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Blueberries and Human Health: A Review of Current Reseach

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Abstract

Renewed interest in the health functionality of blueberry (i.e., *Vaccinium* species with blue surface color) has led to research in several areas including neuroscience, cardiovascular health, cancer chemoprevention and aging. This article reviews these new directions in blueberry research, with emphasis on *in vivo* studies, and will be of interest to those involved in horticulture, food science, and biomedical sciences. The antioxidant activity and polyphenolic constituents of blueberry, and polyphenolic bioavailability and response to processing, are also summarized.

Although research into the association between fruit and vegetable consumption and a lowered risk of various degenerative diseases is fairly recent, blueberries have long been considered a healthy food. The earliest documents describing the possible human health benefits of blueberry involve *V. myrtillus* L., commonly known as the bilberry, European blueberry, or whortleberry. The medicinal use of bilberry was first recorded in the Middle Ages, and since that time it has been used to treat a variety of health disorders. A comprehensive review outlining the medicinal uses of bilberry up to the late 1980s is provided by Morazzoni and Bombardelli (31). Although North American blueberry species were important as a food source for native populations and early European settlers (21), there is relatively little evidence of medicinal use (9). Much of the bilberry research in the 20th century focuses on possible beneficial effects of bilberry in regards to blood vessels and ophthalmology.

In the mid-1990s, the antioxidant capacity of foods became an area of great interest following epidemiological evidence indicating a negative association between fruit and vegetable consumption and the risk of various degenerative diseases including various cancers (4, 40), cardiovascular disease (19, 32), and age-related macular degeneration (2). This epidemiological evidence for the health protective effect of plant foods was supported by mechanistic evidence (1) showing that fruit and vegetable phytochemical antioxidants may protect biological systems against damage arising from oxidative stress. Surveys on the antioxidant capacity of foods, many of which used the ORAC (oxygen radical absorbance capacity) antioxidant assay (6), indicated that blueberry possessed a high antioxidant capacity when compared to other fruits and vegetables (7, 45).

Renewed interest in the health functionality of blueberry (i.e., *Vaccinium* species with blue surface color) has led to research in several areas including neuroscience, cardiovascular health, cancer chemoprevention, and aging. To explore new opportunities related to the health benefits of blueberry fruit, research is ongoing in the areas of blueberry production and food science. This review outlines these new directions in blueberry research and will be of interest to those involved in horticulture, food science, and biomedical sciences.

Evidence for health benefits of blueberry and other foods

Biomedical evidence relating fruit and vegetable consumption to human health differs in form. Epidemiological studies exam-

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ine large populations of individuals and statistically associate health outcomes with the dietary and lifestyle habits reported by study participants. Typically, these studies are conducted over many decades. While it is relatively easy to establish a correlation between two factors (e.g., the incidence of smoking and respiratory disease) it is much more difficult to elucidate relationships among a multitude of dietary factors and health outcomes. However, an abundance of epidemiological evidence supports the notion that fruit and vegetable intake can reduce the risk of some specific degenerative conditions (2, 4, 19, 32, 40, 41).

Another form of biomedical evidence is obtained from *in vitro* studies. *In vitro* studies simulate physiological processes that often use living cultured cells. Typically an experimental treatment (e.g., oxidative stress) is imposed on the *in vitro* system in the presence and absence of at least one component of interest (e.g., blueberry extract). The response (e.g., oxidative damage to a biomolecule such as low density lipoprotein or DNA) to the factor is measured. While *in vitro* studies can evaluate many treatment conditions, the normal processes of digestion and metabolism are bypassed so that translating the results to the whole living organism is tenuous.

Studies conducted *in vivo* involve the use of laboratory animals, often rodents such as mice and rats. Components (e.g., blueberry extract) are fed to animals for a period of time and the responses of interest are measured in the living animal (e.g., behavior, blood, and urine components) and, in some cases, after euthanasia (e.g., biochemical “markers” in tissues). Measurable changes due to the treatment indicate that the components of interest were digestively absorbed and localized in specific target tissues, in a sufficient concentration and form, to establish a process of interest. For this reason, *in vivo* data provide stronger evidence for the potential effect of a treatment, such as blueberry feeding in humans. In vitro studies can further examine biochemical mechanisms that underlie relationships observed in *in vivo* research. Depending on the interest and feasibility, human clinical trials may be conducted; these studies are essential because human physiology is unique.

Our review on the health effects of blueberry mainly cites evidence obtained from *in vivo* studies along with corroborative results from *in vitro* studies.

Blueberries as antioxidants

The potential significance of antioxidants in human health is based on evidence that the oxidation of cellular molecules (i.e., lipids, proteins, and DNA) leads to a disruption of normal cellular processes. Oxidative reactions in cells occur because oxygen is continuously formed through normal aerobic metabolism. Oxidative damage to biomolecules is widely accepted as being an important element in the etiology of the degenerative conditions that lead to disease and aging (1). Both animals and plants possess extensive biochemical defense and repair mechanisms to cope with chronic exposure to oxygen. Dietary antioxidants, such as the antioxidant phytochemicals found in fruits and vegetables, are purported to reinforce the endogenous antioxidant defense systems present in the body. The major groups of fruit and vegetable antioxidants include Vitamin C, tocopherols, carotenoids, and phenolics. Polyphenolics are the phytochemicals most important to the antioxidant capacity of blueberry fruit.

Despite years of research, the role that blueberry polyphenolics play in the antioxidant defenses of the body remains unclear. In a short-term intervention study, plasma antioxidant capacity was only marginally affected when blueberry (*V. angustifolium* Aiton) was fed to humans (24); blueberry antioxidants would not have contributed significantly to the substantial concentration of antioxidants (e.g., uric acid, glutathione, albumin) already present in the plasma. One reason for this, discussed further in later sections, is that many polyphenolics are poorly absorbed into the plasma and tissues of the body (28). The concentration of ingested phenolics is greatest in the gastrointestinal (GI) tract. Polyphenolics may help to protect GI tissues from dietary pro-oxidant molecules (e.g., amines) (12) but their role exclusively as antioxidants in the plasma and tissues of the body has not been established. Nevertheless, health and food researchers should continue to focus on blueberry polyphenolics because ample evidence indicates that these compounds contribute to the health benefits of blueberry fruit. Some evidence indicates that polyphenolics, including those from blueberry, may act as anti-inflammatory agents in the body to exert a physiological effect (46).

Blueberry effects in neurobiology

An increasing body of *in vivo* and *in vitro* evidence indicates that blueberry can protect the brain under conditions of aging and stress (e.g., simulated neurodegenerative disease, induced inflammation). Research interest in this field of blueberry in neuroscience is expanding rapidly due to the groundbreaking work of James Joseph and colleagues (for review, see reference 16). Most studies are based on rats, whose neurophysiology during aging and disease is well-documented. Because rats have a short lifespan (approximately 36 mo.), age-related degenerative processes can be studied over a relatively short period of time. In most studies by Joseph and colleagues, rats were fed either control (non-supplemented) diets or diets containing 2% w/w blueberry (*V. asheii* 'TifBlue') extract. To determine the effects of the blueberry and other experimental diets on cognitive function, various aspects of learning and memory were assessed with the Morris water maze test. Motor abilities were evaluated, including balance, strength, and endurance. "Communication" among neurons declines during aging. These declines were monitored to examine the sensitivity of interactions between neurotransmitters and their receptors; these interactions are centrally important to motor and cognitive performance. The sensitivity of muscarinic receptors, and the regulation of Ca^{++} buffering capacity in isolated neurons, are among the tests employed by Joseph et al. A decline in the Ca^{++} buffering capacity of neurons, which occurs during aging, leads to greater oxidative stress and a loss of function in neuronal cells.

Joseph et al. (18) found that feeding rats diets supplemented with antioxidants (Vitamin E, spinach, or strawberry extract) for a period of 32 wk delayed the onset of signs of brain aging, including decreased loss of motor and cognitive ability, and in the functional physiology of neurons. A subsequent study by Joseph et al. (17) included a blueberry-supplemented diet group. All supplemented diets were standardized based on their ORAC antioxidant capacity. The study examined aged rats that already had measurable decrements in their cognitive, motor, and neuronal function, and employed the same tests of cognitive and neuronal function. In this study, rats actually recovered some brain functions that had been lost due to aging. Interestingly, rats in the blueberry diet group recovered their motor abilities to a much greater extent than the strawberry and spinach diet groups. Also, the blueberry-fed group performed significantly better in a specific test of neuronal function, Ca^{++} buffering capacity, compared with the other phytochemical-enriched diets groups. In both studies (17, 18), rats that received supplemented diets showed fewer signs of oxidative damage due to aging. However, the authors suggest that antioxidant protection by these dietary phytochemicals is insufficient to account for the magnitude of the benefits observed in the aged antioxidant-supplemented rats. A more recent study (11), designed to assess recovery in age-related loss of cognitive function with an object recognition test, found that blueberry was effective in recovering this ability in aged rats. Furthermore, levels of the oxidative stress-responsive protein, nuclear factor- kappa B (NF-κB), correlated negatively and significantly with the object recognition memory scores (11). Another significant finding was that the rate of new brain cell formation (neurogenesis) was greater in rats that received blueberry-supplemented diets than in rats fed a control diet (8). The beneficial effect of blueberry on neurogenesis may contribute to the recovery of brain functions that are lost as a result of aging.

Shukitt-Hale et al. (39) examined the effects of dietary supplementation with blueberry (*V. asheii* 'Tifblue') and strawberry phytochemicals in rats subjected to "accelerated aging". Rats received whole-body exposure to high-energy ^{56}Fe irradiation that was sufficient to disrupt the dopamine-sensitive neuronal systems that normally decline during aging. Behavior and neurophysiological indices of neuronal function were determined in rats that had received experimental diets before the accelerated aging treatment. Both blueberry and strawberry feeding preserved the capacity for release of the neurotransmitter dopamine compared with the control (non-supplemented diets). Also, both phytochemical-enriched diets protected rats against cognitive deficits due to ^{56}Fe-induced damage, which was apparent by their performance in the Morris water maze. The results of this accelerated aging study suggest that while strawberry supplementation had a greater effect on the hippocampus, which controls spatial memory, blueberry had greater effects in the striatum, which influences relearning (i.e., new target position in the Morris water maze). Blueberries and strawberries were therefore both protective to rats in this model of brain aging but in different ways.

Another study examining the effects of blueberry supplementation (15) used mice that were genetically predisposed to developing symptoms characteristic of Alzheimer's disease. These APP/PS1 transgenic mice have mutations that promote the production of amyloid-β plaques and display behavioral abnormalities that are symptomatically consistent with Alzheimer's disease. Transgenic mice fed blueberries for eight weeks performed similarly to non-transgenic mice in a Y-maze test and performed significantly better than transgenic mice that did not receive blueberries. The blueberry-treated transgenic mice also showed improvements in biochemical markers of neuronal function (hippocampal ERK and striatal and hippocampal protein kinase C).

Inflammation and oxidative stress are generally considered to contribute to cell damage and the physiological processes that are characteristic of many diseases and the aging process. While early interest in the health benefits of blueberry focused on their antioxidant effects, more recent studies are evaluating their anti-inflammation effects. Inflammation is a highly regulated process involving multiple signal transductional mechanisms, mediated through numerous cytokines, that can be controlled to either increase or decrease an inflammatory response. To assess factors that may affect certain types of inflammation, four-month-old rats were supplemented with blueberry prior to having kainic acid administered to the hippocampal region of the brain (26). Kainic acid is an excitotoxin which produces neuronal lesions and an inflammatory response in the brain. Gene expression analysis revealed that blueberry supplementation affected the levels of pro-inflammatory cytokines; NF-κB was normalized to the level observed in non-treated rats, and the levels of interleukin-1β and TNF-α in the hippocampus were reduced (26). Blueberry also increased the expression of the neuroprotective trophic factor, insulin growth factor-1 (IGF-1). These results suggest that blueberry affects signal transduction mechanisms to reduce inflammation and neurotrophic events. These effects were associated with enhanced performance in the Morris water maze test (38). In an *in vitro* study these effects also reduced the activation of microglia (25).

Recent neuroscience research has focused on the benefits of blueberry in neural transplantation. In treating Parkinson's disease, embryonic dopamine neurons are sometimes transplanted to replace tissue losses resulting from the disease. However, poor survival of the transplanted tissue, particularly in older recipients, significantly affects the success of this treatment. The effects of blueberry feeding were examined in a rat model of Parkinson's disease where dopamine neurons in the striatum were selectively damaged. The impact of treatment on these lesions was assessed using a behavioral test. Six wk after the dopamine neurons were damaged, rats were fed either a control or 2% blueberry diet, which they consumed for 6 wk before receiving grafts of embryonic dopamine neurons (30). Eight wk after receiving the neural grafts, rats fed blueberry-containing diets had a 75% greater survival of transplanted dopamine neurons. After 8 wk, histological analysis revealed that grafts were about 75% larger in the blueberry-fed rats and the degree of nerve development originating from the graft was 44% greater than the controls (30).

Another recent study examined the effect of blueberry feeding in another model of neural grafts (47) where tissue from the hippocampus of prenatal rat pups was grafted into the eye of recipient rats. In this case, blueberry-supplemented diets were fed for two weeks prior to receiving the grafts. Success of the grafts was measured by the degree of cell survival, the size of the cells, and the intercellular organization of the new cells arising from the graft. The ability of these chimeric tissues to stabilize and grow after transplantation was substantially better in rats that had been fed blueberries.

The effect of blueberry (*V. angustifolium*) feeding on lifespan was recently evaluated in a simple *in vivo* model using the soil nematode *Caenorhabditis elegans* (48). The physiology of the aging of these organisms, which typically live for about one month, is well-documented. Feeding extract of whole blueberry increased the lifespan of the nematodes by about 28%. Although it was hypothesized that blueberry polyphenolics would affect lifespan via a mechanism involving antioxidant protection, the study determined that blueberry affects the thermoregulatory processes. When isolated blueberry phenolic components were fed individually, low molecular weight proanthocyanidins were found to be associated with the increased lifespan.

Blueberries and cardiovascular protection

During ischemic stroke, blood flow in the brain is temporarily blocked, leading to oxygen deprivation and, generally, brain damage. When the blockage is relieved, further damage arises due to a deluge of oxygen radicals. These two aspects of stroke injury are called hypoxia/reperfusion. In a study by Sweeney et al. (43), rats that had been fed either non-supplemented diets or diets supplemented with blueberry (*V. angustifolium*) for 6 wk received a mild ischemic stroke on one side of the brain by ligation of the left common carotid artery. After a one-week recovery period, specific regions of the hippocampus were examined histologically for evidence of cell death. While rats in the control group suffered 40% neuronal cell death in the hippocampus due to hypoxia/reperfusion injury, blueberry-fed animals suffered only a 17% loss. Interestingly, the effect of blueberry on neuronal survival was restricted to two of three regions of the hippocampus.

Pigs are a good model for cardiovascular research because of their physiological similarity to humans. Pigs are omnivores and adults have similar body weights as humans, they possess similar plasma lipid profiles, and they develop atherosclerotic lesions at similar sites as humans (44). In one study, the mean total cholesterol concentration was reduced in pigs fed doses of blueberry (*V. corymbosum* L. 'Jersey') 1, 2 and 4% supplementation by weight for up to 8 wk. The decline in total cholesterol appeared to depend on blueberry dose up to 2%; total cholesterol was lower by more than 11% at 2% blueberry and unchanged between 2 and 4% blueberry (Kalt et al., in review).

Blueberries, grapes, peanuts, and other fruit contain a group of minor phenolics called stilbenes (35) which are notable for their potent bioactivity (34). Pterostilbene is a type of stilbene found in blueberry. A range of concentrations has been reported, from 0 ng/g DW of fruit in *V. corymbosum* to 520 ng/g DW fruit for one selection of *V. stamineum* (35). Pterostilbene, when fed to hypercholesterolemic hamsters at a rate of about 25 mg/kg body weight per day, was found to reduce plasma cholesterol and lipoproteins (36). However, the significance of this finding for blueberry research must be tempered because of its relatively low concentrations in blueberry fruit.

Blueberries and cancer chemoprevention

Many *in vitro* studies document the anticancer effects of blueberry and other berries (for review, see reference 33). Pterostilbene has been reported to be protective against chemically-induced colon cancer in an *in vivo* rat model when it was administered at levels (approximately 25 mg/kg BW/day) that reduced lipids (36). The occurrence of aberrant crypt foci in the colon was 57% less in rats that received pterostilbene as compared with controls (42). Pterostilbene treatment of cultured human colon cancer cells has also been found to reduce the expression of inducible nitric oxide synthase, an enzyme associated with inflammation and colon cancer cell proliferation (42).

Blueberries and vision

Fairly extensive research has been conducted on the possible benefits of European bilberry for eye health and vision. A significant number of *in vitro* and *in vivo* research studies published from the 1960s to the 1980s report benefits, but later studies report negative results. Canter and Ernst (5) published a review of placebo-controlled trials that studied bilberry anthocyanin consumption and aspects of night vision. Based on the results of methodologically-sound trials, they conclude that there is insufficient evidence to support the notion that anthocyanins benefit human night vision, at least in subjects with normal night vision.

Blueberry polyphenolic bioavailability

The bioavailability of various polyphenolics (e.g., anthocyanins) has been studied (for review, see reference 28) but few reports evaluate their bioavailability after feeding blueberry. Although anthocyanins may be considered the "signature" health functional polyphenolic of blueberries and "blue" berries are so named because of their abundant anthocyanins, the bioavailability of anthocyanins is low. Manach et al. (28) indicate that the plasma concentrations of the soy isoflavones genistein and diadzein are almost 50 times higher than anthocyanins. While blueberries continue to be investigated in neuroscience, cardiovascular fields, and other areas of research, more information is needed on how their anthocyanins are absorbed, metabolized, and distributed in the body. A notable blueberry bioavailability study identified anthocyanins in brain regions of blueberry-fed rats (3). Eight different anthocyanins were identified in the cerebellum, cortex, hippocampus, and striatum proving that blueberry anthocyanins cross the blood-brain barrier and can be localized in areas where blueberry-feeding has been reported to provide protection. Correlational analyses revealed a positive relationship between cognitive performance in blueberry supplemented rats and the total number of anthocyanin compounds found in the cortex.

Blueberry polyphenolics

Blueberry juice contains about 15% dissolved solids, with polyphenolics constituting about 2 to 4% of juice dry weight (Kalt, unpublished). Polyphenolics belonging to the flavonoid group are considered to be most relevant to human health. Blueberry flavonoids include anthocyanins, flavonols, flavanols (catechins), and proanthocyanindins. They also contain relatively low concentrations of stilbene polyphenolics, including pterostilbene (36). The most abundant non-flavonoid blueberry phenolics are the hydroxycinnamic acid esters, especially chlorogenic acid.

Compared with other fruit crops, blueberries are a rich source of various phenolics (Kalt et al., 2007, in press) especially anthocyanins. Anthocyanins likely contribute to the health-promoting bioactivities of blueberries by virtue of their flavonoid structure and high concentration. Anthocyanin concentration increases dramatically as blueberry fruit ripen, which is evident from the dramatic change in fruit color. During ripening, blueberry anthocyanins are formed from pre-existing phenolics; the level of total phenolics remains stable or even declines as anthocyanin concentration increases dramatically (22). Compared with other fruit crops, blueberries possess a large variety of anthocyanins. *V. angustifolium* has perhaps the greatest variety with between 25 to 30 specific anthocyanidin glycosides (29). The European bilberry (*V. myrtillus*) and other members of the *Vaccinium* Section *Myrtillus* contain anthocyanins in both peel and flesh, while commercial North American species (Section *Corymbosum*) only contain anthocyanins in the epidermal and hypodermal cells that make up the peel. Therefore, species belonging to the Section *Myrtillus* contain a substantially higher concentration compared with other commercial blueberry species.

A less abundant type of blueberry flavonoid, which is significant because of its unique structure and bioactivity, is the A-linked proanthocyanidin type. Proanthocyanidins are oligomers and polymers of the flavanols (catechin and epicatechin). Among fruit crops, proanthocyanidins with A-linkages are found only in the genus *Vaccinium* and have been studied extensively in cranberries. Proanthocyanidins with A-linkages can interfere with the binding of specific pathogenic bacteria to tissues, thereby reducing the risk of specific conditions that involve bacterial adhesion (e.g., *E. coli* and urinary tract infection, *Heliobacter pylori*, and stomach ulcers) (14).

A study that compared the flavanol content of 11 rabbiteye (*V. asheii*) and five southern highbush (*V. corymbosum* hybrids) varieties reported up to a 38-fold difference in catechin concentration among phenotypes (9.8 to 387 mg/100 g FW) (37). The rabbiteye variety 'Tifblue', which has been widely used by Joseph and colleagues, contains 107 mg/100 g FW catechin. Among the flavanols and flavonols examined, catechin was the most abundant. Flavanols (catechin and epicatehin) are the flavonoid of interest in green tea and in medicinal plants such as *Gingko biloba*. Although flavonols (e.g., quercitin, kaempferol, myricetin, and their glycosides) have been well-studied, their content in commercial blueberry species is relatively low.

There is an opportunity for the blueberry industry to produce new blueberry varieties with improved polyphenolic profiles through artificial selection. However, this is not a viable opportunity for producers of native stands (e.g., *V. angustifolium, V. myrtillus*). Some breeding programs are likely developing varieties with maximal content of the most bioactive types of flavonoids (e.g., anthocyanins, A-linked proanthocyanidins, flavanols). In a study that examined 17 Southern highbush and one Northern highbush blueberry cultivar over two years, differences among cultivars were much greater than differences between years. The authors conclude that genetics plays a greater role in influencing phenolic composition than growing season, although growing season, and the interaction between growing season and phenotype, also influence phenolic components and antioxidant capacity (13).

Effect of processing on blueberry polyphenolics

Food and health product industries aim to capitalize on evidence supporting the healthfulness of blueberry by developing products that deliver blueberry polyphenolics in various forms. It is often not practical for consumers to consume whole fresh or frozen fruit, especially out of season, and they seek more convenient ways to include blueberry in their diet. Blueberry phenolics can be adversely affected by processing due to their particular profile of phenolics and enzymes. The enzyme polyphenoloxidase (PPO), and the abundant non-flavonoid chlorogenic acid, contribute substantially to the loss of anthocyanins during processing. The degradative polymerization of anthocyanins mediated by PPO and chlorogenic acid has been studied in blueberry by Kader et al. (20). Polyphenoloxidase can readily oxidize chlorogenic acid, yielding a quinone derivative of chlorogenic acid. Quinone derivatives of cholrogenic acid can non-enzymatically oxidize anthocyanin molecules yielding brown chlorogenic-anthocyanin products which are easily seen when blueberry fruit are crushed. All of these reactions lead to the formation of various polymeric forms of anthocyanins, which have an undesirable brown color, limited solubility, and are too large to be absorbed by the gastrointestinal tract of the body. Lee et al. (27) report that inhibition of PPO by heat or sulfur dioxide treatments mitigated the loss of anthocyanins during pilot-scale commercial juice production. Peroxidase enzyme can also be involved in anthocyanin degradation, but this reaction is less significant than the coupled reaction involving PPO and chlorogenic acid. Anthocyanins can also react with aldehyde moieties which leads to their condensation with proanthocyanidins (10). The loss of anthocyanins and color quality, and the development of sediments and hazes in anthocyanin-containing beverages, has long been of concern to food scientists. There is now a renewed interest in mitigating these adverse reactions in order to preserve the bioactivity of the anthocyanin pigments in food and health products.

The Future

Research interest in the potential human health benefits of blueberry continues to increase, particularly in the field of neuroscience. Results reported using various animal models will need to be demonstrated in humans in order to determine their potential benefit for health and disease. As research identifies which structural features of blueberry polyphenolics (especially flavonoids) influence particular bioactivities and bioavailability, new blueberry cultivars will be developed to enhance health functionality. Given sufficient evidence in support of the health benefits of blueberry, it may be possible to label fruit and fruit products accordingly. Regulatory approval for product labeling would have a significant impact on all sectors of the blueberry industry. Notwithstanding the many possible outcomes of blueberry health research and development, clearly blueberry can be recommended as part of a diet rich in a variety of fruit and vegetable phytochemicals.

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Erratum

An author's name was inadvertently omitted from an article in the April 2007 issue of the *Journal of the American Pomological Society*. The correct citation should be as follows:

Greene, D., R. Crassweller, C. Hampson, R. McNew, S. Miller, A. Azarenko, B. Barritt, L. Berkett, S. Brown, J. Clements, W. Cowgill, J. Cline, C. Embree, E. Fallahi, B. Fallahi, E. Garcia, G. Greene, T. Lindstrom, I. Merwin, J. D. Obermiller, D. Rosenberger M. Stasiak, and K.Yoder. 2007. Multidisciplinary evaluation of new apple cultivars: the NE-183 regional project 1999 planting. J. Amer. Pomol. Soc. 61(2):78-83.