Original Article

Phytochemical composition: A paradigm shift for food-health considerations

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Foods derived from plants, such as fruits and vegetables, have been the backbone of human nutrition since the beginning of time. Hunting and fishing supplemented diets with protein-rich foods but nutrition was predominantly based on the availability of plant foods. The importance of various plant foods in the development of some civilizations and economies has been well documented: maize in the Americas, potatoes in parts of Europe after their introduction from the Americas, and wheat in Australia. Plant industries are still the backbone of cultures and economies in almost every corner of the world and production figures support the fact that plant industries are still regarded as the most important source of nutrition. Nutrition parameters found in plant foods vary between crops but there is a consensus that plant foods can supply most, if not all, of the essential components for human nutrition. These components were discovered slowly by trial and error during human history, a classic example was the prevention of scurvy in seafarers. When fresh fruit and vegetables were missing from their diet, they learned that products such as pickled cabbages and citrus, rich in vitamin C, could prevent the manifestation of this dehabilitating dietary disease. As early as the turn of the century scientists learned that diet not only affected nutrition but also had an effect on health and well-being. But it was not until 1933 that a direct relationship between consumption of fruit and vegetables and diseases such as cancer was shown. Fruit and vegetables not only have become the backbone of local agricultural markets but also play a major role in international trade. Competition for local and international markets is driving extensive research and development to produce new cultivars. Until recent times research has concentrated on producing new varieties that store longer, yield better, look better, taste better, suit local climates, display disease and pest resistance and suit processing technologies. A new wave of research is addressing the newly developing interest in heath-based foods. Molecular biologists, biochemists, botanists and medical researchers are linking in with plant breeding programmes to develop new varieties of fruit and vegetables that are tailor-made to produce higher levels of health-related phytochemicals. New phytochemical-enhanced products such as broccoli, tomato, oranges and berries are currently being evaluated for commercial exploitation. The present paper will discuss some of the products that are being produced, the driving forces behind their production, the phytochemicals targeted and the problems that must be addressed if this new approach in human nutrition and health is to be of benefit to consumers.

Key words: novel foods, plant foods, phytochemicals.

Drivers for plant food consumption

Although plant-based foods have been eaten since the existence of mankind,[1] there are many drivers for modern man's consumption of plant foods. Plant foods have an incredible range of tastes and aromas. The smell of a fresh apple or the taste of a ripe tomato have been entrenched in our minds as very distinctive and specific sensations. The diversity of texture found in plant foods is also something that is quite unique. Plant foods may have a crisp, granular or creamy texture. The combination of texture, aroma and taste often leads to a unique sensation in plant food consumption.

Another major driver for plant food consumption is their local availability. Plant foods are found almost everywhere in the world, from temperate areas to harsh climates including arctic tundra and tropical areas. Plant foods are often grown for self-sustenance and self-reliability, which adds to the overall food intake index. Commercial growing of crops has assisted rural economies all over the world. Large-scale commercial production has meant that fresh fruit and vegetables are available at consumer's fingertips at all times of the year. Developments in modified atmosphere and controlled atmosphere storage technology of plant foods has meant that local availability has been extended and that imports from other countries are now possible with a minimum loss of quality. Controlled production environments such as glasshouses have added to off-season availability of some plant foods. For these reasons there is a wide range of plant foods available for the consumer.

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Economic pressure has forced many growers to diversify into new products. Consumer demands change in response to new trends and marketing campaigns by distributors and producers. Plant foods have a large following of private dedicated gardeners that protect individual varieties and cultivars. Contests and shows take place worldwide to exhibit the best cultivars and the best products from these cultivars. Another important driver for plant food consumption is that many plant products have found essential roles in traditional recipes and cuisine. Herbs and spices together with specific fruit and vegetables have been used to develop the many region-specific cuisines around the world. Plant foods are often the only food source readily available to humans. In many parts of the world animal-derived foods are not readily available or religious beliefs prevent their consumption.

Finally, many plant products are consumed because of their real and perceived importance for health and well-being. It is well established that plant foods have been shown to contain important nutritional compounds. Both macronutrients and micronutrients are found in fruit and vegetables. The importance of plant products in the human diet has led to the five-a-day and the seven-a-day campaigns which are driven by the nutritional importance of plant foods in terms of essential vitamins, essential trace elements, sources of energy and fibre. Dieticians recognize that vitamin intake is linked directly to consumption of plant foods. An example of this is the carotenoids, which are precursors to vitamin A. Plants supply the only source of carotenoids to the animal kingdom and more than 80% of the world's vitamin A is supplied by horticultural crops.[2]

Plant breeding and the plant industries

Plant breeding has focused on a number of traits that have been important for commercial gains in industry. Initially traits such as increased size, improved colour and improved yields were the main objectives of plant breeding. In recent times plant breeding has also concentrated on increasing post-harvest storage life, disease resistance, uniform maturation and uniform size for ease of harvest, and environmental traits such as plants that thrive in shorter daylight and plants that thrive with less water or fertilizers. Better varieties for new agricultural areas has been the focus of many breeding programmes.[3] Man has employed conventional breeding techniques to develop a large germ plasm bank that can be used for plant breeding. By utilizing natural and artificial selections methods including mendelian variation, interspecific hybridization and polyploidy, man has been able to manipulate plant breeding with a high degree of accuracy and a high degree of specificity. There are many research institutes around the world specializing in plant breeding. There are many scientists trained in this field and governments support much of this work because they have seen the benefits of new plant varieties and economic growth.[4] There are now multinational companies dedicated to plant breeding. The net result of this continuous growth has led to many thousands of new varieties with just as many variations. The genetic stock for horticultural crops is vast and gene banks are common around the world.

Pressure to re-evaluate plant foods for economic reasons

The advent of molecular biology and biotechnology has meant that there is a new pressure to reconsider plants for economic purposes. New analytical screening and test methods using sophisticated diode array high-pressure liquid chromatography (HPLC) and mass spectrophotometers can now be used to detect and quantify a large number of plant compounds in a short time. Traits that were difficult to detect previously are now relatively easy to detect and trace using molecular biology and DNA probes. Genomes of agriculturally important crops are now becoming quite common in databases and are available for utilization by scientists to screen for metabolites with specific functions.[5] One of these functions is health benefit to humans.

Genes responsible for the production of a range of metabolites can be screened rapidly with DNA based tests. Old genetic stocks and stored varieties of plant-based foods can now be re-evaluated using targeted probes for old and new nutritional parameters. High vitamin-producing varieties can be selected rapidly by using both genetic based screening methods and new high precision detection methods. Trace elements and phytochemicals can be studied using both gene technology and the new generation analytical equipment. These tools will become very important for the new generation of plant breeders where they will shorten the time required to breed plants with desired characteristics by conventional breeding methods. Genetic modification is also a possibility with the creation of transgenic plants that could express compounds inserted by gene technology.[6] One major area of research using these new technologies in conventional breeding and genetic modification has been that of nutritionally important compounds in plant food. Value adding, niche marketing and product differentiation will serve as vehicles for the development of plant foods containing these compounds.[7]

Phytochemicals

New rapid diagnostic and molecular techniques will be particularly important for the rapid identification of phytochemicals. They are biologically active compounds that are found in relatively small amounts in plant food. These compounds have been linked to human health by contributing to protection against degenerative diseases. The classification of phytochemicals can be rather complex but phytochemicals can be classified into three major classes (Table 1).

There are many other phytochemicals that may have an impact on human health. Every food plant contains many hundreds of chemical compounds. The importance of some of these may yet be undiscovered or analytical methods not yet developed to allow quantification. For example more than 200 chemical compounds have been identified in cabbage.[9]

Phytochemicals and human health

The link between fruit and vegetable consumption and protection against cancers of the stomach, oesophagus, lung, oral cavity, pharynx, endometrium, pancreas and colon has been discussed by Steinmez and Potter.[10] Many phytochemicals are thought to be involved in conferring this protection[11] and they may have different modes of action on their protection mechanisms (Table 2).

Phytochemicals have been linked to many other positive health effects in humans and animal studies including coronary heart disease, diabetes, high blood pressure, inflammation, infection, psychotic diseases, ulcers and macular degeneration.

It is becoming evident that many phytochemicals may have multiple actions on human health. For example, flavonoids present in many fruits not only have anticancer properties but have also been shown to have anti-allergic, cardiovascular protection properties, anti-inflammatory properties and antiviral properties.[13–15]

Carotenoids belong to the terpenoid family of phytochemicals and include lycopenes, carotenes and xanthophylls. Carotenoids are precursors to vitamin A and more than 40 different carotenoids have been identified. The antioxidant property of these carotenoids has attracted a lot of interest in cancer research.[16] Aside from this these compounds have also attracted interest in cardiovascular protection,[17] and specific carotenoids have been shown to have specific protection against the prevalent eye disease macular degeneration.[18] Carotenoids have also been shown to increase immune responses in animal studies.

Isothiocyanates present in crucifer vegetables (broccoli and cauliflowers) as glucosinilate precursors have been shown to have phase 2 enzyme inducer activity, and are thus capable of reducing risks of cancer formation.[19] Asparagus contains a number of health-promoting phytochemicals capable of antifungal, antimutagenic, cytotoxic and antiviral activities.[20]

Overview of current research on phytochemicals

Given the newly generated interest in phytochemicals and the potential economic advantages of creating novel products based on elevated levels of health-promoting phytochemicals, there has been an increased stimulus to examine phytochemical content of plant cultivars with the aim of identifying plants with elite levels of phytochemicals. Value adding and niche product development in the plant food industry is being guided by the rapidly developing functional food sector. Functional foods can be tailored to contain specific compounds that are beneficial to human health. Through conventional breeding and using the vast genetic resources available to industry, scientists are producing novel agrifoods containing elevated levels of phytochemicals with the hope that these products can be sold to tailored markets. Recent headlines such as 'Vegetables on prescription'[21] and 'Superbroccoli to fight cancer'[22] suggest that

Table 1. Three major classes of phytochemicals and the phytochemicals in each class

Phytochemical class	Phytochemicals
Terpenoids	Monoterpenoids, iridoids, sesquiterpenoids, sesquiterpene lactones, diterpenoids, tritepernoid saponins, steroid saponins, cardenolides, bufadienolides, phytosterols, cucurbitacins, nortriterpertenoids, triperpenoids, carotenoids, limonoids
Phenolic metabolites	Anthocyanins, anthochlors, benzofurans, chromones, coumarins, flavonoids, flavonones, flavonols, isoflavonoids, lignans, phenols, phenolic acid, phenolic ketones, phenyl-propanoids, quinonoids, stilbenoids, tannins, xanthones
Alkaloids and other nitrogen-containing constituents	Amaryllidacea, betalain, diterpenoid, indole, isoquinoline, lycopodium, monoterpene, sesquiterpene, peptide, pyrrolidine, piperidine, pyrrolizidine, quinoline, quinolizidine, steroidal, tropane compounds,-non-protein amino acids, amines, cyanogenic glycosides, glucosinilates, purines, pyrimines

Adapted from Dillard and German.[8]

Table 2. Modes of action of a range of phytochemicals in protecting humans against cancer

Mode of action	End result
Reducing or blocking activation of carcinogen	Many carcinogens need to be activated through a system of enzymes in the body. Some phytochemicals reduce the activation of these phase 1 enzymes, resulting in reduced or inactivation of carcinogen
Increases activation of phase 2 enzymes	These enzymes can detoxify and eliminate carcinogens
Enhancing DNA repair	Reversing and preventing DNA damage
Controlling oncogene expression	Resulting in reduced expression of mutated genes
Modulating cell signalling	Increasing communication between damaged cells and cancerous cells
Promoting cell differentiation	Reversing undifferentiated cancerous cells back to normally growing cells
Angiogenesis	Reducing the growth of cancer
Enhancing immune surveillance	Increasing the capacity to recognize and eliminate cancerous cells

Modified from Dreosti.[12]

research activity in producing functional agrifoods is becoming well established. Claims that broccoli produced by the natural crossing of two existing varieties contains elevated levels (up to 100-fold more) of sulphoraphane mean that produce containing elevated levels of phytochemicals will be in the marketplace as functional foods in the near future. The public's interest in functional foods is driven by a number of factors including increased disposable income, increased interest in health and well-being, increased interest in slowing old age and related symptoms and the increased cost of health care. Fresh functional foods and functional agrifood products are expected to become part of a rapid food industry expansion in this area. The production of these elevated phytochemical food plants raises a number of questions. First and foremost we need to establish just what is the natural background level in these products. Evidence suggests that different cultivars have different levels of these compounds. Table 3 shows the variation in the amounts of glucosinilate, a phytochemical linked to cancer protection found in brassica vegetable crops.

Recent studies have also found large variations in the concentrations of the glucosinolate glucoraphain in different cultivars of broccoli (*Brassica oleracea* var italica) in Australia.[24] The level ranged from 20.6 μg/g for the Claudia cultivar to 193.9 μg/g for the TB-234 cultivar. The same study has also found large variations of sinigrin and glucoraphin concentration and content during plant development, with highest concentrations of sinigrin being found in seeds and the highest concentrations of glucoraphin found in young plants. It is also becoming clear that growing conditions including soil type and fertilisers affect the levels of some of these compounds.[25] By increasing the level of sulphur fertilizer it was shown that the level of the glucosinilate glucoraphin increased in all plant organs including the broccoli head.[24] Some research is also being devoted to the post-harvest treatment of these novel food products with the aim of retaining the biological activity of the phytochemicals. Controlled atmosphere and modified atmosphere protocols are being evaluated for their efficacy to prolong the biological activity of some of these products in harvested plants.

Table 3. Variation in levels of sinigrin, a glucosinilate compound in brassica vegetables

Crop	Level of sinigrin
Cabbage (mg/kg)	70–410
Brussels sprouts (mg/kg; FW)	110–1560
Cauliflower (mg/kg)	10–630
Turnips (mg/kg)	0–100
Broccoli (μg/kg)	0–16
Kale (μg/kg; FW)	0–287
Mustard greens (μg/kg; FW)	6930–7790
Collards (μg/kg; FW)	625–1973

Modified from Drewnoski and Gomez-Carneros.[23]
FW; fresh weight.

Conclusion

The development of higher phytochemical-containing plant foods will require an element of caution. These foods should be considered as novel foods if they exceed the normal levels of phytochemicals, and normal background levels are largely unknown at this time. The development of such foods should follow a process based on proper scientific data where the benefits to the end user are clearly stated and all risks associated with consumption are carefully evaluated. Nutritional profiles should be linked to cultivars and the new products should be controlled by a regulatory process that takes all these points into account. The risks associated with consumption of these natural phytochemicals should be examined in the light that most of these compounds are part of the normal plant defence system and may be toxic in high doses to humans.[26]

The risks associated with high consumption levels of these novel plants should be evaluated fully, especially because it is feasible that these novel plant foods could be introduced into developing countries where they may be the only source of food over an extended period of time. There is compelling evidence that the benefits of developing plants with high levels of phytochemicals that contribute to health and well-being will be high. However, the expectations far outreach the scientific knowledge to support these expectations at present. Much work is still required to properly evaluate the benefits and risks associated with this approach to plant food development.

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