INTRODUCTION

Plants are the foundation for a significant part of human medicine and for many of the most widely used drugs designed to prevent, treat, and cure disease. A number of our cultivated crop plants, including many vegetable crops, were domesticated for medicinal purposes prior to their current use as food. Folkloric transmission of plant-based cures represents a fundamental and formidable reservoir of information for most human cultures.

While such remedies are still widely practiced throughout the world, recent scientific developments in the US and other developed countries ushered in a new era of synthetic medicine. During the 20th century, modern medical science introduced monomolecular drugs, many of which have achieved great success and improved public health. However, along with this revolution has come a realization that many traditional plant-based remedies, which generally contain a wide variety of secondary compounds, have been forgotten or obscured.

Beginning with the discovery of the vitamins in the early part of the 20th century, key elements of the health functionality of specific crop plants were elucidated. This information led to a greater understanding of the importance of vegetable crops in the human diet. In the past decade, great strides have been made to improve our understanding of how plant secondary compounds in vegetable crops influence human health.

Since many of our vegetable crops were originally domesticated for the dual purpose of food and medicine, it should not be surprising that we find significant efficacy for this latter use today. And, the current emphasis on food functionality in the marketplace has highlighted the importance of nutritional components in vegetable crops. While a few vegetable crops have been substantially modified in this regard, much of the research in this area has focused on gaining a better understanding of how secondary compounds that are already present may impact human health, or be influenced by the horticultural environment.

PERCEPTIONS OF VEGETABLES IN THE US

Vegetable crops were widely cultivated by native Americans for many centuries prior to the arrival of European settlers in the early 17th century. Vegetables were also a staple of these immigrant Puritans and Pilgrims, who settled the territories that later became the US. These pioneers brought vegetable seeds with them on their voyages, and used them to develop and select vegetable crops suited to life on the Atlantic coast (Goldman et al. 2000). As the population of the US moved westward, vegetable crops remained important components of the diet.

Vegetables appear as basic staples in the diet of pioneer settlers of the western US. In The Homestead, a 1936 painting by the American Regionalist painter John Steuart Curry (Fig. 1) depicting pioneer life on the

Fig. 1. The Homestead, a 1936 painting by the American Regionalist painter John Steuart Curry.

*Sections of this manuscript will appear in Goldman 2002.
western plains, cabbage (*Brassica oleracea*) is cultivated in a kitchen garden, alongside the grains and forages that made up the basis of the diet for the farm family and its livestock (Junker 1998). Despite the many hardships of life on the plains, vegetable cultivation remained an important element of farm life. Vegetables provided diversity in the farm diet and also delivered the promise of cures for a variety of ailments, passed down through the generations in an oral tradition that bound families and cultures together. The kitchen garden has been a mainstay of rural life in America for at least several centuries (Darlington and Moll 1907). Its emphasis on vegetable crops provided the continuity of vegetable cultivation and use between Europe and the US, and also perhaps served as a cultural bridge between European and American life.

As the traditions of vegetable cultivation stayed strong in many parts of the US, people still relied heavily on vegetables and herbs for their healing properties. However, a marked shift away from these practices and toward synthetic medicine took place during the 20th century (Lawson 1998). This trend was particularly acute as modern, synthetic pharmaceuticals were developed through advanced chemical means. These synthetic monomolecular drugs became a focal point for the practice of modern medicine in the US and many other parts of the developed world, leading to tremendous gains in public health. However, with the shift away from plant-based remedies came a loss of knowledge about their uses and efficacy (Lawson 1998). While this knowledge was retained and even strengthened in Europe, it declined in the US to the point that generations born following World War II were far less inclined to turn toward food-based remedies for health concerns, and instead focused on the more widely-available and highly efficacious monomolecular drugs (Lawson 1998). Today, both food-based natural remedies and highly-purified synthetic drugs are used simultaneously to prevent, treat, and cure disease in the US.

In what might appear a throwback to an earlier point in history, we have again become interested in the healing properties of foods. Today, we seek new knowledge about the connection between crops and human health to supplement our understanding of components of these plants identified in previous eras. Furthermore, vegetable crops are among the crop groups with the greatest human health interest, due in large part to their close connection with medicinal properties stemming from domestication, and the large body of folkloric information about medicinal uses spanning virtually all of the world’s human cultures.

In the past decade, the scientific field that combines knowledge about crops and human health has come to be known as “functional foods.” Functional foods carry this name because they are assumed to deliver some physiological benefit beyond nutrition. Thus, carrot (*Daucus carota*) and tomato (*Lycopersicon esculentum*) contain carotenoids, such as α and β-carotene, that deliver antioxidant activity in addition to their nutritional contribution from pro-vitamin A activity. This multi-functionality of the molecule makes these vegetables, and possibly other foods containing carotenoids, as “functional” for health. Many products in today’s marketplace are labeled for health functionality, and the limits of these claims are currently being tested at both the regulatory agency and clinical research levels (Sloan 2000).

Given this broad definition of food functionality, it is certainly possible that all foods are functional! Perhaps we have simply not discovered the functionality of both known and unknown secondary compounds in foods that are commonplace in our diet. Alternatively, many of these secondary compounds possess toxic effects for the purpose of pest control. Toxicity may contribute to functionality, as in the case of eliminating unwanted cells, or it may limit functional abilities, in the case of adding toxins. The science of food functionality is therefore complex and likely includes both positive and negative effects of secondary compounds from a single food source (Goldman 2002). Finally, although it is clear that these “functional” molecules provide additional physiological benefits to the consumer beyond their basic nutritional value, they may represent a very small slice of potentially functional and anti-functional molecules whose actions remain unknown at the present time.

**VEGETABLE CROPS AND MEDICINAL PROPERTIES**

Taking a step back from modern times, it is important to note that many vegetable crops have been used for medicinal purposes in addition to their use as food for thousands of years (Janick 2002). In some cases, it is possible that vegetable crops were domesticated for this reason (Smartt and Simmonds 1995; Rubatzky and Yamaguchi 1997), although information of this kind is not widely available. More likely, many of these veg-
etable crops may have been domesticated with the dual purpose of food and medicine. Herbs testify to the plethora of health-related properties that have been ascribed to vegetable crops throughout the previous centuries of human civilization (Janick 2002), many of which appear to be connected to the first written records about these crops. The famous Codex Ebers, or Ebers Papyrus, dates from approximately 1550 BCE and contains prescriptions for the use of many plants in treating and preventing disease (Block 1992; Janick 2002). Among these were many herbs, grains, vegetables, and ornamental plants of today including poppy, crocus, bean, cucumber, date, garlic, onion, palm, mint, and willow. Prominent among the medicinal plants in Egyptian society were the Alliums, including onion, garlic, and leek.

Vegetable Alliums were prescribed as cardiovascular curatives, including the promotion of blood circulation. In recent years, the cardiovascular implications of vegetable Alliums has been studied in some detail. It appears that extracts from these vegetable plants possess the ability to inhibit platelet aggregation (Block 1992; Briggs et al. 2001). Platelets are disk-shaped cells in the blood that are important for blood clotting, which they accomplish through the formation of a clump of platelets or platelet aggregate. However, they also aggregate in the presence of ruptured arterial plaque. As coronary arteries become filled with plaque, weaken, and begin to rupture, the risk of platelet-mediated heart attack and stroke increase greatly. Thus, inhibitors of platelet aggregation have the potential to reduce this risk, although the clinical implications of onion and garlic consumption from this point of view are not well understood. The cardiovascular benefit of vegetable Allium extracts is but one example of where ancient cultures such as the Egyptians clearly recognized health-functional properties of staple vegetable crops.

Among the puzzles associated with the medicinal properties of garlic is its alleged curative properties for so many diverse types of ailments. Recent findings suggest that the myriad health benefits associated with garlic may be determined by the method of food preparation and processing (Amagase et al. 2001). Unstable thiosulfenates are formed immediately after garlic tissues are cut or chopped, but disappear early during most types of thermal processing. The thiosulfenates are transformed into a wide variety of organosulfur compounds which have the potential to influence biological systems in different ways, including antibacterial, antiviral, anticancer, antiplatelet, and antidiabetic activities (Block 1992; Lawson 1998; Amagase et al. 2001).

Today, as our interest in the relationship between crops and human health grows, it should not be surprising to us to learn that many of our staple vegetable crops were used as medicinals, and perhaps simultaneously as food crops. Interestingly, many of the medicinal properties described in folklore and, to some extent, verified by modern medical research, have their origins as plant protectants (Block 1992). Secondary compounds are often associated with defensive functions in plants, and many of these compounds are of great interest today as phytonutrients. Compounds such as flavonoids, carotenoids, terpenes, glucosinolates, isoflavones, and thiosulfenates may, through their inherent toxicity, confer significant opportunities for pest control (Drewnoski and Gomez-Carneros 2000). However, this astringency and toxicity that may be important for survival is viewed widely by consumers as negative from a culinary point of view. Thus, agricultural practices, including plant breeding and postharvest handling, have attempted to reduce or minimize the astringency of secondary compounds that impact vegetable flavor (Drewnoski and Gomez-Carneros 2000; Goldman 2002). The vegetable crops of today may therefore be modified significantly from their earlier domesticated counterparts with respect to such phytonutrients. For this reason, it is possible that consumers today do not see the close linkage between crops and human health that may have been apparent to human societies living more closely to the period of transition between hunter-gatherers and agriculture.

THE BEGINNINGS OF FOOD FUNCTIONALITY

Prior to the first decade of the 20th century, nutritional scientists represented their field in several simple categories. This often included carbohydrate or starch, protein, fat, and mineral components, but little else, as vitamins had yet to be discovered (Welsh et al. 1992).

The pioneering work of E.V. McCollum, a United States Department of Agriculture (USDA) employee at the University of Wisconsin, laid the groundwork for the discovery of vitamins. McCollum made several important decisions in his research program that allowed for these discoveries to take place. He was among the first to use rats instead of cows for experimental nutrition research, thereby greatly reducing the time and
cost associated with these kinds of experiments and increasing the potential for discovery. It is well known
that the development of model organisms has fueled the growth of many fields of science, and nutritional
science was no exception. The purified diets used in rat studies differed in only a single constituent, thereby
allowing for more precise interpretations of experimental data. This method came to be known as the method
of biological analysis, which allowed for more comprehensive and realistic analysis of food and its compo-
nents in the animal diet than previous methods that focused solely on chemical composition (McCollum 1957).
McCollum and colleagues identified vitamin A, vitamin B, and after his move to Johns Hopkins University,
vitamin D. By the 1920s, the specific cause of a number of nutritional disorders such as pellagra, rickets, and
scurvy were attributed to vitamin deficiencies, and new support was found for the health-functionality of food.

These pioneering studies led to the discovery of many vitamins, opening up a new area of research in
human nutrition. The presence of vitamins in vegetables also cleared the way for more concrete recommenda-
tions on the nutritional impact of these foods. It also provided parents with a solid rationale for encouraging
their children to eat a more balanced diet, in part through cartoon icons such as Popeye the Sailor Man.

By the early 1920s, marketers had already begun to take advantage of this new knowledge about food
and health. In 1922, The Sunsweet Company, a large seller of dried fruit, advertised prunes in Good House-
keeping as containing both iron and vitamins. The advertisement clearly states that this food is associated
“with a healthier today and tomorrow,” in many ways similar to advertisements for such products found in
today’s marketplace. An emphasis on vitamin content also indicates that Sunsweet felt consumers could be
encouraged to purchase their product because the presence of vitamins was highlighted. By 1932, marketers
were capitalizing on the public’s solid foundation of knowledge about vitamin content. An advertisement for
Bond Bread, also found in Good Housekeeping, steers potential customers toward its product because of its
value-added vitamin D enrichment. The ad shows a naked boy on a bicycle, absorbing the rays of the sun on
his skin and asks whether mothers should expect their growing children to obtain their vitamin D this way, or
if simply consuming a vitamin-enriched bread would be easier. At this point, it is clear that the technologies
associated with enhancing the vitamin content of foods were viewed widely as tremendous public health suc-
cesses (McCollum 1957). This era also was associated with improvements in canning and other processing
technologies, bringing canned and other processed vegetables to a wider range of the US public. As knowl-
edge about the vitamin composition of vegetables grew, canned and other processed vegetable products were
marketed for their vitamin composition.

During World War II, when domestic agricultural production was needed for support of our troops over-
sees, fruits and vegetables were in short supply. For this reason, the US government promoted the growing of
Victory Gardens by individual citizens (Burdett 1943). The Victory Garden was an attempt to encourage
individuals to cultivate their own land, be it an urban backyard garden or a rural plot of land, to enhance their
supply of fresh produce during the war. These efforts were extremely successful in many ways, not the least
of which was to re-acquaint urban dwellers with the simple idea of growing their own food. It is likely that
the opportunity to engage in vegetable production increased awareness of vegetable crops and had an impact
on vegetable consumption patterns following the war. A generation of young people growing up in urban
centers during World War II had an opportunity to participate directly in the cultivation of vegetable crops,
which would likely not have taken place were it not for the war and the Victory Garden program. This was
also a period where patriotic slogans were in vogue, including the “Vitamins for Victory” that were found on
packages of processed flour.

Following World War II, the US government made efforts to improve children’s nutrition through the
National School Lunch Program, a federal program that is still in existence today. This program made it
possible for children to obtain meals at school that were planned to emphasize proper nutrition. Thus, educa-
tors, nutritionists, and parents collaborated on a nutrition program aimed at improving the nutritional status of
US children (Goldman 2002). In order to authorize funds for this program, the Agricultural Act of 1935 was
amended by the 78th congress in July, 1943 (Gunderson 2001). This provided funds not in excess of $50
million for maintaining school lunch and milk programs over the period of one year. Cash payments were
made to school lunch sponsors for the purchase of food for the program. The program expanded rapidly in the
first few years, and by 1946 some 6.7 million children were beneficiaries of this legislation (Gunderson 2001).
At this time, the National School Lunch Program was made a permanent program in the form of the National School Lunch Act.

**VITAMINS, VEGETABLES, AND LAND GRANT INSTITUTIONS**

Throughout the 20th century, the land grant institutions played a major role in elucidating the healthful properties associated with vegetable crops. The land grant schools, founded after the Morrill Act of 1862, and the Agricultural Experiment Stations, founded by the Hatch Act of 1887, paved the way for a unique form of interdisciplinary collaboration between agricultural, medical, and nutritional scientists. McCollum and Steenbock’s early work on vitamin discovery took place in an environment where studies of domestic animals were in close physical proximity to biochemical and medical research leading to collaborative efforts in many disciplines.

The campus of the University of Wisconsin in Madison has a long history of such collaborative work that led to vitamin discoveries and applications (Goldman 2002). In 1936, the Dean of the College of Agricultural and Life Sciences, Chris Christiansen, appointed the American regionalist painter John Steuart Curry as Artist in Residence. Curry chose many of the scientific successes during the early part of the 20th century as material for his canvases. In addition to his many works extolling the successes of US agriculture and the relationship between these successes and the land grant institutions, Curry’s famous 1942 mural on an interior wall in the Biochemistry building, *The Social Benefits of Biochemical Research*, depicted the power of these institutions in solving basic agricultural and human nutrition problems through research. In this mural, white-coated scientists are shown leading children with rickets and other nutritional deficiencies from a darkened farmstead into the light of day, improving their health through the kind of research that has characterized the successful land grant institutions. The mural depicts the challenges pioneer farmers faced in raising livestock, as well as the appearance of nutritional disorders in humans that could not be described until the early part of the 20th century. Curry’s work is a powerful testament to the interdisciplinary nature of research at the land grant institutions and the solution of many basic problems in human and animal nutrition. Curry articulated a view that science offers a unique opportunity for healing agricultural woes, and the vitamin discoveries were an ideal framework for this artistic expression.

**VEGETABLES AND HEALTH: PERSPECTIVE FOR THE 21ST CENTURY**

A tremendous diversity of dietary patterns exists among human cultures. At first, it is likely that dietary patterns were based simply on survival, or avoiding starvation. As human societies developed agricultural practices, and both trade, and industrialization became commonplace, dietary patterns may have been also been influenced by economics. And certainly, religion and culture have always played an important role in the development and maintenance of specific dietary patterns. However, it was not until recently that diets have been developed based on economics, convenience, and the awareness of nutritional value (Heber and Bowerman 2001).

The recognition that certain diets are associated with reduced risk of disease has been very well established in the medical literature in both experimental and epidemiological studies during the 20th century. In many of these studies, diets with higher intake of vegetables, fruits, whole grains, and plant-based proteins are clearly favored for disease prevention. This led nutritional scientists to suspect that the effect was due primarily to diets low in fat or high in fiber, or to the action of one particular phytonutrient such as β-carotene (Heber and Bowerman 2001). Some researchers have suggested that this over-simplification lead to the idea that supplementation of fiber or specific phytonutrients to the diet could reproduce the benefits of the healthy diet described above. Most of the studies designed to evaluate this concept revealed that this type of supplementation had little positive effect, and in some cases detrimental effects. In a provocative paper, Heber and Bowerman (2001) suggest that the American diet has shifted away from diets that are based on fruit and vegetable intake and instead toward three grain-based ingredients: refined flour, corn sweeteners, and vegetable oils. They argue that even though vitamin deficiencies have largely been eliminated through food fortification, obesity and associated forms of cancer are reaching epidemic proportions in the US and other developed countries. Thus, the time has arrived to develop an alternative scheme for promoting vegetable consumption to the public.
Herbs, Medicinals, and Aromatics

Their method, called the “Color Code,” provides a mechanism for consumers to get a quick understanding of the phytochemical basis for their fruit and vegetable choices in the marketplace. For example, red fruits, such as tomato, are red because they contain lycopene, a pigment associated with reductions in prostate cancer. Consumers may choose red fruits, including pasta sauce and other tomato products, to obtain this health benefit. Orange fruits and vegetables, such as carrot, pumpkin, orange, melon, and peach, confer antioxidant properties due to their high concentrations of α-carotene and β-carotene and other related carotenoids (Simon 1997). Green vegetables such as broccoli, kale, and related crucifers may confer anti-cancer benefits due to their high concentration of glucosinolates (Talalay and Fahey 2001). Thus, through a method such as the “Color Code,” the consumer may more easily make choices that have the potential to influence health through known phytochemicals. Despite the simplicity to this method, there are many shortcomings of such an approach. Much research remains to be conducted about the bioavailability of these phytochemicals, and large-scale clinical trials with common fruits and vegetables are both expensive and challenging to conduct. Furthermore, as the authors point out, there are no guidelines in place to standardize the concentration of phytochemicals in common fruits and vegetables, and no nutritional labeling practices for these compounds as of yet. In order for this to be accomplished, much more research and standardization will be required.

With regard to bioavailability, it is important to point out that much remains to be learned about the real levels of specific phytochemicals in our vegetables. Calcium content of vegetables is an excellent example of how dietary recommendations may conflict with the biology of nutrient availability. Heaney et al. (1988) examined the absorption of calcium from milk and spinach, both of which are recommended as good sources of this element. Their work demonstrated that the absorption of calcium from milk was approximately 28%, while from spinach it was only 5.1%. The reason for the low absorption of calcium from spinach was the binding of the calcium ion to oxalate, forming calcium oxalate in the spinach leaves. Thus, oxalate may act as an anti-nutritional factor for such vegetable crops and contribute to their reduction in nutritional value. This is why studies of bioavailability are so crucial to understanding the phytoceutical potential value of a vegetable crop.

Previously, it was stated that thermal processing has the potential to reduce the nutritional and medicinal value of organosulfur compounds derived from vegetable Alliums, such as onion and garlic. On the other hand, certain nutritional elements become more bioavailable with cooking and processing, and the carotenoids are an excellent example of this trend. Gartner et al. (1997) demonstrated that lycopene was two to nearly four times more bioavailable from tomato paste than from fresh tomatoes. Further evidence for this finding was provided by Paetau et al. (1998). This being the case, it may be more valuable from a phytoceutical point of view to consume processed tomato products compared to raw, whole foods. This finding is likely due to the dehydration of raw tomato juice and subsequent concentration of secondary compounds such as the carotenoids, thereby increasing their concentration. However, it is also noteworthy that the carotenoid molecule is less damaged by thermal processing than many other phytochemicals. Furthermore, it would appear that thermal processing also has the effect of liberating the carotenoid molecule from its plant cell matrix, thereby increasing its bioavailability.

Given that many vegetable crops were originally domesticated with medicinal purposes in mind, and that they have been used as both food and medicine by cultures worldwide for millennia, it is not surprising that there exists a resurgence in interest in the close linkage between food and health. Coupled with the aging of a large segment of the US population, the focus on quality factors in vegetable crop production, and the growing body of knowledge in nutrition on the action of specific elements of food, we should expect increased expectations of the health functionality of vegetable crops in future years.

REFERENCES
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