Chapter 3
Vegetable Crops: Linking Production, Breeding and Marketing

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Abstract Vegetable production has been a major and dynamic activity devised by diverse human cultures to sustain their livelihood for centuries. Vegetables, being several times more productive per unit area than cereals, can play a vital role in facing food security and nutrition challenges in the coming decades. However, the predicted climate change and increased demand on limited land and water resources makes water conservation a key component of vegetable production systems. At the same time, there is an increased global demand for healthy and nutritious vegetables. Dramatic improvements have been achieved through breeding for important abiotic stresses and quality traits in many vegetables. Thus, successful emerging small or large commercial farmers now apply integrated strategies from farm to table, including planting, grafting, irrigation, use of modern cultivars and innovative marketing tools. In this chapter we highlight some technological advances in vegetable production, with emphasis on stand establishment and irrigation management for water-limited areas. We discuss the impact of breeding and genetics on the improvement of abiotic stress tolerance and provide evidences on the use of improved germplasm and cultivars to enhance the quality of vegetables. Finally, we discuss the critical role of marketing and consumer trends for vegetable products.

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Introduction

The next 50 years represent huge challenges for worldwide horticulture. This is due to a fast increase in population rates, rising bio-fuel demands and shrinking land and water resources. Current trends show an increase of 70 million people per year, and by 2050 the global population will rise to 9.5 billion, a 36 % increase (Silva and Ryder 2011). The productivity of major cereals is stagnating in certain regions of the world (Ray et al. 2012) while 868 million people are suffering from undernourishment and 2 billion are affected by micronutrient deficiencies (Anon 2012d). With strong urban and industrial land demands, there are limited possibilities to increase the use of fertile areas under crop production. Thus, farmers will have to adopt precise, resource-efficient and environment-friendly production technologies. To extend new production areas into marginal soils and marginal waters, varieties tolerant to region-specific abiotic and biotic stresses will have to be developed.

World vegetable production recorded 1.04 billion tons in 2010, a 33 % rise since 2000 (Fig. 3.1). About 75 % of the total global vegetable production is taking place in Asia, while China, India and USA are consuming 60 % of world vegetable production (Anon 2012f). Hundreds of diverse vegetable crops provide an efficient and economically viable means to deliver crucial, human-health related phytochemicals, minerals, vitamins, antioxidants, essential amino acids, fatty acids and carbohydrates (Galili et al. 2002) in which other foods are deficient. In spite of the increase in per capita availability of vegetables in the last decade, still 80 % of the low-medium income families consume less than the minimum recommended levels (Hall et al. 2009). Therefore, the future economic growth and increased health awareness are likely to cause an upsurge in global demand for vegetables (Silva and Ryder 2011).

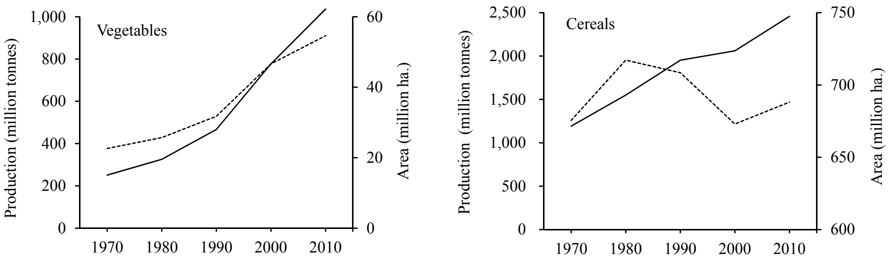

Fig. 3.1 World vegetable and cereal production (—) and area cultivated (…) 1970–2010 (Anon 2010)

Based on 2010 FAO data, the worldwide gross value per ha for a major vegetable such as tomato was $ US 12,556 and much greater than cereals such as maize with $ US 331. Vegetables are adapted to a range of climatic conditions, offering a wide choice for farmers. A good example is the diversity of vegetable production in Middle Eastern countries located near the Mediterranean Sea, an area characterized by a cold and wet winter climate in the north, and a sub-desert climate in the south. Here, several vegetable crops can be harvested up to three times a year, such as in Turkey, Egypt, Syria and Israel. Major abiotic stresses which detract from sustainability in vegetable production systems are water limitations, high salinity, low fertility, and temperature extremes. Economic factors and competition for land and water resources often preclude solving the first three problems by cultural practices alone. The fourth factor is even more difficult to address in open-field production, as farmers are limited by their local production environments. In this chapter we highlight critical aspects that contribute to the success of intensive vegetable production systems. Those are: technological advances in stand establishment and irrigation management systems, breeding and genetics to improve abiotic stress tolerance and product quality, and marketing and consumer trends for vegetable products.

Stand Establishment Systems

Seeding Technologies

In 2012, the global vegetable seed market was estimated at US $ 4 billion with the distribution being solanaceous (39 %), cucurbit (18 %), root and bulbs (15 %), brassicas (14 %), leafy (7 %) and large seed vegetables (7 %) (Anon 2012f). Direct seeding has been the standard establishment system of vegetable production for centuries. This is in large part due to the use of cultivars developed by open pollination, which are much less costly than F_1 hybrid seeds. Direct seeding is the recommended method used for large-scale vegetable production aimed at machine harvesting such as tomato, sweet corn, snap bean, chili pepper, cucumber, leafy vegetables, roots and bulbs such as carrots, beets and onions. Farmers demand seeds that have rapid germination and seedling emergence, leading to uniform stands, particularly under stressful conditions of extreme temperatures, drought and high soil salinity.

Seed enhancement technologies such as seed coating (pelleting, encrusting, and filmcoating), hydration treatments (priming at low water potential) or gel mixtures with growth promoting compounds such as rhizobacteria or gibberellic acid have been developed to improve speed and synchrony of seedling emergence as well as seedling vigor in open fields of several vegetable crops, including tomato, pepper, and cucumber (Orzolek 1983; Watkins and Cantliffe 1983; Cantliffe et al. 1987; Bradford et al. 1990; Edelstein et al. 1995; Kloepper et al. 2004; Nowak et al. 2004; Halmer 2008; Cantliffe 2009).

Fig. 3.2 Container grown onion transplants

Fig. 3.3 Melon plug plant

Transplanting Technologies

The development and adoption of polystyrene trays, known as Speedling®, for transplant production in nurseries was a "stepping stone" technological advancement in the vegetable industry during the early 1970s in Sun City, Florida. Now containerized transplants or plugs grown in trays with 72 to 800 cells have become prominent for small and large commercial vegetable farmers worldwide (Cantliffe 2009) (Figs. 3.2 and 3.3).

The use of grafting technology for vegetable transplants has also been increasing rapidly in Europe, Korea, Japan, Mediterranean Basin and the United States in the last decade, however its use is most common under protected rather than open field cultivation (Lee and Oda 2003; Davis et al. 2008) (Fig. 3.4).

Machine transplanting is the standard method of establishment for numerous commercial vegetable crops, including solanaceous (tomato, eggplant, pepper), cucurbits (melon, seedless and seeded watermelon), cruciferous (cauliflower, cabbage and broccoli), asparagus, celery, leek, and artichokes. This is mostly due to the high cost of hybrid seeds and the minimum root disturbance during transplanting. The importance of improving root development during the nursery period and to enhance seedling performance in the field has been reviewed by Leskovar and Stoffella (1995). Transplanting allows precise spacing, ensures the production of early crops and permits timing harvests for specific markets. Weed control may be

Fig. 3.4 Grafted watermelon plant

Fig. 3.5 Placing pepper transplants through plastic mulch

improved with transplants, without additional thinning costs as required for direct seeding. Furthermore, substantially less irrigation input is required to establish the transplanted crop under a plasticulture system as compared to direct-seeding, which is critical when growing vegetables in water restricted areas of semi-arid regions (Fig. 3.5).

Improved techniques aimed at modifying transplant root and shoot morphology, and physiology, have been developed in the nursery to suppress plant height, enhance plant compactness and condition or 'harden' transplants to better withstand post-transplanting stress. Many of these techniques have beneficial post-transplanting responses on early vegetative growth (e.g. tomato, pepper), but few provide long-term effects influencing reproductive development and yield potential. Numerous variables affecting growth and development of vegetable transplants in the nursery have been researched and several have been implemented in commercial nurseries. These include nitrogen, phosphorous and potassium management (Edelstein and Nerson 2001; Dufault 1998; Soundy et al. 2001), supplemental light (Boivin et al. 1987; Fierro et al. 1994), irrigation management and systems (Leskovar and Heineman 1994), selection of cell volume in the tray (Bar-Tal et al. 1990) and physiological conditioning with abscisic acid (Goreta et al. 2007; Agehara and Leskovar 2012).

Fig. 3.6 Lysimeter and center pivot irrigation rig

Irrigation Management

The Problem of Water Scarcity and Resources

Irrigated agriculture is a major consumer of water, accounting for about two thirds of the total fresh water diverted to human uses (Fereres and Evans 2006) (Fig. 3.6).

The predicted climate change coupled with increasing number of drought events for many areas of the world is exacerbating the problem of water scarcity (Petit et al. 1999; Anon 2001; Luterbacher et al. 2006). The rising demands on water resources and limited availability makes water an increasingly valuable commodity. This is true for several southern regions of the U.S., such as Texas, which is heavily dependent on underground water resources. In Egypt, where farming is confined to less than 3 % of the total land area near the Delta, irrigation is mainly based on pumping of the Nile water from Lake Nasser and mixing it with underground water (Mason 2003). A much more complex scenario occurs in central and southern-desert areas of Israel, where the main water source for vegetable irrigation comes from a combination of water reservoirs, saline water, recycled sewage water and more recently, desalinated water.

Water Conservation and Deficit Irrigation

Water conservation and crop water-use efficiency (WUE) is a matter of great concern among researchers, vegetable growers and government agencies. The WUE in the agricultural sector has been improving by the use of drought tolerant cultivars and by the utilization of efficient cultivation and irrigation practices (Chaves et al. 2003; Condon et al. 2004). The development of drip or "trickle" irrigation in Israel during the 1960's together with the adoption of the plasticulture technology on raised beds have been two major technological "milestones" for vegetable production. These systems are now widely used for fresh market vegetable production in open fields around the world (Goldberg et al. 1971; Hanson et al. 1997; Lamont 2005). Drip irrigation alone or in combination with plasticulture has significantly contributed to water savings and in many cases improved WUE by reducing runoff and evapotranspiration losses (Stanghellini et al. 2003; Jones 2004; Kirnak and Demirtas 2006) (Table 3.1) For large-scale production, water savings can be achieved with center pivot systems using drops converted to low-energy precision application (LEPA) heads placed at about 30 cm above the ground (Piccinni et al. 2009). Deficit irrigation implies that water is supplied to the crop at levels below crop evapotransiration (ET) levels, deliberately allowing crops to sustain some degree of water deficit without significant yield reduction but with important savings in irrigation water. Deficit irrigation strategies applied through drip systems have been shown to optimize water savings and productivity in several vegetable crops (Table 3.1). One environmentally-friendly approach to increase the use of marginal water (saline water) is grafting of salt-sensitive plants onto salt-tolerant rootstocks (Colla et al. 2010; Edelstein et al. 2011).

Application of Crop Coefficients

Irrigation can be improved by the application of on-site microclimatological data and crop coefficients (K_C), which are calculated as the ratio of the crop evapotranspiration (ET_C) to a reference crop (ET_O) (Allen et al. 1998). ET_O may be measured directly from a reference crop such as a perennial grass (Watson and Burnett 1995) or computed from weather data using either temperature models (Thornthwate 1948; Doorenbos and Pruitt 1977), radiation models (Doorenbos and Pruitt 1977; Hargreaves and Samani 1985), or combination models (Allen et al. 1998). Weighing lysimeters are employed to measure ET_O and ET_C directly by detecting simultaneous changes in the weight of the soil/crop unit (Schneider et al. 1998; Marek et al. 2006). Once K_C values are determined, growers can calculate real time irrigation recommendations (ET_C) which can be obtained by local weather stations that determine ET_O and therefore solve the equation: $ET_C = K_C \times ET_O$. Current K_C values published for vegetable crops are given based on three growth stages: initial, K_{Ci}; middle K_{Cm}; and late development K_{Ce} (Allen et al. 1998). Some examples include cabbage (0.7_i, 1.05_m and 0.95_e), tomato (0.6_i, 1.15_m and $0.7–0.9_e$), cantaloupe (0.5_i, 0.85_m and 0.6_e), potato (0.5_i, 1.10_m and 0.65_e), peas (fresh) (0.5_i, 1.15_m and 0.30_e), artichoke (0.5_i, 1.0_m and 0.95_e), spinach (0.7_i, 1.00_m and 0.95_e) and onions (0.7_i, 1.05_m and 0.75_e). Recent studies have confirmed that K_C recommendations need to be more precise both in terms of time and space. Piccinni et al. (2009) developed growth-stage specific K_C's for onions and spinach based on leaf developmental stages in order to further assist growers in maximizing irrigation management. The values obtained for onion in the semi-arid Wintergarden region of Texas under silty-clay soils were: 0.40 (emergence), 0.55 (two leaf), 0.75 (3–4 leaf), 0.85 (5–6 leaves), 0.90 (7–9 leaves), 0.85 (fully developed bulb) and 0.70 (dry leaf). The application of newly-developed K_C's for irrigation management has shown improvements in water use efficiency, yield and quality of short-day onions (Leskovar et al. 2011).

Table 3.1 Impact of irrigation strategies on water saving, WUE, yield and/or quality of selective vegetable crops

Crop	Water applied (ET_c, mm)		Water Saving (%)	WUE (± %)	Irrigation Strategies[z]	Yield and/or Quality Responses	Country	References
	Full 100 %	Deficit <100%						
Artichoke	614	509	17	8	DFI + mulch (SDI)	75 % ET_c decreased yield by 20 %	USA	Shinohara et al. (2011)
Tomato	379	204	46	53	DFI (DI)	50 % ET_c did not affect yield but improved fruit quality (TSS and ascorbic acid)	Italy	Patanè et al. (2011)
Pepper	360	272	25	4	DFI (DI)	75 % ET_c decreased yield by 23 %. DFI can be used cautiously in water limited regions	Ethiopia	Gadissa and Chemeda (2009)
Watermelon	395	298	25	−16	DFI + mulch (SDI)	75 % ET_c decreased yield by 36 %, but increased fruit lycopene content by 7 %	USA	Leskovar et al. (2004)
Potato	207	128	38	50	PRD (SDI)	PRD increased N content, starch and antioxidant activity in tubers, without reducing yield	Serbia	Jovanovic et al. (2010)
Onion	628	537	14	−10	DFI (SDI)	75 % ET_c caused modest reduction in bulb yield. Flavor and nutritional quality were maintained	USA	Leskovar et al. (2011)
Cabbage[y]	400	240	40	156	DFI (DI)	60 % ET_c increased yield by 54 %	India	Tiwari et al. (2003)
Cantaloupe[y]	612	381	38	64	Mulch (SDI)	Mulch (SDI) increased yield by 40 %	USA	Leskovar et al. (2001)
Lettuce[y]	271	171	41	52	(SDI)	SDI did not affect yield	USA	Hanson et al. (1997)

[y] Furrow irrigation was used as control for cabbage, cantaloupe, and lettuce
[z] DFI = deficit irrigation (less than 100 % ET_c), SDI = subsurface drip irrigation, DI = drip irrigation, PRD = partial root drying

Fig. 3.7 Cold tolerant pepper

Genetic Improvement Targets

As with many crop plants, vegetables have received considerable attention from plant breeders and geneticists over the past 150 years. It was in fact a common vegetable, garden pea that served as the model for Mendel's remarkable experiments establishing the principles of trait inheritance and the foundation for the science of genetics. Dramatic improvements have been achieved for important traits in many vegetable species. Yield, quality and disease resistance have been the attributes of high priority for most vegetable breeders. Advances in molecular biology have been actively applied by plant geneticists in recent years to unravel the complex nature of important qualitative traits at the DNA level. At the same time, many complex traits which may contribute to sustainable production have yet to be characterized genotypically. In some instances this is due to a lack of phenotypic data or methods to generate such data. In other cases, there is not a consensus amongst plant scientists about which traits contribute most to sustainable productivity for a given vegetable crop. Here we will focus on some efforts to identify traits and specific genes which impact the resistance of specific vegetable crops to abiotic stresses (Fig. 3.7).

Breeding for Drought Stress Tolerance

Because most vegetable crops have a relatively high water requirement, drought and water quality are factors which must be addressed to achieve sustainability in most production regions. Genetic improvement for both drought and salt tolerance is the key to sustaining productivity in many cropping systems around the world. The demand for high quality water by urban and industry groups, puts pressure on farmers to use less for irrigation. Natural and human induced salinity of irrigation supplies also limits crop selection and negatively impacts yield and quality.

Extensive research into mechanisms of drought and salinity tolerance has been conducted by plant physiologists for more than 60 years. Recently, geneticists and plant breeders have begun to screen for traits and genes conditioning resistance to these stress factors. Melon and watermelon are very important vegetable crops in warm climates, often produced in regions with both drought and salinity problems. Screening watermelon germplasm by breeders in Turkey, Japan and the USA has revealed genetic variation for drought stress resistance. Wild species of *Citrullus* demonstrated enhanced drought tolerance and produced elevated levels of citrulline. The investigators were able to identify a gene which codes for an enzyme of the deacetylase/carboxypeptidase family, involved in producing free citrulline (Kawasaki et al. 2000). Seedling drought stress screening revealed 25 *Citrullus lanatus* accessions from Africa with high tolerance amongst 1066 germplasm and breeding lines assayed (Zhang et al. 2011). Many of these accessions were from Zimbabwe, with an equal split between domestic (var lanatus) and wild (var citroides) types. These have potential for use as breeding parents to create both cultivars and rootstock lines with enhanced drought tolerance. The author has investigated root vigor and morphology in crosses between cultivated ('Crimson Sweet' and 'Dixie Lee') and wild (var. citroides) watermelon. Extreme heterosis for root length, area, diameter and lateral numbers was observed. Subsequent field trials revealed enhanced tolerance to both drought and vine decline due to *Monosporascus* root rot (Crosby 2000). These lines are currently the focus of rootstock trials in Texas. In Turkey, 85 watermelon accessions were screened for drought tolerance in field experiments with deficit irrigation. Over a third demonstrated drought tolerance based on 9 trait measurements, with one accession rating 99 on a scale of 100 (Karipcin et al. 2008). These drought tolerant genotypes are serving as the basis for development of new watermelon cultivars adapted to deficit irrigation and periodic drought conditions. The shift to smaller fruit size in commercial watermelon markets will complement enhanced drought tolerance traits due to reduced water demand at fruit maturity.

Onion is another major vegetable crop, produced and consumed on a year round basis. Resistance to drought in onion has been documented since ancient times. This crop evolved in semi-arid regions of central Asia. However, breeding has traditionally focused on increasing bulb size, and thus water content of the crop, under irrigated production systems. Survival of onions under deficit or dryland production systems has been demonstrated, but quality and yield are typically sacrificed. The shallow root system of onions suggests that the mechanism for drought tolerance may relate to leaf structure and transpiration more than root absorption capacity (Levy et al. 1981). Specific candidate genes involved in drought tolerance were isolated from leaf tissue of onions based on their homologies to *Arabidopsis* genes (Kutty et al. 2012). Protein candidates based on the sequences included Aquaporin and Calcium-dependant protein kinase. Thus, internal flow of water in onion leaf tissues and modulation of ABA activity may reduce water loss or limit oxidative stress under drought conditions. Selection of genotypes with enhanced expression of such genes could lead to more drought tolerant onion cultivars. Another approach would be to select onion genotypes with enhanced root area and vigor. This has been accomplished in Texas by introgression of resistance to the root destroying fungus *Phoma terrestris*, and selection in dry regions for large, vigorous root systems.

Cultivated tomato is probably the most important vegetable crop on a worldwide basis, and is often grown in arid regions to avoid serious foliar diseases. Breeding for drought tolerance in tomato (*Solanum lycopersicum*) has had limited success, possibly due to the extreme sensitivity of the large fruit to water stress. Investigations into leaf physiology have revealed differences in cell structure between genotypes with greater drought tolerance and more susceptible ones. Thicker leaves, longer palisade mesophyll cells and fewer, larger stomata were found in the more drought tolerant genotypes (Kulkarni and Deshpande 2006). They described a simple selection protocol for these leaf traits to breed tomato cultivars with enhanced drought tolerance. Another investigation of drought responses among different tomato species found no differences in stomatal conductance and leaf water potential, despite diversity in their natural habitats (Easlon and Richards 2009). Lack of shoot and leaf response variation, among the five species, for these traits suggests that other physiological attributes may contribute to drought tolerance. As in melon and onion, root physiology traits may contribute to differences in water uptake from native soil under stress conditions.

Breeding for Salt Stress Tolerance

Salt stress is frequently associated with drought conditions, poor water quality and high pH soils in arid regions. Much progress has been made in breeding agronomic crops for tolerance to salt in soils and irrigation water. More recently, efforts to exploit salt tolerance traits in major vegetable crops have produced mixed results. Inherent salt tolerance is evident in some vegetable species such as asparagus, beets and melons. Efforts to screen germplasm for salt tolerance have yielded positive results for some major crops such as tomato, pepper, and cabbage, but not for onion, carrot and radish (Shannon and Grieve 1999).

Salt sensitivity varies among species depending on the environmental conditions, source of the salts and irrigation method. As many vegetable crops are being grown with drip or other limited irrigation systems, salt damage will likely increase. Flood irrigation helps leach detrimental salts from the soils, but is not sustainable in most regions where population growth is straining available water supplies. Generally, tolerance to sodium salts is more important for many vegetable crops, as calcium and potassium are important nutrients with high threshold levels before negative impacts occur. Screening germplasm and exploiting salt tolerance traits to develop novel cultivars has been successful in certain vegetable species. Variation for salt tolerance in lettuce revealed significant differences among germplasm accessions (Shannon and McCreight 1984), and Romaine types showed greater salinity tolerance than iceberg cultivars (Pasternak et al. 1986).

Salt tolerance in tomato has been investigated for at least 60 years. Wild species of tomato, including *Solanum pennellii. S. cheesmanii,* and *S. pimpinellifolium*, have been documented as salt tolerant by several investigators (Fredrickson and Epstein 1975; Cuartero et al. 1992). Several salt tolerant tomato lines have been developed through inter-specific hybridization and backcrossing between cultivated tomato and these species (Rush and Epstein 1981). Additionally, some salt-tolerant tomato lines have been selected from open-pollinated cultivars over multiple generations of production under saline conditions (Shannon 1997). Recently, candidate genes and QTL (quantitative trait loci) for salt tolerance traits at the seedling and vegetative stages have been discovered (Foolad 2004). Thus, DNA sequence data may be useful for marker-assisted selection to improve the efficiency of introgressing salt tolerance genes from wild species into cultivated tomato.

Peppers are frequently produced in arid regions to achieve optimum fruit quality with minimal pests and diseases. However, soils and irrigation water are frequently saline. Salt tolerance in cultivated pepper, *C. annuum*, is considered moderate, but variation for this trait exists within the germplasm. Aktas et al. (2006) screened 102 pepper germplasm accessions for salinity resistance and found 6 lines with only slight symptoms. Further tests revealed significantly less sodium accumulation in shoots of the 6 tolerant lines compared to 6 sensitive ones. In west Texas and New Mexico, salinity is a constant threat to pepper production, and tolerance is a valuable attribute within the germplasm. In another experiment, 20 diverse pepper lines of *C. annuum* and *C. chinense* were irrigated with a saline solution in pots for 4 weeks as a rapid screen for salt tolerance. Shoot dry weights were not significantly reduced compared to control plants for 6 of the 20 entries and final height was not significantly reduced for half of the entries (Niu et al. 2010). Total plant survival of several entries was also 100 %, while the most salt-sensitive entries had between 33 and 0 % survival. The most salt tolerant entry, 'AZ 20,' was selected in Arizona and New Mexico, under conditions of high salts in both irrigation water and field soils. In addition to breeding salinity problems can be overcome by different conventional ways as reviewed by Plaut et al. (2013).

Breeding for Cold Tolerance

Open-field vegetable production is often subject to extreme temperatures which can inhibit growth, reduce quality and even destroy crops. Tolerance to low and high temperatures is determined by species adaptation, plant health and genetics. Breeding for cold and heat tolerance has been successful in both vegetable and agronomic crops to a limited extent. Tropical origin crops such as cucurbits, peppers, tomatoes and beans have almost no resistance to freezing or frost conditions. By contrast, onions, brassicas, spinach and carrots can withstand periods of exposure to sub 0 °C temperatures. Within species, progress has been made to select cultivars with greater degrees of cold tolerance, even for some tropical vegetables. In onions, Japanese germplasm has been utilized for its inherent cold tolerance, compared to other short day onions. Many of the European brassicas, such as cabbage and kale have greater tolerance to freezing conditions than East Asian brassicas. In tomato, cold tolerance from wild species *S. hirsutum* and *S. pimpinellifolium*, has been introgressed into cultivated tomato to develop some improved lines (Vallejos and Tanksley 1983;

Foolad et al. 1998). In both of these investigations, linkages between some molecular markers and cold tolerance QTL were confirmed in the interspecific populations. These may be useful for marker assisted selection to introgress cold tolerance traits. The emphasis was on seedling cold tolerance as this is an issue for early planting in many locations. Even within the *S. esculentum* germplasm, breeders have exploited cold tolerance traits to enhance flowering and fruit set at lower temperatures for short season regions. Cultivars such as 'Siberia,' 'Sub-Arctic Plenty,' and 'Manitoba' have these attributes.

Cold tolerance in melons has been achieved through traditional breeding as well. Hutton and Loy (1992) identified a cold temperature germination trait in melon and determined that both recessive genes and a cytoplasmic factor were involved. They successfully developed lines with this important trait for regions were direct seeding into sub-optimal soil temperatures is carried out. Edelstein and Kigel (1990) identified some melon accessions that are able to germinate at low (14 °C) temperature, and also have investigated the inheritance of these traits (Edelstein and Nerson 2009). Another investigation into mature melon plant cold tolerance demonstrated the positive impact of heterosis on performance traits under colder than normal conditions. Seven open-pollinated cultivars with above average cold tolerance were intercrossed and the F1 hybrids outperformed the parents under two cold temperature regimes. In cultivated pepper (*C. annuum*), very little cold tolerance exists in commercial types. The wild chile piquin (*C. annuum* var. aviculare) has some resistance to freezing temperatures and grows as a perennial in northern Mexico and south Texas. It may serve as a useful source of cold tolerance genes for breeders. The authors have conducted investigations into freezing tolerance within interspecific families derived from *C. annuum* x *C. baccatum* crosses. The latter species has a natural range that includes high elevations of the Andes in Bolivia and Peru. Preliminary results have demonstrated resistance to temperatures of −3 °C for 6 h in these lines. Backcross introgression and genetic studies of the cold tolerance genes is underway.

Breeding for Heat Tolerance

Heat tolerance may be even more important for sustainable vegetable production, considering that many countries within the tropics struggle with food security issues. Though cucurbits, solanaceous crops and many other vegetables originated in tropical regions, not all are capable of yielding good crops in lowland areas or in the warmest growing periods. Adaptation to higher temperatures has occurred through human selection, but needs continued efforts. Quality of heat tolerant cultivars is often inferior to crops grown at optimum temperatures. Heat tolerance in tomato has been the focus of extensive breeding efforts in Texas, Florida and Taiwan. Heat tolerant, large fruited cultivars have been released by both Texas A&M and the University of Florida (Leeper and Cox 1986; Scott et al. 2006). High temperature pollen stability and fruit set are traits which permit these cultivars to yield even when day and night temperatures are high.

Heat tolerance also exists within pepper germplasm of cultivated species. The pepper breeding and physiology programs at Texas A&M University (TAMU) have investigated heat tolerance for the last 40 years. Thermo-stability of pollen and ability to develop flower buds at high temperatures are key traits present in heat-tolerant cultivars. Several cultivars, including bell, jalapeño, serrano, mild green chile, and habanero types have been released by TAMU for warm climates. Yields and plant growth are superior to many heat sensitive commercial cultivars in south Texas and other warm regions (Crosby and Villalon 2002; Crosby et al. 2010). Additional work on pepper heat tolerance has been conducted in other warm climate locations, such as Taiwan. Saha et al. (2010) investigated the response of different sweet peppers to high day/night temperatures and found clear differences in yield and fruit quality. Additionally, leaf proline content of heat-tolerant lines was found to be higher than in heat-sensitive ones. This could be a useful marker for breeding programs.

Marketing

Defining Marketing

Marketing is one of the most important factors in determining the success of any vegetable farming enterprise. However, vegetable growers and business managers usually tend to only associate marketing with either selling or advertising and promoting their products. Those two functions are an important part of a long and comprehensive decision making process called marketing. Marketing can be defined as the process of business activities designed to plan, price, promote and distribute products that satisfy the needs of current or potential customers while achieving the business objectives. The overall and main objective of any vegetable farming operation is to generate profits. While strategic marketing does not guarantee profitability it provides the necessary tools to gather information and make more informed decisions.

The decision making process starts before planting any vegetable seeds, by deciding which vegetables to grow, when to grow, and what quantities to produce to satisfy market requirements. In the traditional supply chain, marketing activities are viewed as the necessary steps to deliver the products from the farm to the consumer's plate. The modern marketing definition requires putting the consumer as the first and major emphasis in the marketing planning process. The process starts by identifying consumer trends and preferences for vegetable products, including varieties, sizes, colors, texture, labels, and packaging. Then, the manager plans the operations required to meet the consumer expectations for the products and services. It is important to keep in mind that it is always easier to sell consumers what they want to buy, rather than growing the products and then trying to find a buyer for it (Fig. 3.8).

Fig. 3.8 High quality artichoke head

Vegetable Consumption Trends

Total per capita consumption of vegetables in the USA increased from 336.8 pounds per year in 1970 to 424.6 pounds in 2000. This change represents a 26.06 % increase over that period. Since then, per capita vegetable consumption has decreased 7.94 % to 390.9 pounds in 2009 (Anon 2012b). Even with this decline the vegetable industry has been experiencing overall growth in the last decade. There are four main factors for this growth:

a. *Increase in population*. The USA population grew 8.89 % in the last decade from 282.4 million in 2000 to 307.5 million in 2009 (Anon 2012b).
b. *Increased consumer interest for non-traditional/exotic foods*. There has been an overall trend of increased consumption of non-traditional vegetables. This may be explained in part by the increasing demographic diversity in the USA and increasing demand for specialty niche products. One of the main obstacles why consumers are not willing to try new products is lack of knowledge about preparation and cooking of certain vegetables. During the last decade there have been several advances in food preparation mass education to consumers. There are currently several television networks devoting airtime to teach consumers how to prepare and mix non-traditional foods. As a result, there has been an increase in the demand for these products.
c. *Technological advances in the supply chain*. Advances in production, transportation and storage of the cold supply chain of vegetable products have allowed the industry to become more global. International trade of vegetable products has increased substantially in recent years. The share of US consumption derived from imports more than tripled from 8.3 % in 1980 to 25.0 % in 2010 (Anon 2012c).
d. *Year-round demand*. The global nature of the produce industry with movements of products, literally all over the world, has changed the consumer's view of seasonality of vegetable production. Consumers have become accustomed and expect to find most fruit and vegetable products available at supermarkets, retail stores and restaurants all year long.

Supply and Demand Macro-Trends

At the beginning of the twentieth century, most vegetable products were sourced locally. Advances in infrastructure, transportation and the cold supply chain have converted the horticulture industry into a global activity. In spite of the perishable nature and weather conditions necessary to grow fruit and vegetables, technological advances have translated into increased efficiency of production, transportation and storage and a reduction in the cost of producing vegetables. Seasonality of production has allowed opportunities for certain regions to specialize in fruit and vegetable production for specific market windows where prices are usually higher due to a limited supply. Market window analysis helps match the demand for a product when the supply of that region is limited or restricted due to climatic differences that translate into significant increases in the cost of production.

There are certain factors in the vegetable industry that have the potential to make big structural changes and create considerable opportunities for growers all over the world. These factors are referred to here as produce macro-trends, due to the global nature and potential implications in changing the structure and paradigm of the produce industry.

a. *Demand for organic products*. The demand for organic foods has remained strong and continues to grow. According to Baginski (2011), total organic sales in the USA were estimated at $ US 23.4 billion in 2010. The produce industry was the top selling category and accounted for 37% of total sales in 2008.
b. *Increased consumer interest in the origin of the products with an emphasis on local.* There is increasing consumer interest about the origin of fruit and vegetable production. Even though there is no generally accepted definition of local, and the term has different connotations to different people, locally grown products are becoming more important to consumers (McGarry et al. 2005). The number of farmers' markets in the USA has grown substantially from 340 in 1970 to 7,175 in 2011 (Anon 2012a). Total local food sales by farmers in the USA were estimated to be at $ US 4.8 billion, including $ US 887 million in direct-to-consumer sales, $ US 2.7 billion in intermediate marketing channels only, and $ US 1.2 billion through markets with both direct and intermediate channels (Anon 2008). The rapid increase in the number of farmers' markets is attributed not only to changes in consumer tastes and preferences and changes in the economics of agriculture, but also to the passage of the Farmer-to-Consumer Direct Marketing Act of 1976 by the USA Congress (Brown 2001).
c. *Food safety.* A proliferation in the number of food-borne illness outbreaks around the world has brought more attention to food safety in the produce industry. In the USA, the spinach outbreak of 2006 changed the consumer's view of food safety for the vegetable industry (Palma et al. 2010). As a result there have been many changes to both industry and government driven standards to ensure a safe food supply (Knutson and Josling 2009). The 111th Congress enacted the Food and Drug Administration (FDA) Food Safety Modernization Act (FSMA), which was signed into law by President Obama on January 4, 2011. This is the

first comprehensive reform of FDA food safety policy since the Federal Food, Drug, and Cosmetic Act was enacted in 1938. The most important policy change contained in the FSMA is that it authorizes and mandates that the FDA pursue a science-based and a risk-based food safety policy (Knutson and Ribera 2011).

d. *Functional foods for healthier lifestyles*. According to the American Dietetic Association, functional foods "include whole foods and fortified, enriched, or enhanced foods that have a potentially beneficial effect on health when consumed as part of a varied diet on a regular basis, at effective levels" (Hasler and Brown 2009). The functional food market was estimated at $ US 39 billion in 2010. There has been an overall change in the consumer's paradigm from using functional foods as medicine and disease-prevention, to a more comprehensive approach that views food as part of a healthy lifestyle in combination with exercise and other health promoting activities. Palma and Jetter (2012) found that the actual levels of consumption of fruits and vegetables were significantly lower than the recommended intake levels of the Dietary Guidelines for Americans (DGA) released in 2010. Ribera et al. (2012) point out that if consumers were to increase their consumption of fruits and vegetables in response to the DGA recommendations, the total supply of vegetables would have to increase 114 % to satisfy the increased demand. They projected the majority of the increase in supply would come from horticulture production areas domestically and overseas.

e. *International trade agreements.* There has been an increase in the number of trade agreements with several of them still pending negotiations. The worldwide volume of agricultural products traded has had an average annual increase of 3.8 % since 1990. The total value of agricultural products exported worldwide in 2010 was estimated at $ US 1.36 trillion (Anon 2011). The USA has trade agreements with Mexico and Canada (North American Free Trade Agreement), Central America (Central America Free Trade Agreement), Australia, Bahrain, Colombia, Chile, Israel, Jordan, Korea, Morocco, Oman, Peru, Singapore, and a pending agreement with Panama.

Prospects

Large-scale vegetable production in open fields has evolved rapidly with improvements in technologies and use of resources. The diversity of production is highly dependent on weather conditions and crop input requirements. Commercial farmers now efficiently select, integrate and monitor environmental variables and preharvest production factors such as geographical location, weather conditions, soil and water resources, new cultivars, seed technologies, precision seeding, transplanting, grafting, irrigation systems, soil and canopy sensing technologies, fertilizer placement, mechanical harvests, crop protection strategies and food safety management. In fact more than 90,000 farmers in the world now follow standard field production practices as part of the voluntary Global Good Agricultural Practice or GlobalGAP program. The integration of new technologies has dramatically improved the quality of fresh produce with impressive yield gains per area of cultivation. High demand for more nutritious and healthier diets has also contributed to the vertical integration of large farmers. The future outlook for intensive open-field vegetable production is promising, as a 65 % increase in production was recorded between 1990 and 2009 (Anon 2012e). However, large scale production can be very cyclical and heavily dependent on global demands, trades, price structure and year-round availability.

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