC levels in these herbs at times of the year when flavor would otherwise not be as good as it should be. EC levels in many of these hardy woody herbs can be raised quite high and this has the added advantage of keeping growth compact as well as improving the essential oil content.

Winter nutrient solutions for these woody herbs are best manipulated to increase the level of potassium relative to nitrogen and include some extra magnesium, similar to what is applied to winter tomato crops under low light to maintain flavor quality. Supplementary lighting can also be used with winter-grown hydroponic herbs to intensify essential oil concentration and hence flavor

The Brassicas

The brassica family includes a wide range of hydroponically grown crops, the main com-

mercial ones being watercress, arugula and various Asian greens such as pakchoy, although a range of others including cabbage, cauliflower, broccoli and kale are grown by many hobbyists. The characteristic flavor of many of these brassica crops comes from sulphur containing compounds called glucosinolates that yield break-down products giving the familiar flavor and aroma, from distinctive taste of cabbage to peppery and pungent tastes in watercress and sharp and nutty flavors in arugula.

Much of these distinctive flavor compounds are linked to sulphur, and this element can be manipulated in hydroponic solutions to improve the taste of certain brassica crops.

Studies have found that hydroponic watercress growing in solution culture can develop maximum flavor when sulphur levels are increased above those required for maximum growth. The sulfur requirements for optimal growth rates in water cress were found to be 0.20 – 0.25 meg/l in the nutrient solution, however those for maximum flavor were 0.75 meg/l (Freeman and Mossadeghi 1972).

Zinc has also shown to play a role in the development of certain flavor compounds, most notably gluconasturtiin, in some brassicas and could potentially be used to improve flavor (Coolong et al 2004).

Unwanted flavors

Part of producing a well-flavored hydroponic fruit or vegetable is not only having the right level of certain flavor compounds and aromatic volatiles, but also low levels of unwanted taste components.

Bitterness is the most common flavor problem in hydroponically grown produce, most notably in vegetables such as lettuce, other salad greens and cucumber. Some crops such as endive, chicory or radicchio naturally have bitter compounds that are accepted as part of

the flavor profile, provided they are not too strong or prominent. Lettuce, cucumbers and eggplant however, in modern cultivars, should not contain any trace of bitterness and this trait has largely been bred out of the hybrids grown commercially.

Growers producing older, heirloom types of cucumber and eggplant may certainly experience bitterness in the fruit. The levels of bitter compounds are influenced by the growing conditions. Cool conditions, a long slow growth period, inadequate nutrition, weak plants, and over maturity all increase the level of bitter compounds in fruit.

In lettuce, bitterness is often caused by slow growth and by bolting, or the production of the flower stalk that corresponds with rapidly increasing levels of bitter compounds in the foliage. The same is true for many of the salad greens and these should be harvested before flowering occurs.

In part 3 of this series, details of how to run different types of taste or consumer panels will be covered along with some basic analytical flavor indicator tests that hydroponic growers can carry out on site. 🍷

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