- Tatsumi, Y., A.E. Watada, and W.P. Wergin. 1991. Scanning electron microscopy of carrot stick surface to determine cause of white translucent appearance. *J. Food Sci.* 56:1357–1359.
- Torres, J.A. 1987. Microbial stabilization of intermediate moisture food surfaces, p. 329–368. In: L.B. Rockland and L.R. Beuchat (eds.). *Water activity: Theory and applications to food*. Marcel Dekker, New York.
- Torres, J.A. and M. Karel. 1985. Microbial stabilization of intermediate moisture food surfaces. III. Effects of surface preservative concentration and surface pH control on microbial stability of an intermediate moisture cheese analog. *J. Food Processing Preservation* 9:107–119.
- Torres, J.A., J.O. Bouzas, and M. Karel. 1985a. Microbial stabilization of intermediate moisture food surfaces. II. Control of surface pH. *J. Food Processing Preservation* 9:93–106.
- Torres, J.A., M. Motoki, and M. Karel. 1985b. Microbial stabilization of intermediate moisture food surfaces. I. Control of surface preservative concentration. *J. Food Processing Preservation* 9:75–92.
- Trout, S.H., E.G. Hall, R.N. Robertson, F.M.V. Hackney, and S.M. Sykes. 1942. Studies in the metabolism of apples. I. Preliminary investigations on internal gas composition and its relation to changes in stored Granny Smith apples. *Austral. J. Expt. Biol. Med. Sci.* 20:219–231.
- Vojdani, F. and J.A. Torres. 1990. Potassium sorbate permeability of methylcellulose and hydroxypropyl methylcellulose coatings: Effects of fatty acids. *J. Food Sci.* 55:841–846.
- Vojdani, F. and J.A. Torres. 1989. Potassium sorbate permeability of polysaccharide films, chitosan, methylcellulose and hydroxypropyl methylcellulose. *J. Food Processing Eng.* 12:33–48.
- Wells, J.M. 1971. Heated wax-emulsions with benomyl and 2,6-dichloro-4-nitroaniline for control of postharvest decay of peaches and nectarines. *Phytopathology* 62:129–133.
- Wills, R.H., T.H. Lee, D. Graham, W.B. McGlasson, and E.G. Hall. 1981. *Postharvest, an introduction to the physiology and handling of fruits and vegetables*. AVI, Westport, Conn.
- Wong, D.W.S., W.M. Camirand, and A.E. Pavlath. 1994. Development of edible coatings for minimally processed fruits and vegetables, p. 65–88. In: J.M. Krochta, E.A. Baldwin, and M.O. Nisperos-Carriedo (eds.). *Edible coatings and films to improve food quality*. Technomic Publishing Co., Lancaster, Pa.
- Wong, D.W.S., F.A. Gastineau, K.S. Gregorski, S.J. Tillin, and A.E. Pavlath. 1992. Chitosan–lipid films: Microstructure and surface energy. *J. Agr. Food Chem.* 40:540–544.
- Wong, D.W.S., S.J. Tillin, J.S. Hudson, and A.E. Pavlath. 1994. Gas exchange in cut apples with bilayer coatings. *J. Agr. Food Chem.* 42:2278–2285.

Selection of Cultivars for Lightly Processed Fruits and Vegetables

William R. Romig¹

DNA Plant Technology Corporation, 2611 Branch Pike, Cinnaminson, NJ 08077

Some retail economists have projected that as much as 50% of the dollar volume generated by the supermarket produce department will come from fresh-cut fruits and vegetables by the end of the century (Graziano, 1993). To provide high-quality, value-added products throughout the year will require superior raw material and the optimization of all postharvest steps. Fruit and vegetable cultivars are routinely screened and selected for specific functional properties. Processors of lightly processed fruits and vegetables have selected those cultivars that, when evaluated under current cultural, postharvest, and distribution practices, meet their economic needs and the general specifications of the intended product. Although the trade and the consumer have provided incentives for such convenience products, no cultivar has been deliberately developed with the process and distribution in mind.

Microbiologists have revealed the potential sanitation problems associated with lightly processed produce (LPP). To combat this hazard, processors are implementing Hazard Analysis of Critical Control Points (HACCP) protocols (Bryan, 1988). HACCP identifies all steps in the process that can contribute to increased incidence of microbial growth (and loss of quality) and implements protocols at each step to monitor key elements and minimize quality deterioration. The status of the raw material and hence the characteristics of the selected cultivar greatly impact the microbial population by its degree of resistance or particular substrate availability and response to stress conditions. *Pseudomonas* spp. and *Erwinia* spp. can become significant problems, or weak and opportunistic organisms, such as *Leuconostoc*, can become problematic, especially in extended-shelf-life products. Therefore, cultivar selection, preharvest cultural practices, postharvest handling, and grading raw material are interactive and their optimization is crucial to routinely producing quality products.

There are several types of latent damage, the extent of which is determined by the interaction of the genotype with its cultural and postharvest environment. Bruising is the most common latent damage, as impact can occur at any point in the process, but tissue breakdown or discoloration becomes noticeable later. For example, potatoes

(*Solanum tuberosum* L.) begin to discolor in ≈ 4 h after initial impact (Belknap et al., 1990). Exocarp thickness, fruit shape, turgidity, etc., will affect the physical damage incurred during processing. Harvest maturity of the individual cultivar is another important factor that affects processing and product quality (Shewfelt, 1993). A variety of disorders can result from preharvest and postharvest stress conditions. Nutrition and soil conditions greatly impact the quality of root crops, such as carrots (*Daucus carota* L.). Heavy soils, poor nutritional balance, and moisture conditions cause abnormal root growth of carrots that can lead to various degrees of latent damage, depending on the cultivar. Postharvest desiccation or increased temperatures of the raw material during transit will affect the processing and final product quality, with carrot varying in its susceptibility to such stress conditions (unpublished). Under stress conditions, produce is commonly stored and transported under refrigeration to repress metabolism and desiccation, and maintain harvest quality (Uritani, 1978). Quiescent infection, where the organism has infected fruits and vegetables before harvest but remains quiescent until after harvest or processing, when stress conditions provide favorable growth conditions, is another example of latent damage (Wills et al., 1989). The extent of infection and microbial growth after harvest depends on cultivar resistance and its interaction with environmental factors.

Lightly (minimally) processed fruits and vegetables

Since the mid-1980s, there has been an increasing amount of activity in this area, with individuals applying various working definitions, depending on their research or specific goals. Huxoll and Bolin (1989) stated that "Minimally processed fruits and vegetables are products that have the attributes of convenience and fresh like quality." They go on to say something even more critical. "For minimal processed foods, processing and distribution are accomplished in a highly integrated system." To maintain a focus on providing a consumer product, the definition of minimal processing is extended to processing that, when combined with the optimization of all other steps of production, preparation, and distribution of produce to the consumer, will yield products of extended shelf life with fresh-like quality. This process starts with the selection/development of the most suitable variety.

¹Current address: EPL Technologies, 200 Four Falls Corporate Center, Suite 315, Conshohocken, PA 19428.

Integrated systems approach

Interactions between genotype, environment, and cultural practices must be taken into consideration when developing LPP or the process to manufacture such a product. A systems approach, where each step in the process is optimized with respect to the other steps, can make possible the development and delivery of quality and safe consumer products with extended shelf life (Shewfelt, 1987). However, if, for example, a carrot cultivar is selected that is highly susceptible to soft rot organisms, such as *Erwinia* or *Pseudomonas*, the product will immediately begin to deteriorate with the first exposure to abusive temperatures. Selection should be made for a line with some inherent resistance, which is less prone to predisposition by other stress factors, and whose moisture characteristics are not favorable to microbial growth.

Requirements of genotypes for (value-added) LPP

Value-added and LPP are those products that have added appeal to the consumer because of their improved sensory characteristics, convenience, or extended shelf life. To develop/select cultivars for such products, one must initially establish broad criteria for the plant breeder.

1) What is the intended product (i.e., product specifications)? Obviously, these criteria must be well defined during the early stages of cultivar development, and may require input from the trade and the consumer. It makes little sense to invest significant time and money in a cultivar that will not meet the specifications of the fresh-cut product and, thus, the needs of the consumer. Physical properties (e.g., size) may be important to the trade or consumer and undoubtedly will affect the economies of processing. For example, it seems obvious that celery (*Apium graveolens* L.) cultivars with elongated petioles would be ideal for lightly processed sticks. However, if the petioles will not fit the standard carton, the processor will not be able to market the excess production through normal channels.

2) Identify shelf life needs and limitations such that these characteristics are incorporated into the breeding program and suitable selection pressures are applied to evaluate for response to preharvest growing conditions; susceptibility to pre- and postharvest pathogens; compatibility with the intended process, packaging, and distribution; and susceptibility to deterioration due to high activity of endogenous enzymes.

3) Identify other products that can be derived from the same production lot. Market fluctuations (demand) and environmental factors will mandate flexibility in the product line. Consider what is the largest volume product or most highly valued product for which the harvested crop will be used. Is this the product for which you develop a cultivar? In some cases this could be true; in others, it may be best to select the cultivar for maximum flexibility (most products). For example, a processor of carrot sticks cannot afford to grow (develop/select a cultivar) a crop specifically for sticks. Preharvest and postharvest stress can reduce shelf life potential, thereby making the crop unacceptable for a lightly processed and extended-shelf-life product. Disease and water stress will limit the use and shelf life of cut vegetables, and the more extensively the product is processed (e.g., shredded), the more dramatic the impact of preharvest growing conditions and postharvest handling can be. Market situations and availability will determine the economic mix of products. With multiple products, size becomes an issue. If the primary product is a 7- to 10-cm-long stick, the processor must identify an outlet for the remainder of the carrot root. What are the optimum dimensions to maximize plant efficiencies? The available carrot cultivars ('Imperator', 'Nantes', 'Chantenay', 'Danvers') provide a significant range in geometry, but they also vary significantly in sensory characteristics.

Cultivar characteristics for LPP

If one considers the expense, time, and effort that must go into developing a cultivar, it is important that it not only have suitable agronomic characteristics but also meet the product criteria, as defined

by the consumer, when it is released. *First and foremost, the cultivar (product) must meet the needs and expectations of the consumer.* If a long-shelf-life tomato with fresh quality is desired for the fresh market, germplasm selection must focus on these attributes. Overemphasis of processing genotypes will not meet the consumer's expectations. Exact definition of the specifications is even more crucial if expensive advanced biotechnology techniques are to be applied. Therefore, input from the trade and consumers early in the development process relative to distribution, pricing, sensory quality, etc. is imperative and can help to avoid the high cost of developing cultivars that do not meet consumers' needs and expectations.

Consider the potential for multiple outlets (products) for the cultivar. A celery cultivar that can only be used for the precut market is not affordable. For economic and logistical reasons, a critical area must be planted, grown, and harvested. Undoubtedly, the demand for sticks at any one time may not be such to require this amount of cultivation. However, a combination of sticks, cut celery, and stalk celery will absorb the entire crop. As the consumer has come to expect convenient and value-added products (LPP) to be available year round, the appropriate mix of products must be determined to fulfill this demand economically and logistically. *Therefore, the cultivar must be grown for year-round supply.* This increases trialing costs, due to the increased number of trialing locations, and probably will require developing several cultivars with similar sensory and postharvest characteristics. Seldom does a single cultivar perform well under the range of growing conditions required to provide year-round availability. Cultivars grown for the light processing market should have similar cultural characteristics, acceptable pest resistance, and no unique harvesting or postharvest requirements. With the sophistication of today's growing systems, it is important to the grower that new cultivars conform to standard cultural practices as much as possible. There must be additional concern for resistance to environmental stress factors and stress due to pests, as such factors can predispose the fresh-cut product to more rapid deterioration. Cultivars with reduced key enzyme activity are desired for LPP. Enzymes that contribute to degradative processes (e.g., browning, softening, volatile generation) have demonstrated a range of activities depending on the genotype. High levels of polyphenol oxidase activity and hemicellulase activity can reduce shelf life to an unacceptable level. Fruits and vegetables destined for a lightly processed product and the rigors of the processing plant may need to be more durable to withstand the bruising, desiccation, and continuous physiological changes during postharvest handling and processing. Shape, skin characteristics, and exocarp thickness are a few characteristics that one may need to select.

Cultivars developed for the light processing market

Based on definitions that encompass postharvest handling and storage [precooling, refrigeration, controlled- or modified-atmosphere storage, irradiation, and preparation for consumption (e.g., peeling, slicing, shredding)] of lightly processed vegetables, there are few examples of crops with cultivar development activities directed at the lightly processed market. Carrot cultivars developed by DNAP Plant Technology Corp. may be the only example of genotypes selected and developed specifically for the precut market (Table 1). These cultivars provide limited examples of cultivar development programs that combine conventional breeding and advanced biotechnology. Products such as cherry tomatoes (*Lycopersicon esculentum* Mill.) and sugar snap peas (*Pisum sativum* L.) stretch the definition of minimally processed products. However, both exhibit a short shelf life; therefore, to provide the various consumer products, they require optimizing each step in the process that would include calyx removal, the use of cleaning enhancers, edible films, treatments to maintain flavor (e.g., slow sugar to starch conversion), and specific packaging.

Conclusion

Within a specific crop, the diverse cultivars have varied genotypes and, therefore, vary in physical attributes, color, flavor, firmness, pest resistance, response to stress, etc. Genetic management for quality attributes includes selection by the processor and the development of

Table 1. Cultivar development for minimally processed vegetables.

Commodity	Consumer trait	Minimal processing traits
Carrot	Flavor, texture, convenience	Size, resistant to dehydration, pathogen-resistant, reduced substrate or enzyme levels
Pepper (<i>Capsicum annuum</i> L.)	Flavor, convenience, low seed	Size, wall thickness, low seed, increased invertase
Cherry tomato	Flavor, shelf life, texture	Durable, slow ripening, shelf life, calyx removal
Sweet corn (<i>Zea mays</i> L.)	Flavor, texture	Shelf life, reduced enzyme activity
Sugar snap pea	Flavor, stringless	Shelf life, reduced enzyme activity

Table 2. Partial list of enzymes for which genes have been cloned that could affect fruit and vegetable quality.

Enzyme involvement	Reference
Fruit ripening	
Ethylene biosynthesis/action	
ACC synthase	Rottman et al., 1991
ACC oxidase (EFE)	Bouzayen et al., 1992
Ethylene perception (E-8)	Peñarrubia et al., 1992
ACC diaminase	Klee et al., 1991
Softening	
Polygalacturonase	Bird et al., 1988
Cellulase	Lashbrook et al., 1993
Color/pigment biosynthesis	
Phytoene synthase	Fray and Grierson, 1993
Fruit quality	
Sucrose phosphate synthase	Worrell et al., 1991
Invertase	Elliott et al., 1993
Sucrose synthase	Martin et al., 1993
Pectin methylesterase	Tieman et al., 1993
Polyphenol oxidase	Cary et al., 1992

new cultivars with desired characteristics through plant breeding and biotechnology. Currently, little effort is being expended on developing cultivars specifically for LPP. Processors are using a portion of the crop grown for standard produce distribution or are screening established cultivars for application to their products. Advanced technologies have been developed, and some genes have been cloned that affect fruit and vegetable quality (Table 2). With the current genetic diversity and modern capabilities, characteristics such as shelf life and specific sensory properties can be altered. With much of the minimally processed produce, browning of cut surfaces and softening due to endogenous enzymes can reduce product quality and shelf life. Minimizing the activity of polyphenol oxidase could minimize browning and improve the appearance of cut fruits and vegetables. Reducing cell-wall-degrading enzymes in cut fruits from sense or antisense transgenic plants would impart a better texture and reduce the availability of substrate for rapid microbial growth. However, a major question remains: Is the benefit to the trade and return on investment sufficient to justify the cost in time and resources?

Literature Cited

- Belknap, W.R., T.M. Rickey, and D.R. Rockhold. 1990. Blackspot bruise dependent changes in enzyme activity and gene expression in Lemhi Russet potato. *Amer. Potato J.* 67:253–265.
- Bird, C.R., et al. 1988. The tomato polygalacturonase gene and ripening-specific expression in transgenic plants. *Plant Mol. Biol.* 11:651–662.
- Bouzayen, M., A. Hamilton, S. Picton, S. Martin, and D. Grierson. 1992. Identification of genes for the ethylene-forming enzyme and inhibition of ethylene synthesis in transgenic plants using antisense genes. *Biochem. Soc. Trans.* 20(1):76–79.
- Bryan, F.L. 1988. Hazard analysis critical control point: What the system is and what it is not. *J. Environ. Health* 50:400–401.
- Cary, J.W., A.R. Lax, and W.H. Flurkey. 1992. Cloning and characterization of cDNAs coding for *Vicia faba* polyphenol oxidase. *Plant Mol. Biol.* 20:245–253.
- Elliott, K.J., et al. 1993. Isolation and characterization of fruit vacuolar invertase genes from two tomato species and temporal differences in mRNA levels during fruit ripening. *Plant Mol. Biol.* 21:515–524.
- Fray, R.G. and D. Grierson. 1993. Identification and genetic analysis of normal and mutant phytoene synthase genes of tomato by sequencing, complementation and co-suppression. *Plant Mol. Biol.* 22:589–602.
- Graziano, J. 1993. Fresh-cut at a glance. *Produce Business* 9(10):42–48.
- Huxoll, C.C. and H.R. Bolin. 1989. Processing and distribution alternatives for minimally processed fruits and vegetables. *Food Technol.* 43(2):124–128.
- Klee, H.J., M.B. Hayford, K.A. Kretzmer, G.F. Barry, and G.M. Kishore. 1991. Control of ethylene synthesis by expression of a bacterial enzyme in transgenic tomato plants. *Plant Cell* 3:1187–1193.
- Lashbrook, C.C., D.A. Brummell, C. Gonzalez-Bosch, E. del Campillo, and A.B. Bennett. 1993. Molecular characterization of differentially expressed endo- β -1,4-glucanase (cellulase) genes in tomato flower abscission and fruit ripening. *Plant Physiol.* 101(1 suppl.):99.
- Martin, T., W.B. Frommer, M. Salanoubat, and L. Willmitzer. 1993. Expression of an *Arabidopsis* sucrose synthase gene indicates a role in metabolization of sucrose both during phloem loading and in sink organs. *Plant J.* 4(2):367–377.
- Peñarrubia, L., M. Aguilar, L. Margossian, and R. Fischer. 1992. An antisense gene stimulates ethylene hormone production during tomato fruit ripening. *Plant Cell* 4:681–687.
- Rottman, W.H., et al. 1991. 1-Aminocyclopropane-1-carboxylate synthase in tomato is encoded by a multigene family whose transcription is induced during fruit and floral senescence. *J. Mol. Biol.* 222:937–961.
- Shewfelt, R.L. 1987. Quality of minimally processed fruits and vegetables. *J. Food Qual.* 10:143–156.
- Shewfelt, R.L. 1993. Measuring quality and maturity, p. 100–125. In: R.L. Shewfelt and S.E. Prussia (eds.). *Postharvest handling: A systems approach*. Academic, New York.
- Tieman, D.M., D.M. Serra, K.D. Kausch, and A.K. Handa. 1993. An antisense pectin methylesterase gene alters pectin chemistry and soluble solids in tomato fruit. *Plant Cell* 4:667–679.
- Uritani, I. 1978. Temperature stress in edible plant tissue after harvest, p. 136–160. In: H.O. Hultin and M. Milner (eds.). *Postharvest biology and biotechnology*. Food and Nutrition Press, Westport, Conn.
- Wills, R.B.H., W.B. McGlasson, D. Graham, T.H. Lee, and E.G. Hall. 1989. *Postharvest: A introduction to the physiology and handling of fruit and vegetables*. 3rd revised ed. Blackwell Scientific, Boston.
- Worrell, A.C., et al. 1991. Expression of a maize sucrose phosphate synthase in tomato alters leaf carbohydrate partitioning. *Plant Cell* 3:1121–1130.