Nutritional and Health Benefits of Fresh Vegetables – Past, Present and Future:

A Literature Review

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Executive Summary

This study outlines the importance of eating fresh, antioxidant-rich vegetables when possible. This is a review of relevant literature into production practices that focus on the importance of nutraceutical content in fresh vegetables. The end goal is to be able to give growers information on increasing the nutraceutical content of their vegetable crop.

The vegetables discussed in this paper are sweet corn (*Zea mays*), onion (*Allium cepa*), tomato (*Lycopersicum esculentum*), kale (*Brassica* family), broccoli (*Brassica* family), garlic (*Allium sativum*), carrot (*Daucus carota*) and lettuce (*Latuca sativa*). Some vegetables, such as the tomato and onion, have an abundant amount of literature on them and have been the subject of numerous studies worldwide. Other crops, like sweet corn and spinach, have very little information on both agronomic practices and their nutraceutical benefits. There is indeed a need for more study in these areas. While there is available literature on the health benefits of garlic, work on identifying the optimal agronomic practices to assist the producer in producing a crop high in levels of antioxidants is limited.

The consumption of fresh vegetables gives the consumer a variety of compounds that have a positive influence on human health. The phytochemicals found in fresh vegetables and fruit have anti-flammatory, enzyme inhibiting and bioactive features capable of combating the activities of oxidants. In tomatoes, the highest levels of lycopene were found in cherry tomato types. Consumption of lycopene by human beings has been said to lower the incidences of prostate, lung and digestive tract cancers. As for supplements, numerous studies have pointed out that they may not be as effective as whole foods. The way in which the vegetable is consumed influences the level of carotenoids available to the consumer. Some studies have revealed that cooked carrots have lower carotenoid levels, but because the human body is unable to fully break down the cellular nature of the carrot, the cooked carrot may have more carotenoid to offer the consumer. The best way to take full advantage of broccoli's high levels of vitamin A and B is to eat it raw.

Various agronomic factors have a bearing on the expression of phytonutrients including the soil type, temperature, water supply, type of mulching, nutrients supply and exposure to pests and diseases. The flavonoids in onions have been shown to have anti-carcinogenic, antithrombotic, antiplatelet, antiasthmatic and antibiotic qualities. However, the onion grower must exercise caution; an oversupply of water may lead to the reduced expression of flavonoids. One study revealed that field structure may influence the flavonoid level, stating that the carrot was able to amass more glucose and

fructose when grown in narrow ridges and flat land. It was interesting to note that one study revealed that there was little or no difference on the (carrot) carotene levels between a compost and mineral fertilizer. However for tomatoes, when chicken manure and clover was used instead of the mineral fertilizer the total phenolic content of the crop was raised by as much as 17.6% and 29% respectively. Field grown lettuce was found to contain more protein than greenhouse grown lettuce.

Temperature levels are an important consideration for the grower. For tomatoes, temperatures below 12ºC were found to interfere with the proper biosynthesis of lycopene while high temperatures above 32ºC bring lycopene biosynthesis to a stop. A tomato plant's exposure to direct sunlight was proven to lead to increased levels of vitamin C. Cool season temperature crops like spinach, cabbage, and broccoli, however, produce higher levels of vitamin B at lower temperatures. Carotenoid levels in kale where proven to be higher when grown in the summer than in the winter.

To maximize nutritional benefits in some vegetables like the onion and the tomato, it is best to harvest at peak maturity. For kale, one study indicated that the concentration levels of lutein, β-carotene, chlorophyll and vitamin B reached their highest levels in the leaves between the first and third week. After harvest the vegetables have been separated from their source of nutrients and begin to deteriorate as they start using their own resources. In broccoli, freezing has been proven to be a viable option to prevent quality deterioration.

Factors ranging from vegetable cultivar, soil type, season and time of harvest have a significant impact on the quality of vegetables put into storage. After harvest, carrots suffer loss in sweetness and carotenoid levels. In order to prevent this, one study suggests cool storage at 0ºC for carrots. It was also revealed that while tomatoes stored at room temperature decrease in weight, the concentration of lycopene increases.

The majority of genetically modified crops have been shown to be produced to express enhanced herbicide and pest tolerance more than anything else. Grey literature suggests that in general, organically produced crops have higher levels of nutrients. However, there is an acknowledgement of the fact that plant breeders have targeted size, quantity and yield at the expense of nutritional levels.

Overall, it can be safely stated that there is a need to identify more agronomic practices which serve to increase the levels of phytochemicals in vegetables. Plant breeders must move away from selecting for yield, size and sometimes appearance and to start selecting for enhanced levels of nutraceuticals.

Health-Benefiting Properties of Fruits and Vegetables

The World Health Organization acknowledges that the global intake of vegetables is less than 20-50% of the recommended amount. In developed countries, the significantly low vegetable intake is due to the consumer's preferences for convenience foods and not the scarcity of the vegetables. In the US more processed vegetables are consumed than fresh vegetables (Rickman et al., 2007).

Phytochemicals are strong antioxidants that can modify metabolic activity, aid in the detoxification of carcinogens, and even influence processes in a tumor cell. It is best to consume a variety of fruits and vegetables, rather than limiting oneself to those with highest anti-oxidant capacity (Wargovich, 2000).

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This paper reviews the literature that shows how eating fresh vegetables containing compounds such as phytochemicals can improve human health. It will address the importance of consuming vegetables in their entirety as opposed to reducing them to their constituent compounds. For example, some evidence suggests that high consumption of tomatoes and tomato products has been linked to carcinogenesis reduction, especially regarding prostate cancer. This has been linked to lycopene, which gives tomatoes their red colour (Giovannucci, 2002). However, tomato powder has been shown to reduce prostate carcinogenesis in rats, while lycopene supplements had no effect, even though they are considered the primary active ingredient in tomatoes (Boileau, 2003).

Whole foods are increasingly seen to be more beneficial to human health than isolated components such as those that are found in supplements. Evidence from studies show that increased consumption of carotenoid rich fruits and vegetables outperforms carotenoid dietary supplements in increasing LDL oxidation resistance, lowering DNA damage and inducing higher repair activity in human volunteers (Southon, 2000). Adding vitamins A, C and E dietary supplements to the diet of cancer treatment patients negatively affected the results of their radio and chemotherapies (Siegfried, 2003).

Nutraceuticals

When it comes to gathering secondary chemical products called phytochemicals, plants are experts. Phytochemicals can be taken by humans as food or as supplements and they serve to boost human health. Some plants contain compounds that have anti-inflammatory, enzyme inhibiting and bioactive features that greatly assist in countering the effects of oxidants (Lila, 2006). These phytochemicals and other health benefiting compounds are referred to as nutraceuticals.

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The American Nutraceutical Association, which publishes the JANA Journal, gives a definition of nutraceuticals. Dr. Stephen DeFelice, the chair of the Foundation for Innovation in Medicine coined the term as a combination of nutrition and pharmaceutical in 1989. He stated that,

> **"A nutraceutical is any substance that is a food or a part of a food and provides medical or health benefits, including the prevention and treatment of disease. Such products may range from isolated nutrients, dietary supplements and specific diets to genetically engineered designer foods, herbal products, and processed foods such as cereals, soups and beverages" (ANA, 2007).**

Under American legislation, the term nutraceutical is commonly used in marketing and has no regulatory definition. In Canada, its meaning has been modified by Health Canada which defines nutraceutical as, "a product isolated or purified from foods, and generally sold in medicinal forms not usually associated with food and demonstrated to have a physiological benefit or provide protection against chronic disease" (ANA, 2007).

For the purpose of this paper, nutraceuticals will be considered to be compounds that have been identified in plants as having potential or proven health benefits. A frequently used term for any whole food product containing nutraceuticals is a functional food.

Research shows that it is difficult to determine the protective benefits of individual components without taking the entire composition of a fruit or vegetable into consideration.

Also addressed are studies that suggest it is more beneficial to consume whole foods than to take a supplement of the nutraceutical compound, but not addressed is the development and use of isolated nutraceuticals directly. This paper will focus on the practices that producers could adopt to increase the presence of these identified compounds in their product.

Research shows that it is difficult to determine the protective benefits of individual components without taking the entire composition of a fruit or vegetable into consideration. We will define compounds to be addressed for clarity, but they should be considered in terms of the whole food composition.

The below definitions have been borrowed from the Verified Health Quality web resource, which cites from Linus Pauling from Oregon State University, and the Harvard School of Public Health.

Vitamins

These substances are essential for normal body functions, cell function regulation, growth and development. They must be obtained from the diet, as the body cannot produce them in adequate amounts. Vitamins such as A, B6, C, and K are important to the human body and can be provided by vegetables.

Antioxidants

Antioxidants protect against highly reactive metabolic byproducts (known as free radicals) that cause cell damage in the human body. Vitamins, minerals, and phytochemicals contained in fruits and vegetables each have antioxidant activity. Carotenoids, selenium, Vitamin C and E are all examples of antioxidants. They have been investigated for their specific role in the prevention of cancers, heart disease, eye disease and other human health conditions.

Phytochemicals

Plant chemicals considered to be beneficial to health but are not essential nutrients are called phytochemicals. Carotenoids and flavonoids are examples of compounds that are considered phytochemicals. Associations between disease prevention and individual phytochemicals remain unproven,

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although many studies show the benefit of a diet high in fruits and vegetables. Further research is needed to directly attribute specific health benefits to specific compounds.

Carotenoids

Carotenoids are a class of pigments that are responsible for giving plants a red, yellow or orange colour. Lutein, beta-carotene, lycopene and zeaxanthin are examples of carotenoids that are important to the human diet. For optimal absorption in the human body, they are best consumed cooked with a little fat after they have been chopped or pureed. They are a very important source of vitamin A. They are being investigated for their role in heart disease, some cancers, and eye disease.

Lycopene

Lycopene gives tomatoes and some fruits their red colour. Most lycopene in our diet is obtained from cooked and processed tomato products. Lycopene may play a preventative role in certain cancers and heart disease.

Lutein and Zeaxanthin

Dark green and leafy vegetables are the predominant source of lutein and zeaxanthin in the human diet. They may play a role in preventing oxidative damage to the eye, and may reduce the risk of age related macular degeneration.

Beta-Carotene

Beta-carotene is responsible for the orange and yellow colour often seen in fruits and vegetables. Carrots, squash, sweet potatoes and spinach are good sources of beta-carotene. It has been investigated for its role in the prevention of cardiovascular disease and certain cancers.

Flavonoids

This is a large family of phytochemical compounds produced by plants. High intake of flavonoid rich foods have been shown to reduce the risk of cardiovascular disease, but whether this is due to specific, individual compounds remains to be proven. Anthocyanins are a subclass of flavonoids that give red, blue and purple berries and grapes their colour. They have been associated with improving blood vessel health in humans. Quercetin is one of the most widely distributed flavonoids in the human diet, found in apples, onions and citrus fruits. It may have antioxidant and anti-inflammatory activity, but firm conclusions on its role in heart disease, arthritis and eye disease still need to be shown.

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With the increased focus on nutraceuticals, there is much potential for new and exciting opportunities. Growers will have value added crop options and transitioning to organic crop production will be easier with the availability of information (Greenleaf, 1999).

Agronomic Considerations for Onions, Garlic, Tomatoes, Leafy Greens, Sweet Potato, Carrots and Sweet Corn

Production Practices to Achieve a Higher Phytonutrient Content

Soil type, mulching, irrigation, fertilization and other practices can affect the water and nutrient supply to the plant and therefore also the plant composition and quality. Other environmental factors include altitude, soil pH and salinity, ozone levels, insect injury and plant diseases. Finally, production practices also impact vegetable nutritional quality with differences present between organic and conventional systems, and greenhouse and field grown plants (Goldman, 1999).

Growth Conditions

Sweeney and Marsh (1971) evaluated the effect of herbicides on the provitamin A (carotene) content of carrots, squash, and spinach. Each vegetable was treated with the herbicides suggested by the Crops Protection Branch, Agricultural Research Service, U.S. Department of Agriculture; carrots were treated with CIPC, spinach with CDEC, and squash with amiben or dinoseb. Sampling occurred four or five times for each vegetable. It was found that CIPC-treated carrots were higher in carotene content than were the controls. Carotene content was lower in spinach in the treated samples. No significant differences were found in squash.

The addition of endomycorrhizal fungi to vegetables has been found to increase the uptake of trace elements in certain conditions. The fungi consisted of *Glomus Mosseae, Glomus Calendonium*, E3 spores and mycelium and was tested on a variety of vegetables, including carrots, onions, parsnips, and potatoes, among others. Plants were treated with mycorrhizal inoculum, with mycorrhizal inoculum coupled with additional rock phosphate, NPK fertilizer or wood ash, with only one of the three fertilizers, or were placed into a control group. Plants given only one of the three fertilizers had lower trace element uptake. When the mycorrhizal inoculum was applied, trace element content increased. However, when rock phosphate and NPK fertilizer were used in conjunction with the inoculum, the mycorrhizal colonization and uptake of trace elements (with the exception of phosphorus) was lower. When both wood ash and the inoculum were applied, trace element uptake was also increased (Ward et al., 2001).

Recommendations for maintaining and increasing the carotenoid content and other phytonutrients in vegetables are given by Rodriguez-Amaya (2003). Suggestions include the use of cultivars known to have higher levels of the beneficial compounds and that are appropriate to the local climate and geographical region. When harvested closer to maturity, carotenoid levels are usually highest. It is also noted that all levels of carotenoids were higher in kale grown in an organic system than those grown conventionally (Rodriguez-Amaya, 2003). Others (Lester, 2007; Kadar, 2002; Kadar, 1988) emphasize the same factors but also note that crops grown in a sandy soil tend to accumulate fewer nutrients than those grown in clay soils. Nutrient concentrations also tend to be lower when the crops receive more rainfall or irrigation.

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Organic and Conventional Methods of Production

The effect of organic production methods on the overall nutritive value has been of recent interest. Many studies have investigated the relative nutrient value of organically and conventionally produced food. As a number of literature reviews indicate, (Mitchell et al., 2007; Safefood Consulting, Inc., 2007; Bourn et al., 2002; Worthington, 1999) the results have not been consistent.

One study examined the differences in vitamin C, riboflavin and beta-carotene between five organically and conventionally grown green vegetables including Chinese mustard, Chinese kale, lettuce, spinach and swamp cabbage. Only in the swamp cabbage were the levels of all three nutrients higher in organically produced food than that which was conventionally produced. In general, food produced according to organic standards generally contained higher nutrient levels. However, the authors admit that the environmental and post-harvest factors which may have some influence on the numbers were poorly controlled (Ismail, 2003).

Another study, conducted over a period of two years, evaluated the nutritional value of apples, pears, potatoes, and corn on a fresh weight reading rather than

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the usually used dry weight. The differences between the two methods of production were drastic. The average elemental accumulation in organic food was twice that of conventionally produced food (Smith, 1993).

Benbrook (2005), in the *State of Science Review*, also noted that, in general, organic farming practices were responsible for higher levels of total phenolics. Organic produce had higher elemental concentrations of zinc and magnesium and had higher total phenolic content in the majority of cases when cover crops were used. However, when the soil was tilled, the conventionally produced food tended to have more total phenolics.

Worthington (2001) examined the literature for values of nutrient content in organically and conventionally produced foods. To these values she applied various statistical analyses to determine significant differences and relative trends. In half of all cases, the number of data was too small for analysis to occur; when enough data was available, over half demonstrated increased nutrient value in organically produced food. Harmful nitrates, however, were found in lower rates in organics.

A plant contains higher levels of many phytochemicals and antioxidant compounds if it experienced some stress during its development whether from weed, insect or disease pressures, or from lower rates of fertilization. Organic fruits and vegetables that have been exposed to pests and other environmental insults may be lower in quality and not very appealing to the eye, but have a higher antioxidant capacity and bioactive potency. It has been observed that a plant growing in a stress-unregulated environment is able to accrue more active and medicinally effective secondary compounds. It is therefore necessary to acknowledge that manipulation of the environment has a bearing on the final product of the plant (Lila, 2006).

Synthetic fertilizers do not contain many important nutrients used by plants, and also may alter soil properties which may inhibit phytochemical uptake.

Plants produce these medicinally active compounds to aid in self-protection against diseases, pests and climatic conditions. Accordingly, plants under higher stress produce more of these compounds so that the plant’s vulnerability to their enemies (weeds, insects and drought conditions) is decreased. Garlic plants manufacture allicin compounds to protect against pathogens. These compounds have been found to be beneficial to humans also (Lila, 2006).

Research has challenges in that it seeks to grow and examine plants (their ability to produce phytochemicals) in conditions that are extremely regulated and unnatural.

One long term study at the University of Illinois met this challenge, and displayed evidence of this process through the study of flavonoid content in tomatoes by comparing conventional and organic agriculture practices. They observed that flavonoid levels in tomatoes increased under organic management. These results were attributed to the levels of available nitrogen with over-fertilization (as occurs in conventional systems) leading to a dilution effect, as rapid plant growth is prioritized. Plants with limited N were shown to accumulate more flavonoids than those that are well supplied. They concluded that over-fertilization, especially with synthetic fertilizers in which N is easily accessible to the plant may reduce the health benefits of tomatoes. It is worth noting that a reduction in total nitrogen from compost applications in the organic system did not reduce yields, but did increase flavonoid level (Mitchell et al., 2007).

The study revealed that quercetin content increased by 79% as a result of organic management over the ten year study, and kaempferol levels rose 97 percent. It also showed that the longer a field was managed organically, the greater the nutrient increase would be, with the largest increases coming after seven years of organic management. The team focused on long run impacts of typical and well defined organic and conventional cropping systems, using the same tomato cultivar on same soil, side by side, in university test plots (Mitchell et al., 2007).

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The team considered that organic farms emphasize fertility through soil organic matter accumulation by using cover crops, manures and composts, and that they rely on the diversity of their soil ecosystem for nitrogen availability for plants. The conventional system used fertilizers containing soluble inorganic nitrogen and other nutrients that are more directly available to plants (Mitchell et al., 2007).

It had previously been proposed by Stamp (2003) that increased rates of crop growth and development with greater accumulation of biomass would correlate with a decrease in the allocation of resources towards the production of plant starch, cellulose and non-nitrogen containing secondary metabolites.

The University of Illinois team pointed out that a number of factors can trigger biosynthetic pathways in plants that lead to production of flavonoids. These include nutrient deficiency, pest attack, wounding, pathogens and radiation from sunlight. The research also states that prior to their study, well-quantified changes in tomato nutrient content over years in organic farming systems had not been previously reported. Their study has successfully shown that nutrient source can play a role in determining the level of antioxidants in tomatoes (Mitchell et al., 2007).

On the other hand it is argued that organic food is no healthier than conventional food. Both methods of production produce a healthy and quality food given that nutrients are supplied with correct timing and amounts to promote both yield and quality (Bruulsema, 2002).

A number of sources have indicated that today's produce has less nutritional value than the produce of the past. A brief article by the Organic Consumers Association (2001) provides statistics to this effect. Nutritional values listed in the USDA's food tables of the years 1963, 1975, and a more recent one showed significant decreases in fruit and vegetable nutrient concentrations throughout the years (Organic Consumers Association, 2001). OrganicAuthority.com (Accessed: 2007) also emphasizes the decrease in nutritional value. It is pointed out that as plant breeders have selected for higher and bigger yield varieties, the nutritional value has been compromised. As it grows, produce takes up water and carbohydrates more quickly, but nutritional compounds are accumulated no faster, resulting in a nutritionally poor food (Godal, 2007).

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Halweil (2007), writing for The Organic Center, echoes this point in his discussion of the negative impact that increasing yields have had on the nutrient density of the food supply. Citing many studies to support the difference in nutritional value between plants of the past and those of today, the author suggests several reasons for this decline in nutrient density. First, plant breeders have been selecting for higher yields and have considered lowering nutrient density to be an unimportant trade-off. Increased yield means that plants are able to expend less energy towards other plant functions such as growing root systems, and synthesizing and absorbing vitamins and minerals. Less vegetative tissue and faster growth limits the amount of nutrients available and the length of time for the nutrients to be transferred to the fruit. Pesticides and herbicides inhibit the ability of plants to take up and accumulate phytochemicals. Synthetic fertilizers do not contain many important nutrients used by plants, and also may alter soil properties which may inhibit phytochemical uptake. Over-fertilization results in the plant

Synthetic fertilizers do not contain many important nutrients used by plants, and also may alter soil properties which may inhibit phytochemical uptake.

having to take up more water, which causes a dilution effect. Manure, compost, or other organic matter releases nutrients more slowly, allowing the plant to accumulate phytochemicals more efficiently. Halweil says it is for these reasons that produce from organic plots has a higher nutrient density (Halweil, 2007).

There has now been an abundance of information released for public use through the mainstream media of the influence of organic cropping systems on the health benefiting compounds present in fresh fruits and vegetables. One large scale European Union study which was released this week should be peer reviewed and published within a year.

> "The Integrated Project QualityLowInputFood aims to improve quality, ensure safety and reduce cost along the organic and "low input" food supply chains through research, dissemination and training activities. The project focuses on increasing value to both consumers and producers using a fork to farm approach. The project was initiated on March 1, 2004. It is funded by the European Union with a total budget of 18 million Euros. The research involves thirty-one research institutions, companies and universities throughout Europe and beyond" (Leifert - QLIF, 2007).

The London Times has reported on the press release from the study in October 2007. They state that "already one conclusion is clear: organically produced crops…usually contain more 'beneficial compounds' such as vitamins and antioxidants believed to help combat disease." This study took place over four years, with 27 million dollars of funding. One of the co-ordinators of the project pointed out that the differences were so striking that moving to organic food was the equivalent of eating an extra portion of fruits and vegetables every day. The study showed that organic tomatoes, cabbage, spinach and onions have more minerals, and 20 to 40 percent more antioxidants than conventional fruits and vegetables. This study was conducted on adjacent organic and conventional plots on a 293 hectare farm at Newcastle University, as well as other sites around Europe (Ungoed-Thomas, 2007).

The higher levels of extra antioxidants cited earlier in this article in the study by the University of Illinois again shows that levels can continue to increase the longer that a site is maintained organically (Mitchell et al., 2007).

Harvest Considerations

Vegetables and fruit offer more nutritional benefits when harvested at their peak maturity. It is inevitable for fruits and vegetables to start deteriorating soon after harvest when there is a discontinued connection to their source of nutrients. Plants may start using up their own resources. Fruit and vegetables are over 90% water but the process of respiration after harvest results in moisture loss thus leading to the deterioration in quality and spoilage from other microbial activities (Rickman et al., 2007).

Since harvesting means discontinuing their connection to their source of nutrients, they may start using up their own resources.

In most cases, the shelf life of fruit and vegetables is very limited – generally just a few days. Storing vegetables by freezing and canning methods stop plant respiration, thereby reducing both moisture loss and micro-organism growth. Helping to preserve produce in this way allows for transport to other parts of the world (Rickman et al., 2007).

Processing Considerations

In vegetables, phenolic compound changes during processing, storage and cooking appear to vary and are dependent on the particular vegetable (Rickman et al., 2007).

Differences can be seen between the antioxidant capacity of fresh and frozen vegetables. Canning and pre-freezing processes may lead to the destruction of ascorbic acid (Vitamin C) as it is sensitive to exposure to heat. Heat treatment may also lead to oxidation usually occurring during heat treatments and storage. Since most frozen vegetables require additional cooking prior to consumption, there may be a further loss of nutrients; the extent of the loss is dependent on the type and length of time of cooking. The effects of storage on vegetables are dependent on the cultivar, season, growing location, area and harvest time. When it comes to ascorbic acid, freshly picked vegetables have a higher level. There is an 11 – 66% loss in wet weight for vegetables after they are cooked (Rickman et al., 2007).

Vegetable Specific Literature

Sweet Corn

Corn kernel tissue contains abundant levels of both carotenoids and tocopherols. In fresh market sweet corn the most basic carotenoids were found to be lutein and zeaxanthin. The genotype will influence the levels of lutein and tocopherol with some types of sweet corn offering more nutritional benefits to human beings than the others (Kurilich and Juvik, 1999).

There has been a shift in focus not only to the sweetness and tenderness of sweet corn but also to the nutritional value of corn to the consumer. There is a dearth of information on dosage regarding the prevention and treatment of diseases by the antioxidants lutein and tocopherol in corn. There is an assumption (from study) that **daily** consumption of 250g would provide the required level of beta-carotene to bring protection (Kurilich and Juvik, 1999).

> **There is a dearth of information on dosage regarding the prevention and treatment of diseases by the antioxidants in corn, lutein or tocopherol.**

Health Benefits

The cultivar Jubilee sweet corn (more yellow) is said to have more ά-carotene and carotenoid pigment (J. Agric Food Chem. 1981). In another report by Dewanto et al. (2002), processed sweet corn was said to have more antioxidant capabilities as compared to the non-processed sweet corn.

Growth

A three year experiment was conducted on five replicates of organic and conventional treatments. Sweet corn varieties of L. *var. saccharata* Sunnyvee or Pride and Joy were examined. This study showed that the sweet corn treated conventionally with pesticides, lime and N, P and K out produced the organic treatment of lime, composted manure and insect control applications. No difference in yield, vitamin C or E content in the kernels was found in any year. Only extractable Mg was affected by treatments, with a higher concentration found in organic sweet corn plots (Warman et al., 1998).

Sweet corn is mostly consumed in North America for its taste, yet it is still a good source of vitamins C and E and some essential minerals. In one study (Termeer, 1994), the yield and macronutrient uptake of sweet corn was evaluated by comparing corn fertilized with NPK, and various race track manure based composts. Differences were found between the plants' responses to compost, but the corn treated with NPK yielded more than all composts and also had the greatest uptake of nutrients.

Warman (1995) also investigated the effects of five rates and incorporation of dairy manure composts on yield, soil fertility and nutrient uptake. They found similar results to the earlier study by Termeer (1994); the commercial fertilizer provided the highest yield, even when the compost application was based on 200% of the total N added as fertilizer. The study indicated that these experiments took place on sites of relatively high fertility, as indicated by the yield produced by the zero fertilizer control zone (Warman, 1995).

Sweet corn is mostly consumed in North America for its taste, yet it is still a good source of vitamins C and E and some essential minerals.

Analysis of three years of data in the 1998 study showed that there were very few differences found in plant elements or extractable soil nutrients caused by the two treatments. These results surprised the authors since inorganic fertilizer applications to low fertility soils tend to provide high nutrient uptake, favouring the conventional system of production especially when considering that the sites were only used once. The senior author is now finding that the long term application of composts to the same plots is producing higher soil fertility of some elements, based on equivalent N applications and similar plant growth in comparison to conventionally fertilized vegetables (Warman, 1997). This study does show that seasonal variations in the weather have a greater influence on plant production than the source and amount of compost applied.

A study by Asami et al. (2003), found that corn grown using organic and sustainable production practices contained higher total phenolics, such as flavonols and kaempferol, than corn grown using conventional methods. This may be explained by the fact that plants produce these antimicrobial compounds in response to pathogenic attack, which is less prevalent in conventional agricultural methods where pesticides and herbicides are used. Additionally, frozen samples of fruit contained higher total phenolic levels than air-dried samples (Asami et al., 2003).

Bulb Crops

Garlic

Allicin (thiosulfinate) is a compound found in garlic that contains sulfur and is known for its health benefits to humans. This compound gives garlic its characteristic taste and aroma. It is produced when the physical structure of the bulb is changed through, for example, crushing or cutting. Because allicin is highly unstable (starts decaying in 4 days), it cannot be used as a primary compound. Researchers have countered this by using a method called supercritical fluid extraction (high pressure and low temperature) (Ryback et al., 2004).

Benefits

Ali et al. (2000) stated in their report that there is some inconsistency regarding the effectiveness of garlic against hypertension. Conversely, a study by Mousa and Mousa (2007) stated that when garlic is taken together with vitamin C, it brings down marginally high blood pressure.

Garlic may have the ability to retard the development of oral pathogens and so may be effective against periodontis (Bakri and Douglas, 2005). Garlic is said to have the ability to affect cardiovascular, cancer, hepatic and other microbial infections (Banerjee et al., 2003).

When eaten raw, garlic may be effective against the development of thrombosis (Ali, 1995). In another report (Fleischauer et al., 2000), raw or cooked garlic has been shown to have an effect against stomach and colorectal cancers.

Due to the attention paid to the beneficial antioxidant effects of garlic, it was expected that there would be research into how producers might be able to increase the allicin content of their garlic crop. Very little was found in this regard. Much of the garlic literature focused on the breakdown and composition of the beneficial compounds after processing, but no relevant research into production practices was uncovered.

Onions

At 44 million tones the onion is second in line to tomatoes on the world's most produced vegetable. With more emphasis on disease prevention than cure, there has been an increased interest by scientists on the high content of polyphenolic flavonoids in onions (Mogren et al., 2007). Onion and leek are high in flavonoids (Tarwadi, 2005). Even though the onion has high nutritional value, it is largely consumed for its unique flavour and its ability to improve the flavour of other foods (Randle, 1997). Soil sulfur (S) content however can influence the flavour of a vegetable – e.g. onions grown in soil that has high sulfur content will have a stronger flavour/smell (Brecht et al., 2006).

At 44 million tones the onion is second only to tomatoes as the world's most produced vegetable.

Health Benefits

The carbohydrates found in onions are fructose, glucose and sucrose (Mogren et al., 2007). The antioxidant flavonoids that are present in onions may reduce heart disease. The flavonol called quercetin is found in high levels in onions mostly in the outer dry scales (Williamson et al., 1996).

According to Griffiths et al. (2002), the onion has anti-carcinogenic, antithrombotic, antiplatelet, antiasthmatic and antibiotic abilities. The theosulfinates in onions have anti-microbial properties. Furthermore, the onion is effective against some bacteria like *Bacillus subtilis*, *Salmonella* and *E. coli*.

Growth

The minimum growing temperature for bulbing is between 10ºC and 35ºC (Randle, 1997). Higher levels of sulphate are ideal for good early growth while low sulfur (S) fertilization of soil may lead to retarded growth and bulbing (Randle and Bussard, 1993).

The cultivar genetics determine the uptake of sulfur and its integration inside the onion.

The cultivar genetics determine the uptake of sulfur and its integration inside the onion. Lower temperatures and wetter conditions result in lower sulfur intake, making the onion less pungent (Ketter and Randle, 1998). The sulfur in the soil has an impact on the carbohydrate composition of the onion

(McCallum and Grant, 2001). Too much water increases the chance of bulb rots in maturing onions. For this reason, restricted irrigation improves the storage quality of the onion.

Low nitrogen (N) fertilization may however lead to decreased yields (Mogren et al., 2007). Bumping up levels of N supplied to the onions has little effects on the onions' carbohydrate (quercetin glucosides) content (Mogren et al., 2007). N supply also has no bearing on the flavonol content and does not influence the onion size (Mogren et al., 2007). The grower has to exercise caution because it has been proven that N fertilization at the end of the growing season leads to increased rots in the bulbs (Mogren et al., 2007). Soil sulfur content can influence the flavour of a vegetable such that onions grown in soil with high sulfur content will have a stronger flavour and smell (Brecht et al., 2006).

In order to discover to examine the effects of different levels of CO_2 on the total biomass, phytochemical and folate levels, and the onion's sensory characteristics, nine onion cultivars were grown hydroponically in environmental growth chambers at elevated CO_2 (1200 ppm) and ambient CO_2 (400 ppm) in a study by Thompson et al. (2004). Higher carbon dioxide levels resulted in a higher biomass and increased total flavonols. The cultivars, 'Purplette' and 'Cal 296' had the highest levels of phytochemicals which were measured at more than 4000 mg/kg. These levels increased by 41% when the onions were grown in elevated CO_2. Folate remained unaffected by the level of carbon dioxide. Sensory changes were evident in the cultivar 'Choesty', but not in any others (Thompson et al., 2004).

Mogren (2006) analyzed the effects of cultivar, nitrogen fertilization, lifting time, curing, and the cultivation system on quercetin content in the yellow onion. It was found that global solar radiation towards the end of the bulbing phase resulted in the highest levels of quercetin. Differences between cultivars yielded only inconsistent results. High levels of nitrogen did not change the concentrations of quercetin available, and it was suggested that if applied with the right amount and timing, nitrogen use could be reduced. Onions lifted early had lower concentrations of quercetin than later lifted onions, but these differences disappeared after curing. These results were largely dependent on whether or not the leaves were fallen or erect, with those onions with fallen leaves having higher levels of quercetin. Differences in quercetin levels between organic and inorganically fertilized onions did not reach significance, nor was there any relationship between soil water content and quercetin concentration (Morgren, 2006).

Onions lifted early had lower concentrations of quercetin than later lifted onions, but these differences disappeared after curing.

Having selenium in one's soil should not be a major problem because the onion is tolerant to it, as low levels of selenium are necessary for the onion roots to take in S from the soil (Kopsell and Randle, 1997).

In order to compare elemental accumulation and total flavonol content between the two systems, Thompson et al. (2005) grew spring onions both hydroponically and in the field. Calcium, magnesium, potassium and nitrogen were analyzed weekly or bi-weekly as wet matter and were found to decrease as the onions approached maturity. Total flavonol content however, increased as the season progressed. Similar results were found between the hydroponically grown onions and field onions.

Harvest

Damage due to mechanical loading can cause surface lesions and internal bruising in onions. This is known to result in nutrient losses and decay (Kopsell and Randle, 1997). Removing roots too soon after harvest or breaking off the neck prior to full maturity has been known to limit the bulb storage duration (Kopsell and Randle, 1997). It was also found that onion bulbs left in the field after foliar lodging decreased bulb storage life and quality. Late lifted onions had fewer chances of sprouting than early lifted ones (Mogren et al., 2007).

Removing roots too soon after harvest or breaking off the neck prior to full maturity has been known to limit the bulb storage duration.

Field drying may increase level of fructose and removal of roof and top may also increase glucose, fructose and fructane levels (Kaack et al., 2004).

Storage

Caution must be exercised in avoiding higher mean temperatures during storage as they limit the bulb dormancy (McCallum and Grant, 2001). High respiration, resumption of growth and pathogen are the major three things that cause bulb deterioration (Chope et al., 2006).

Root Crops

Carrots

In Canada, all regions grow carrots because of its ability to adapt to long cool growing seasons. Ontario produces about 44% of the carrots followed by Quebec with 35% (Howatt, 2004). The carrot is a biennial plant and is a member of the Apiaceae (formerly Umbelliferae), the parsley family). Carrots are a popular vegetable world wide.

Health Benefits

In Canada, all regions grow carrots because of its ability to adapt to long, cool growing seasons.

Carrots contain β-carotene, a precursor for vitamin A, which is responsible for their orange colour. Carrots contain the highest amount of beta-carotene (Pearson, 1982). Vitamin A is a potent antioxidant, and it is widely believed to be able to shield the cells from oxidative damage and reducing the risks of chronic diseases (Rao et al., 1999).

There is much discussion on whether the carrot should be consumed raw or cooked to maximize its nutritional value to humans. Unless a carrot is juiced or cooked, the body is not able to break down the cellular nature of the carrot (Hornero-Mendez and Minguez-Mosquera, 2007). While cooking lowers the carotenoid content in carrots, cooked carrots release more carotenoids to the consumer than raw carrots. Rodriguez-Amaya (1996) stated that the bioavailability of beta-carotene was only 5% in raw carrots.

Unless a carrot is juiced or cooked, the body is not able to break down the cellular nature of the carrot.

Growth and Maturation

Although most carrots in Canada are grown in organic soils, it is still common for Ontario carrots to be grown in non-organic soils. The ideal temperature for carrots is between 15º and 20ºC, with the minimum at 5ºC and the maximum at 24ºC. Carrot germination takes place between 6 and 21 days after planting and maturity occurs between 70 and 120 days. “Baby carrots” is a type of carrot that has grown in popularity since the 1990’s. These comprise of pre-washed and pre-packaged ready to eat baby carrots (Howatt, 2004).

Carrots will accumulate more glucose and fructose when grown in narrow ridges and flat land. With carrot tap roots being very sensitive to soil compaction, ridging serves an important function in loosening the soil (Evers et al., 1997; Pietola, 1995).

High temperatures adversely affect carrot production through low yields and slow growth rates. As far as moisture is concerned, carrots need water especially during germination and root enlargement. In most cases irrigation is necessary (Howatt, 2004).

Organically grown carrots…have been found to have higher levels of vitamin B1 and beta-carotene content compared to those fertilized by mineral fertilizers.

Organically grown carrots, in a study by Leclerc, Miller, Joliet and Rocquelin (1991), have been found to have higher levels of vitamin B1 and beta-carotene content compared to those fertilized by mineral fertilizers. Warman and Havard (1997) state that crop cultivar, cropping history, timing of various stages (e.g. fertilization, harvesting), handling and storage have some influence on the final nutrient content.

Packaging and Storage

After harvest, carrots may experience some loss in sweetness and carotenoids. In order to prevent these changes, carrots may have to be stored at 0°C with a relative humidity of about 93-98% (Chen, Peng and Chen, 1995). More research is necessary to see what type of storage and transportation systems the growers may need in order to limit the loss of nutrients or quality degradation in the carrots.

Tomatoes

All over the world, tomatoes occupy a significant position in agriculture and as well human diet. Second to potatoes, tomatoes are the most produced and consumed vegetable (Moreno et al., 2006). Though tomatoes are eaten fresh it has been established that over 80% of tomatoes are eaten in the form of the following by-products (Rao et al., 1999), tomato juice, paste, puree, ketchup, sauce and soups.

Health Benefits

Moreno et al, (2006) state that the tomato is not only the largest source of lycopene in the US, but also ranks third and fourth as the source of vitamin C and vitamin A respectively. Compared to other vegetables it has high levels of lycopene, folate, vitamin C and vitamin E.

The carotenoids found in carrots and tomatoes were studied by a team of Harvard researchers. An analysis of over 124 000 men and women participating in a ten-year study found that those whose diets were high in lycopene and alpha-carotene, had a 20-25% lower risk of lung cancer, especially among current smokers (Willoughby, 2000).

An extensive study published in the spring of 2007 may cast doubt on claims that lycopene has protective benefits against prostate cancer. This study, conducted by the Fred Hutchinson Cancer Research Center in Seattle, found that there was no correlation between the levels of lycopene and prostate cancer in 28 000 men who had no history of prostate cancer when the study began 8 years ago. The researchers found no significant differences in blood levels of lycopene between those later diagnosed with prostate cancer and those who were not (Peters et al., 2007). Peters et al. (2007) stated that tomatoes are still healthy and that their antioxidant properties could still be proven to have health benefits, and that this study was simply an incremental step to discover what role nutrients play in disease.

Genotype Considerations

There are differences in genotypes in terms of the level of lycopene found in a tomato. Tomatoes seem to have had the bulk of research attention when it comes to studying specific varieties for nutraceutical traits, both in the peer-reviewed and grey literature. Research in this area could be done for all other vegetables considered.

The highest levels of lycopene are found in cherry tomato types which are field grown (mean = 91.9 mg kg^{-1}) whereas greenhouse grown cherry tomatoes are lower in lycopene (mean = 56.1 mg kg^{-1}). Greenhouse grown cluster and round tomatoes on the other hand are higher than field grown (respective means= 30 mg kg $^{-1}$ vs 25.2 mg kg $^{-1}$ (Kuti, 2005).

For specific levels for different tomato varieties (plum, cherry and round type, grown in greenhouse or field) see Appendix A.

Dorais et al. (2001) also state that the compound content is determined by cultivar, crop management and stage of fruit ripening at harvest. Orange cultivars have a higher content of carotenoids, vitamin A and volatile compounds, but have ten times less lycopene than red cultivar counterparts. Dumas et al. (2003) also confirmed that the quality of the tomato fruit is influenced by cultivars, environmental factors such as light and temperature, composition of the nutrient solution and crop management styles.

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Growth and Maturation

Martinez-Valvarde et al. (2002) pointed out that agronomic, geographic and seasonal factors have some influence on the levels of lycopene and other phenolic compounds in the tomato. They also highlight the need to increase the understanding of the co-relation between these factors.

Bruulsema et al. (2004) conducted a study in which he added higher levels of phosphorus (45 and 150 pounds P_2O_5/A) to already highly fertile soils to determine its effect on the accumulation of phytochemicals in tomatoes and apples. In both fruits, the effect of added P seemed to be dependent on the weather. Levels of lycopene increased with corresponding increases in the level of phosphorus in tomatoes grown in years of higher stress. In years of lower stress, no response to additional phosphorus was found.

Temperatures below 12°C have been shown to greatly reduce lycopene biosynthesis and high temperatures above 32°C bring it to a halt (Dumas et al., 2003). While lycopene development is also enhanced by light, direct excessive sunlight inhibits it. Lycopene content increases sharply during the ripening period, from the pink stage onwards and may be influenced by plant growth regulators. The ideal temperatures for lycopene and carotene synthesis are 22-25°C and tomatoes grown in the open field had higher lycopene content than tomatoes grown under glass and plastic tunnel (Dumas et al., 2003).

Levels of lycopene increased with corresponding increases in the level of phosphorus in tomatoes grown in years of higher stress.

…greenhouse grown tomatoes have lower vitamin C content than their field grown counterparts.

Light intensity seems to have some influence on vitamin C content. Dumas et al. (2003) observed that ascorbic acid increased by as much as 66% when mature green plants were moved from the shade into the sunshine. The study also points out that greenhouse grown tomatoes have lower vitamin C content than their field grown counterparts. Very little information exists on the impact of seasonal temperature variations on antioxidant activity (Raffo et al., 2006).

Raffo et al. (2006) point out that there is lack of information regarding the influence of the interactions between the environment and agronomic practices on the accumulation of antioxidants during the maturity stage. Over heating or overexposure to sunlight may inhibit lycopene formation (Raffo et al., 2006).

For red and pink large tomatoes, low levels of soil water led to increased lycopene synthesis but had no effect on ß-carotene synthesis (Dumas et al., 2003). The tomato, like most crops, is sensitive to salinity (Foolad, 2004). Conversely, in another study by Dumas et al. (2003), tomato fruits irrigated with increasing levels of controlled salinity showed a rise in the lycopene content. A need for further research to confirm these results is needed.

When chicken manure and grass clover mulch are used as a form of fertilization, the total phenolic and ascorbic acid content of tomatoes is raised by 17.6% and 29% compared to the usage of mineral nutrients. High chloride levels reduce the mean lycopene content by as much as 40%. Where ammonium treatment is used the tomato antioxidant activity is 14% lower compared to the other treatments (Toor, Savage and Anuschka, 2006).

Fruit lycopene content has been known to increase by as much as 30% when the level of nitrogen (N) was increased. Similarly, most N fertilizers enhance carotene accumulation in plants, while increased phosphorus (P) levels also increase the lycopene accumulation in the plants. A deficiency in potassium (K) may adversely affect the rate of carotenoid synthesis. Intensively applying supplementary N may lead to a decrease in vitamin C and this could be due to increased foliage. Again, there is need for more research in this area (Dumas et al., 2003).

When chicken manure and grass clover mulch are used as a form of fertilization, the total phenolic and ascorbic acid content of tomatoes is raised by 17.6% and 29% compared to the usage of mineral nutrients.

The temperature sensitivity of B vitamins is crop specific. Tomatoes, along with other warm season crops, produce more B vitamins at the higher temperatures of 27°C to 30°C than at lower temperatures.

Light intensity does not affect B vitamin accumulation. However, increasing light intensity will increase the concentration of vitamin C as more sugars leading to vitamin C are produced. The amount of vitamin A precursors (carotenoids) and chlorophyll decrease with increasing light intensity. While the temperature increases, beta-carotene (vitamin A) production, which protects chlorophyll from photo-bleaching, is inhibited (Gross, 1991).

Light intensity does not affect B vitamins. However, increasing light intensity will increase the concentration of vitamin C, but will decrease the amount of vitamin A precursors (carotenoids), and chlorophyll.

Harvest Practices for Higher Nutrient Retention

Nutritional quality and flavour can be lost through delays between harvest and consumption or processing. Temperature, relative humidity or concentrations of O_2, $C0_2$ and C_2H_4 outside of optimal ranges will increase the magnitude of the losses (Lee, 2000). For example, a study examining the affect of harvest dates on lycopene content in tomatoes found that lycopene synthesis is inhibited in temperatures exceeding 30^{o}C. But they found that lycopene levels could recover if the fruit was left in the field and harvested after they had not encountered prolonged, excessive temperatures. The researchers harvested tomatoes on three separate dates, and recorded the following levels:

Harvest dates	Average lycopene levels
June 18, 2002	64.9 mg kg^{-1}
June 25, 2002	35.5 mg kg^{-1}
July 9, 2002	68.9 mg kg^{-1}

The harvest on June 25th had the highest preceding temperatures, with an average between 28^{o}C to 32^{o}Cs, with the maximum temperature reaching 40^{o}C to 43^{o}C. This study indicated that strong radiation is harmful for lycopene synthesis (Brandt et al., 2006).

This study also addressed the relationship between colour and lycopene content. Average lycopene levels at different stages of maturity can be recorded according to maturity classifications based on colour. Between each stage of ripeness there is a 2 day gap (Brandt et al., 2006).

Stage

1) Mature green - fruits are mature and light to dark green

- Lycopene= 0.1 mg kg^{-1}

2) Breaker – not more than 10% yellow or pink colour

- Lycopene = 5.5 mg kg^{-1}

3) Turning – 10-30% yellow or pink colour

- Lycopene = 15.3 mg kg^{-1}

4) Pink – 30- 60% pink or red colour

- Lycopene = 25.4 mg kg^{-1}

5) Red – 60-90% red colour

- Lycopene = 39.8 mg kg^{-1}

6) Deep red – more than 90% red colour

- Lycopene = 59.0 mg kg^{-1}

The variety used for measurements was Lemance F1 Round tomato.

As tomatoes ripen, chlorophylls are broken down and carotenes are built up. Already the chlorophyll and carotene have identified reflection spectra. Using these already known spectra, it is possible to measure the intensity of chlorophyll and carotenes. A light imaging system could be placed on a conveyor belt and therefore sort the vegetables and or fruit according to their lycopene or chlorophyll content (Polder et al., 2004). The online spectral imaging system would be able to measure the contents of the following in tomato:

- Lycopene
- B-carotene
- Lutein
- Chlorophyll a
- Chlorophyll b (Polder et al., 2004).

Post Harvesting and Storage

While the tomato weight decreases when stored at room temperature for 7 days, the lycopene content increases compared to that of tomatoes stored at low temperatures. Tomatoes stored at 12°C contain a higher lycopene content compared to those stored at 5°C (Javanmardi and Kubota, 2006). Again there is need for more studies on the influence of storage temperature on the tomato's antioxidant capabilities.

Processing

Processing and cooking can change the nutrient quality of foods. Fat-soluble compounds such as lycopene can be stabilized or enhanced through cooking. Water-soluble vitamins such as vitamin C and folate can be lost at high rates when cooking water is discarded (Lee, 2000).

Regular consumption of lycopene has been linked to decreased incidence of prostate cancer, lung cancer, digestive tract cancer and cardiovascular disease. It has been shown to induce cell-to-cell communication, modulate hormones and immune systems and affect other metabolic pathways (Kuti, 2005).

While the tomato weight decreases when stored at room temperature for 7 days, the lycopene content increases compared to that of tomatoes stored at low temperatures.

The bioavailability of *cis* isomers is higher in processed tomato products than in unprocessed fresh tomatoes. Isomerisation and oxidation are the main causes of lycopene degradation during processing. Isomerisation converts all-*trans* isomers into *cis* isomers, which results in an unstable, energy rich state. In fresh tomato fruit, lycopene occurs in all-*trans* configuration (Kuti, 2005).

Commercial tomato canners and processors use microwave hot break procedures (simultaneous high shear, high temperature of 100°C and evaporation to extract tomato juice). This produces a tomato extract with better colour and consistency and which is more stable due to the enzyme de-activation caused by the procedure (Kuti, 2005).

It has been suggested that cherry tomatoes may be useful varieties for processing. Improvements in nutritional and health benefits of tomatoes could be realized by incorporating cherry tomatoes into breeding programs. All cherry tomato varieties tested, whether they were field grown or greenhouse grown had higher lycopene content than any round or cluster tomato type, regardless of the cultivation system (Kuti, 2005).

This large variation in total lycopene in the study by Kuti et al., 2005, can be attributed to differences in genotype, sun exposure and other environmental factors, cultivation factors such as fertilizer and water used, which taken together can greatly influence carotenoid biosynthesis. Lycopene content is responsible for 80-90% of the total carotenoids in red-ripe tomatoes. The difference in lycopene content of cherry tomatoes grown in the greenhouse and in the field may have been due to excessive greenhouse temperatures, which exceeded 32°C during the study. High temperatures can inhibit lycopene biosynthesis (Kuti, 2005).

Leafy Greens

As a diverse group of vegetables, leafy greens vary considerably in their respective nutritional value with some containing naturally high levels of certain nutraceuticals. For example, broccoli, spinach and green cabbage are high in flavonoids (Tarwadi, 2005) and so, have a high antioxidant capacity. Compared to other vegetables, canned spinach contains the least amount of vitamin B (Rickman et al., 2007).

Spinach, cabbage, broccoli and other cool season crops produce more B vitamins at low rather than high temperatures.

Kale

Health Benefits

Kale is an excellent source of a variety of carotenoids including β-carotene, provitamin A and lutein (de Azevedo and Rodriguez-Amaya, 2005). Nutraceuticals in kale have been shown to reduce the risk of eye diseases and lung cancer (Kopsell et al., 2007).

A study by Kopsell et al. (2003) examined the influence of soil sulfur levels on various nutritional components of kale including elemental accumulation, sulfur compound production, and the accumulation of carotenoid pigments. Sulfur was applied to greenhouse grown kale in the form of a nutrient solution in concentrations of 4, 8, 16, 32, and 64 mg S/L. When soil sulfur levels were low, the sulfur content in the leaves was also low. However, calcium and magnesium, two beneficial elements for our health, were found to be present in higher amounts when soil sulfur was low. Production of sulfur compounds, which give *Brassica* vegetables their characteristic bitter taste, declined with decreasing sulfur levels. No relationship was found between the soil sulfur level and the presence of lutein, β-carotene, chlorophyll *a*, and chlorophyll *b* (Kopsell et al., 2003).

Kale is an excellent source of a variety of carotenoids including β-carotene, provitamin A and lutein.

Genetic variability between twenty two kale and collard cultivars was investigated with respect to their individual rates of elemental accumulation, to help define the relative nutritional value of each cultivar. The elements examined were calcium, magnesium, potassium, iron, and zinc. All types were grown over two years under similar fertilization after which leaf tissues were analyzed for each of the elements in question. Although variability existed between the two years of growth, the relative cultivar ranking remained consistent between the years. No one type of kale or collard ranked among the highest across all elements. In general, the results of this study indicate that the cultivar, 'Redbor F1' had the highest elemental accumulation (Kopsell et al., 2004).

Growth and Maturation

The temperature sensitivity of B vitamins is crop specific. Spinach, cabbage, broccoli and other cool season crops produce more B vitamins at low rather than high temperatures (Gross, 1991).

The concentration levels of lutein, beta-carotene, chlorophyll and vitamin B reach their optimum levels in the leaves between the first and third week (Lefsrud et al., 2007). The study states that baby kale leaves have lower carotenoid accumulation compared to mature leaves. This is confirmed in a study by de Azevedo and Rodriguez-Amaya (2005) where leaves harvested closer to maturity contained more β-carotene, compared to less mature leaves. The study also pointed out that with increased exposure to sunlight and high temperatures, there as a corresponding increase in carotenoid accumulation in the leaves. However, if exposure to sunlight and temperature is too high, photo-degradation may lead to the reduction to the carotenoid concentration. As a result, the leaves record lower levels of carotenoids due to photo-degradation in the summer.

The concentration of lutein, beta-carotene, chlorophyll and vitamin B reach their optimum levels in the leaves between the first and third week.

Nitrogen levels in the soil may alter the plant composition more than any other element (Kopsell et al., 2007). Kale leaf tissues realize more biomass when nitrogen is more available. Carotenoid levels were not affected by changing rates of nitrogen application.

In a 2005 study into the carotenoid composition of kale from conventional farms compared with kale from organic farms, the major carotenoids identified were violaxanthin, neoxanthin, beta-carotene and lutein. In kale grown on conventional farms, the levels of beta-carotene and lutein were significantly higher in the mature leaves; violaxanthin was unusually high in the young leaves and neoxanthin was the same at both stages of maturity. In samples taken from the organic farms, the carotenoid compositions were essentially the same for young and mature leaf stages (de Azevado and Rodriguez-Amaya, 2005).

Carotenoid concentration of minimally processed kale for market was significantly higher in the summer grown kale than kale grown in winter. Beta-carotene concentration however, did not differ with the season. This is due to the fact that exposure to sunlight and high temperatures enhances biosynthesis increasing carotenoid concentrations. In this work, vegetables were grown under polyethylene roofs, which may have protected the plants from excessive sunlight over the summer, thus favouring carotenogenesis over photo-degradation. On the other hand, these roofs may have restricted sunlight access for the plants during the winter months, thereby limiting carotenoid accumulation (de Azevado, 2005).

Harvesting

In order to capture more carotenoid nutrition from the leaves, the producer should aim at harvesting kale as close as possible to maturity (Lefsrud et al., 2007).

Storage

During storage spinach loses between 13 and 46% of its dry weight original thiamine content in temperatures between 4°C and 6°C (Rickman et al., 2007).

In order to capture more carotenoid nutrition from the leaves, the producer should aim at harvesting kale as close as possible to maturity.

Processing

Minimal processing does involve high temperatures as well as shredding and cutting, which can expose the plant to oxidative degradation and rapid biochemical and physiological changes (de Azevado, 2005).

When kale was monitored during storage for 5-7 days at 7°C to 9°C, beta-carotene was reduced by 14%, lutein composition dropped by 27%, violaxanthin decreased by 20% and neoxanthin was lowered 31%. Minimal processing, season and maturity and whether a farm is organic or conventional can have an influence on kale carotenoid composition (de Azevado, 2005).

Broccoli

Broccoli is one of the world's most important vegetables. In Canada it is particularly popular, with 60% of the adult participants in a health survey mentioning broccoli as part of a healthy diet (Howatt, 2004). Broccoli ranks 19th out of 23 vegetables in consumption per world capita (Sun et al., 2007).

Health Benefits

Broccoli has a high antioxidant capacity due to its high concentrations of vitamins A and B. Vitamin A has been known to have one of the greatest antioxidant activities (Sun et al., 2007). The isothicyanate in broccoli is a potentially anticarcinogenic phytochemical (Steck et al., 2007). Eating fresh broccoli is the best way to fully utilize its antioxidant capacity since cooking destroys the enzymes associated with phenolic biosynthesis (Vajello et al., 2003).

Broccoli ranks 19th out of 23 vegetables in consumption per world capita.

Growth and Maturation

In the study by Lisiewska and Kmiecik (2006) (Poland), it was disclosed that N content in the soils has an impact on the size and quality of the broccoli heads. The study also revealed that increasing the N doses from 80 N ha^{-1} to 120 N ha^{-1} raised the level of nitrates, a toxic compound, by 44% in the broccoli heads and may delay the harvest.

Eating fresh broccoli is the best way to fully utilize its antioxidant capacity since cooking destroys the enzymes associated with phenolic biosynthesis.

The growing season influences the accumulation of free glucose, fructose and sucrose levels in the broccoli (Rosa et al., 2001). Lower levels are recorded in the summer/winter season since it is cooler than the spring/summer season.

Storage

Broccoli is a perishable vegetable so proper storage after harvest is crucial. When stored at 0ºC and 95% relative humidity the green colour is maintained (Zhuang et al., 1997). High temperatures may lead to a loss of nutrients in the broccoli (chlorine and protein). In a study by Peter Toivonen (1997), immediate low temperatures for the heads after harvest were recommended to preserve them.

Lettuce

At a value of $315 million dollars a year in trade, lettuce is among the most common leafy vegetables in the USA, (Santos et al., 2004). In Ontario, the most common types of lettuce are head, romaine and red and green lettuce. (Food Safety Risk Assessment Foods of Plant Origin (OMAFRA), 2001). According to this ministry website, lettuce can be grown in both organic and mineral soils. In the case of heavy mineral soils, organic matter can be added in.

Health Benefits

Romaine lettuce is rich in vitamin content and minerals. It contains vitamins A, C, B1, B2, manganese and chromium and is a source of dietary fibre (http://flavoursofindia.tripod.com/lettuce.html). The outer open green leaves are highly recommended for their nutritional value as opposed to the inner white ones. The outer ones are purported to have enjoyed direct exposure to the sun and are therefore high in vitamin and chlorophyll content. In another report by Hohl et al. (2001), it is stated that head lettuce contains glycosides which are largely concentrated on the outer leaves and have antioxidative activity. The high magnesium content in the lettuce is good for the brain, nerves and muscular tissue. Lettuce has an impact on conditions such as insomnia, constipation, pregnancy and lactation, and menstrual disorders.

At a value of $315 million dollars a year in trade, lettuce is among the most common leafy vegetables in the USA.

Growth

Rattler et al. (2005) conducted a study investigating links between type and amount of fertilizer on the accumulation of some harmful and beneficial compounds in lettuce in the spring and summer of 2004 in Germany. For all fertilizers, including fresh farmyard manure, composted farmyard manure, fermented nettle extract, and calcium ammonium nitrate, it was found that higher applications of fertilizer resulted in increased nitrate levels within the plant. However, organically fertilized lettuce contained lower levels of nitrate than non-organically fertilized lettuce. Lutein, β-carotene, and polyphenol levels were lower with the manure fertilizers. However, increased applications of all fertilizers increased lutein levels at both times and β-carotene content in the summer, while composted manure was the only fertilizer that increased β-carotene in the

Lettuce has an impact on conditions such as insomnia, constipation, pregnancy and lactation, and menstrual disorders.

spring. Polyphenols were not increased with more fertilizer, although there was some seasonal variation evident. Finally, the type of fertilizer used had no effect on the amount of bacteria present on the lettuce (Rattler et al., 2005).

Lettuce, like radish, is able to accumulate nitrate from the soil (McKeehen et al., 1996) but this has been said to lead to methemoglobin (inability to carry and circulate oxygen in the blood and other carcinogenic conditions).

Greenhouse lettuce is said to contain more protein than field grown lettuce (McKeehen et al., 1996). When it comes to growing conditions, the crop season has more impact on the lettuce growth than nitrate accumulation (Pavlou et al., 2007).

Phosphorus fertilization is essential if there is a deficiency in phosphorus. This raises an environmental concern since phosphorus is immobile and has potential continuance in the soil (Santos et al., 2004). Organic matter, calcium and magnesium carbonates could be a better alternative. Because of the shallow roots of lettuce, direct application of P to the plant is more effective (Santos et al., 2004).

Greenhouse lettuce is said to contain more protein than field grown lettuce.

Spinach

Bozak (2006) conducted a study to determine if the stressors that are placed upon plants in organic farming result in higher levels of secondary plant metabolites than in conventional production methods. Five variables related to organic and conventional methods were tested on the quercetin, rutin, and quercitrin accumulation in spinach. These include organic soil, synthetic soil, synthetic pesticides, synthetic herbicides, and simulated herbivory. Differences in quercetin concentrations between treatments were not found to reach significance. Rutin and quercitrin levels were immeasurably small. However, the variables are not properly controlled and so the results can be called into question. Additional fertilizers were added to the synthetic soils to prevent nutrient loss but not the organic soils. For this reason, the values of quercetin found for spinach in this study grown in synthetic soils might be artificially low or high (Bozak, 2006).

Biosafety Considerations for GMO Plants Bred to Express Nutraceuticals

Another option for growing plants with higher nutraceutical content includes the use of genetically modified organisms that express a gene that leading to higher concentrations of the desired compounds. Very little literature was uncovered that was directly referring to specific developments in designer plants, but the article outlined below did address some agronomic practices and concerns that should be addressed before a producer should work with these plants.

Plants that are bioengineered to produce nutraceuticals should meet general requirements for genetically modified organisms, and must meet the specific requirements related to the production of the health compound.

Plants that are bioengineered to produce nutraceuticals should meet general requirements for genetically modified organisms, and must meet the specific requirements related to the production of the health compound (Kleter et al., 2001).

Over 90% of transgenic crops which are currently produced worldwide are used to express properties of herbicide and pest tolerance. A new trend is beginning however, with a focus on creating new and improved plant products, instead of a plant that expresses certain agronomic properties. The creation and marketing of specific plant traits can enable producers to produce higher value products for food and feed (Kleter et al., 2001).

Over 90% of transgenic crops which are currently produced worldwide are used to express properties of herbicide and pest tolerance.

Before choosing a crop for genetic modification for nutraceutical expression, the crop's agronomic characteristics, crop protection and the possible removal of plant residues must be considered (Kleter et al., 2007).

Any crop type has the potential to be genetically modified to produce nutraceuticals. Active compounds in functional food crops can involve increased mineral and vitamin levels. Each type of compound, when present in unnatural quantities may require its own safety approach. Invasiveness, pollen dispersal, host insects, outcrossing to adjacent fields and weedy relatives must be considered for safety. During culture and harvest, attention must be given to the safety of the farmers (Kleter et al., 2007).

Conclusion

The end goal of this review was to identify methods known from existing literature information to increase the nutraceutical content in selected vegetables for the grower. For some vegetables like the tomato, carrot and onion the goal was fulfilled. Books and journals researched from all over the world yielded vital information on these vegetables. The information ranged from the health benefits to the agronomic factors that influence the expression of high levels of phytochemicals in the vegetables from the time of growth, harvest and storage. In this review, while most of the scientists seemed to agree on most aspects, their differences in opinion were highlighted.

Spinach, sweet corn and surprisingly garlic had many information gaps. While the health benefits of garlic have been the subject of many studies, very little still exists on the agronomic factors surrounding its production. The research on spinach was the most limited. There is a pressing need for more studies to close these information gaps if the grower is to be provided with a more balanced and consistent information package.

Overall, this research managed to search out from the available European and North American literature the information needed by growers to improve their production practices for a crop that has a superior phytochemical content. From the information gathered, the grower will see how factors like cultivar selection, soil type, terrain, temperature, water quantity and quality, nutrient supply, pest and disease management may be manipulated into producing an ideal product.

Finally, it is imperative for today's plant breeders to start selecting for more "relevant" cultivars. The 21st century consumer appears not to be concerned with just the health benefits of what is on their dinner plate but also with the production practices throughout the growing season. The plant breeders have to factor in these consumer concerns if they are to produce an acceptable and relevant cultivar.

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Appendix A

VARIETY	GREENHOUSE	FIELD
L. esculentum Mill	**lycopene content mg kg {exp-1} fresh weight**	
ROUND TOMATO TYPE		
Golden Jubilee	30.4	23.3
Early Cascade	29.6	20.2
First Lady	37.2	26.5
Better Boy	19.9	14.0
Early Girl	23.9	20.2
Super Steak	8.4	6.2
Early Pick	18.0	12.6
Fantastic	35.1	16.2
Monte Carlo	8.3	6.1
Dona	5.7	4.3
Italian Beefsteak	20.6	**29.6**
Terrific	23.4	11.7
Mar Globe Select	26.1	21.3
Stupice	**45.9**	27.5
Druzba	29.7	23.6
Red Brandywine	37.3	17.6
Miracle Sweet	30.6	**28.8**
Sweet Cluster	34.2	16.2
Big Beef	27.4	13.5
Saint Pierre	**39.6**	27.2
Boxcar Wille	31.5	19.8
Goliath Bush	23.8	20.5
Red Plum	**47.8**	**31.5**
Husky Red	33.6	10.8
Bonnie Best	26.4	16.2
Polish Giant	9.7	5.3
Keepsake	27.2	18.3
Kada	35.1	19.9
Sun Master	27.8	20.1

	Greenhouse	Field
L. esculentum Mill		
CLUSTER TOMATO TYPE		
ALMA-01	**34.4**	**27.4**
GS-111	21.9	15.3
GS-114	33.3	12.6
TMT-510	**30.6**	**23.4**
TMT-521	**35.4**	**21.6**
TMT-555	29.6	14.3
Mean	***30.3***	***25.2***

	Greenhouse	Field
L. esculentum var. cerasiforme		
CHERRY TOMATO TYPE		
Juliet Hybrid	54.7	94.5
Gardener's Delight	48.9	73.8
Sugar Lump	**63.6**	**116.7**
Sun Cherry	57.3	82.5
Mean	***56.1***	***91.9***

Source: Table 2: Total lycopene contents in raw red-ripe samples of 40 tomato varieties grown under greenhouse and field environments (Kuti & Konuru, 2005).