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# Maturity and Quality of 'Liberty' Apple Fruit Under Integrated and Organic Fruit Production Systems Are Similar

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***Abstract*. Maturity and quality of fruit harvested from an orchard of disease-resistant 'Liberty' apple (*Malus* ×*domestica* Borkh.) trees was investigated during and after the transition from conventional to integrated (IFP) and organic fruit production (OFP) systems. Over 4 years, internal ethylene concentration, starch pattern index, flesh firmness, soluble solids concentration (SSC), titratable acidity (TA), and percent of surface blush of fruit at harvest were not consistently different between fruit from IFP and OFP systems. Total phenolic content and antioxidant capacity of the fruit were also similar between treatments. IFP-grown fruit contained more potassium during the first 2 years and more calcium in all years than OFP-grown fruit. After fruit were stored in air at 0.5 °C for 9 weeks in 2007, OFP-grown apples were firmer and had higher SSC, TA, and SSC:TA ratios. In double-blind triangle taste tests, consumer panelists were able to discriminate between the fruit from each treatment, but in double-blind hedonic and intensity tests, panelists did not consistently rate one treatment more highly than the other. Overall, consumer panelists favorably rated internal quality of fruit grown under both IFP and OFP systems. In 2006, when weather and disease caused a high percentage of OFP-grown fruit to have cosmetic defects, the panelists rated the appearance of OFP-grown apples as less acceptable than the cleaner-looking IFP-grown apples. Our study of 'Liberty' apple fruit maturity and quality during a 4-year transition period from conventional to IFP and OFP systems showed that differences were small if present, whereas internal fruit quality was rarely different between systems.**

The northeastern United States has a humid climate where frequent summer precipitation creates high disease pressure and intense weed competition as well as a long history of apple (*Malus* ×*domestica* Borkh.) cultivation that has allowed for the development of a large arthropod pest complex. Thus, despite the high market value of apples and the increasing interest in ecologically based farming schemes by growers, consumers, and public officials, little is known about the effects of transitioning apple orchards from conventional management to integrated (IFP) and organic fruit production (OFP) systems in the northeastern United States. However, some barriers to IFP and OFP might be overcome by implementing better biocontrol, integrated pest management (IPM), and groundcover management strategies as well as new pesticide formulations (Merwin et al., 2005). With the possibility of expanding IFP and OFP in the northeastern United States, there is a need to understand the impact these systems have on fruit maturity and quality.

Originally developed by the International Organization for Biological and Integrated Control of Noxious Animals and Plants, IFP is a science-based system that encompasses all aspects of fruit growing. An IFP system includes biological, chemical, and cultural pest controls based on monitoring and damage action thresholds, selection of disease-resistant and locally adapted fruit cultivars and rootstocks, strict limits on fertilizer applications determined by crop nutrient status and soil fertility tests, a short list of permissible and restricted pesticides, and on-farm inspections to certify that growers are following appropriate guidelines. In much of western Europe as well as in countries exporting fruit to Europe, IFP has become the standard system used in commercial apple orchards (Sansavini, 1997).

Likewise, organic apples have become an internationally traded commodity (Peck et al., 2005). The U.S. Department of Agriculture oversees organic food production in the United States with established lists of allowed and prohibited substances (most nonsynthetic materials are allowed, whereas most synthetic materials are prohibited) for organic production as well as specifications on how farm operations must maintain or improve natural resources, including soil and water quality. Consumers often purchase organic foods because they believe them to have better quality and be more nutritious (Wier et al., 2008), and the popular media tend to reinforce the perception of higher quality (Nestle, 2006; Pollan, 2006). However, fruit quality is a complex notion that includes sensory components, size, color, nutritional value, the presence of pesticide residues or pathogens as well as externalities such as environmental and societal benefits, and the location where fruit was grown. Because of these diverse attributes, fruit quality means different things to the end-user and depends on the needs within the supply chain (Watkins and Ekman, 2005). For organic foods, purchase decisions appear to be motivated by attributes that directly benefit consumers such as freshness, taste, and nutritional value more than externalities (Chryssohoidis and Krystallis, 2005; Wier et al., 2008).

One recent review of studies comparing IFP with OFP and conventional production found limited evidence supporting the hypothesis that organic production increases essential nutrients or phytochemicals for a wide range of fruit crops (Zhao et al., 2006). For apples, the results of quality comparisons of IFP with OFP and conventional production have also been inconclusive. DeEll and Prange (1992) reported higher soluble solids concentrations (SSC) for OFP-grown 'Cortland' and 'McIntosh' apples in Nova Scotia compared with conventional apples of the same cultivars, but they found no differences for firmness, titratable acidity (TA), or sensory perception. In a single-year study, OFP-grown 'Golden Delicious' apples in Switzerland were firmer, rated better by sensory panelists, and had higher concentrations of phenolic compounds in unpeeled apples than IFP-grown apples, but no differences between systems were detected for SSC or TA (Weibel et al., 2000). In Washington State, OFP-grown 'Golden Delicious' apples were found to be firmer and sweeter (as measured by the SSC:TA ratio) at harvest and after 6 months of storage than either conventional or IFP-grown fruit, but only the higher sweetness of

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the OFP-grown apples was discernible by sensory panels (Reganold et al., 2001). Organically grown ‘Gala’ apples were reportedly firmer with higher peel and flesh total antioxidant activity than IFP-grown or conventional apples in Washington State (Peck et al., 2006). Also, consumer panels found IFP- and OFP-grown apples to have equal or better overall acceptability, firmness, and texture than conventional apples (Peck et al., 2006). However, few differences were found for antioxidants in ‘Jonagold’ apples grown under IFP and OFP systems in Belgium (Róth et al., 2007) or for antioxidant activity and potential antigenotoxic effects on DNA between OFP-grown and conventional ‘Golden Delicious’ whole apples from Switzerland (Briviba et al., 2007).

Production practices such as fruit thinning materials and timing, pesticide a.i. and formulations, the use of kaolin clay, fertilizers, and groundcover management systems are inherently different between IFP- and OFP-managed apple orchards. These differences may affect crop load, pest and disease incidence, weed competition, nutrient status, and edaphic conditions, which can ultimately affect fruit size and maturity and therefore quality. For this reason, a systems comparison should evaluate fruit of similar size and maturity. Furthermore, Harker (2004) recommended that a comparative systems study should match cultivar and rootstock, plant age, and soil type by using paired orchards or replicated treatments within the same orchard to minimize external variables.

In the current study, we measured the maturity and quality of fruit from IFP with OFP management protocols over 4 years. Both systems were transitioned from conventional management in the same ‘Liberty’ apple orchard block. The systems used published certification protocols and recent advances in IPM, groundcover management, pesticides, machinery, and crop load management techniques. The objective of this experiment was to compare fruit maturity and quality between IFP and OFP systems in an orchard of disease-resistant apple trees.

## Materials and Methods

*Experimental site and design.* A 0.42-ha block of high-density (1537 trees/ha; 1.5 m between trees; 4.3 m between rows; 2.7 m tall) disease-resistant ‘Liberty’/‘M.9’ apple trees at the Cornell Orchards in Ithaca, NY (long. 42°26′ N, lat. 76°27′ W) was used for the experiment. The orchard was planted in 1994 and trained to a modified vertical-axe form with pollenizer crabapple trees located throughout. The soil was a Collamer silty clay loam series (fine-silty, mixed, active, mesic Glossaquic) formed from glacial lacustrine sediments.

Previous (1994 to 2003) control practices at this orchard for pests, diseases, and weeds used conventional IPM appropriate for New York (Agnello, 2007). In 2004, a randomized complete block design was implemented with four replications of the two production systems (IFP and OFP). The IFP system followed published guidelines for New York (Carroll and Robinson, 2006). It included carbaryl and plant growth regulators for fruit thinning; *Bacillus thuringiensis*, indoxacarb, neonicitinoids, spinosad, pheromone mating disruption, and trapping for insect control; strobilurins and anilides for disease control; and bark mulch and glyphosate for weed control. From 2004 to 2006, the OFP treatment was considered transitional under U.S. Department of Agriculture National Organic Program guidelines (Federal Register, 2000). Under these regulations, the OFP-grown apples would have first been considered certifiable as organic in 2007. The OFP system included lime sulfur and fish oil for fruit thinning; kaolin clay, *Bacillus thuringiensis,* spinosad, pyrethrum, *Cydia pomonella* granulosis virus, petroleum oil, pheromone mating disruption, and trapping for insect control; lime sulfur and potassium bicarbonate for disease control; and mechanical cultivation for weed control.

Each experimental plot was four adjacent rows wide by 16 trees long (Fig. 1). The experimental design and execution of the treatments were designed to prevent spray drift across treatments. Only the 12 centermost trees of the two middle rows of each four-row treatment unit were used for sampling, which allowed for a four-tree buffer between abutting treatment plots. Additionally, airblast sprays were directed in such a way as to create a three-row buffer between adjacent treatment plots that were situated lengthwise to each other with the middle row (Row 5) being a completely unsprayed buffer strip. A similar spray pattern was used to buffer Blocks 3 and 4 from an adjacent orchard block. The other three sides of the experimental area were not in close proximity to sprayed crops. Chemical thinners, crop protectants, and foliar fertilizers were applied on a tree row volume basis of 935 $L\cdot ha^{-1}$ with a low-drift Turbo-mist curtain airfoil sprayer (Slimline Manufacturing Ltd., Penticton, BC, Canada). Spray drift across plots was not observed after the use of highly visible kaolin clay. Further details on the experimental design and practices used for each production system have been described elsewhere (Peck, 2009).

*Sampling procedures.* To assess the effects of each production system on fruit maturity and quality at harvest, sequential harvests at weekly intervals were conducted each year. At each harvest, a 10-fruit subsample was selected from each plot for measurements of percent surface blush, internal ethylene concentration (IEC), flesh firmness, SSC, starch index rating, and TA. Comparisons of sensory, mineral concentration, and biochemical measurements were based on the harvest indices, as recommended by Harker (2004). The fourth harvest in 2004 and the third harvests in 2006 and 2007 were used for these evaluations. In 2005, the first harvest for IFP was compared with the second harvest for OFP. On the selected harvest date, a 10-fruit subsample was used for measurements of dry matter content and fruit mineral concentration. A different 10-fruit subsample was used for analysis of total phenolic (TP) concentration and vitamin C-equivalent antioxidant capacity (VCEAC). Also on the selected harvest day, two separate 100-fruit subsamples were collected for the consumer sensory evaluations (triangle test and hedonic test). Fruit for the 2007 storage quality assessment were from samples taken on each harvest day conducted that year. All subsampled fruit were midsized (135 g mean over 3 years) for the fruit within the respective treatment and similarly sized across treatments. Fruit with visible subsurface damage were excluded, but surface blemishes were not a consideration for the subsampling among harvest data.

*Maturity and quality measurements.* Each apple from the harvest sample was weighed and visually assessed for percent red blush. The IEC was determined by gas chromatography (Series II; Hewlett Packard 5890, Wilmington, DE) using a 1-mL gas sample

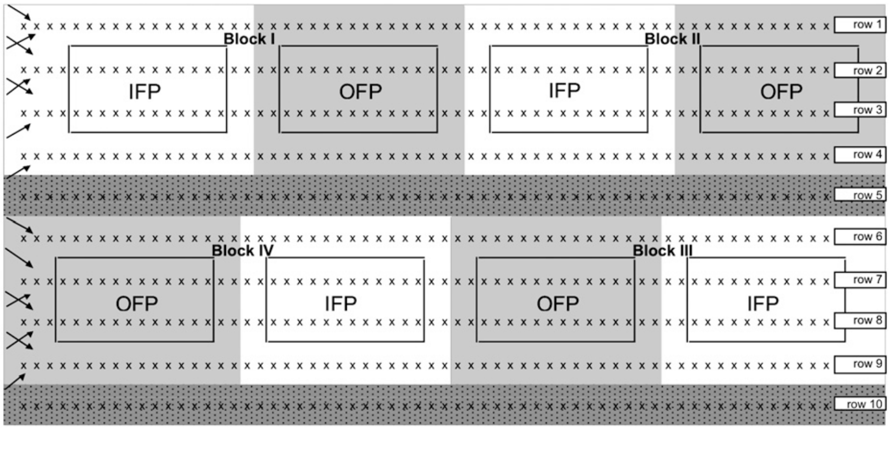

Fig. 1. Integrated (IFP) and organic fruit production (OFP) systems study area map. Each “×” represents an individual tree. The dark lined rectangles surround trees from where apples were sampled. Arrows on the left show the spray direction, which minimized drift among the treatment plots. Rows 5 and 10 were unsprayed buffer strips.

from the core cavity of each apple (Alwan and Watkins, 1999). Flesh firmness was measured, after removing part of the peel at two locations along the equator of each apple, with a penetrometer (EPT-1; Lake City Technical Products, Inc., Kelowna, BC, Canada) fitted with a cylindrical 11.1-mm diameter Effegi tip. Juice from the punctures was pooled to measure SSC using a digital refractometer (PAL-1; Atago, Inc., Bellevue, WA) and reported as °Brix. The starch index was determined by staining the stem side of an equatorial cross-section of the apples with iodine solution ($I_2$-KI) and visual rating, in which 1 = 100% staining and 8 = 0% staining (Blanpied and Silsby, 1992). TA was measured on two slices taken from opposite sides of the fruit, from the stem to the calyx, by titrating a 10-mL juice aliquot against a 0.1 N KOH solution to an end point of pH 8.1 with a Mettler-Toledo DL12 autotitrator (Columbus, OH).

*Year 2007 poststorage evaluations.* Fruit was stored in air at 0.5 °C and a relative humidity range of 90% to 95% for 9 weeks. Samples were sequentially removed from storage according to harvest date and held at 20 °C for either 1 or 7 d, and a 10-apple subsample from each experimental unit was then assessed for firmness, SSC, and TA as described previously.

*Sensory evaluations.* Once per year in 2005 to 2007, two separate double-blind consumer (untrained) taste panels were conducted at the Cornell Sensory Testing Facility. In the triangle test, panelists tasted three slices of apple (two from one treatment and one from the other) and were asked to identify the slice that was different from the other two (Lawless and Heymann, 1999). Each panelist assessed all four blocks separately and in a randomized order. Between 83 and 88 independent observations were made per block each year. In the second panel, the overall acceptability, texture, and overall flavor were rated on a 9-point hedonic scale (1 = dislike extremely; 5 = neither like/dislike; 9 = like extremely), whereas sweetness, tartness, crispness, firmness, and juiciness were rated on a 9-point intensity scale (1 = not at all sweet, not at all tart, not at all crisp, extremely soft, or not at all juicy, respectively; 9 = extremely sweet, extremely tart, extremely crisp, extremely hard, or extremely juicy, respectively). To minimize sensory saturation and context effects (Lawless and Heymann, 1999), individual panelists were limited to evaluating both treatments from only two of four blocks. By the end of the evaluation in each year, all four blocks were tested an equal number of times. Samples were presented separately and in a randomized order.

On each test day, apples were moved from cold storage and kept at room temperature (22 °C) for ≈4 h before testing. Unpeeled apples were cored and cut into eight equally sized slices (stem to calyx) with an apple corer/slicer. Individual slices were placed in a 3.8-cm wide plastic cup, identified with a three-digit blinding code, and immediately served to a panelist. Panelists were provided water for rinsing and cleansing the palate. Taste tests were conducted under red lights to mask blemishes and flesh browning. Each panelist used an individual booth equipped with a computer that led them through the tests and collected data using Compusense® *five* software (Version 4.6; Guelph, Ontario, Canada).

In 2006 and 2007, panelists also judged the overall appearance of apples on a 9-point hedonic scale. From each experimental unit, 10 whole apples were rinsed in water and placed on white trays with three-digit blinding codes. Appearance tests were conducted under fluorescent lighting to simulate a retail market. Each panelist judged both treatments from two blocks separately in a randomized order. By the end of the evaluation, all four blocks were tested an equal number of times. Each year, 48 to 56 independent observations were made per block for both the hedonic/intensity tests and the appearance tests.

Participants were recruited from the Cornell University community and were screened for product use, lack of health problems, and normalcy of smell and taste (by self-report). The Institutional Review Board of Human Participants at Cornell University approved our protocols. Participants received no prior training and were unaware of the purpose of the study. Each participant gave informed consent at the beginning of the study and received a token incentive at the conclusion of the session.

*Fruit mineral concentration.* A 2-cm equatorial slice of fruit flesh was taken from each sample and two 1.5-cm diameter plugs (No. 9 cork borer) of cortical tissue were removed from opposite sides of the apple beneath the peel (Turner et al., 1977). Composite fruit tissue was lyophilized and then analyzed on a dry weight basis at the Cornell Nutrient Analysis Laboratory. Total carbon and total nitrogen (N) were measured with Dumas combustion. Macro- and micronutrients were measured with an inductively coupled argon plasma spectrometer (Kalra, 1998). Dry matter content was determined after 24 h at 80 °C from two 1.5-cm diameter plugs taken from the same 2-cm thick equatorial slice.

*Total phenolic concentrations and antioxidant capacity.* Unpeeled cored apples were diced and 150-g subsets were lyophilized. Finely ground 1-g subsamples were extracted with 10 mL of 80% aqueous methanol (Kim and Lee, 2002). The headspace of sample bottles was flushed with nitrogen and samples were sonicated for 20 min with a Branson 2200 (Fischer Scientific, Fair Lawn, NJ) under continual nitrogen purging and then decanted. The previous process was then repeated with the supernatant. The two decant volumes were combined and diluted to 25 mL with 80% methanol. Samples were stored in glass bottles at –10 °C until assays were performed. Total phenolic concentrations were measured using the Folin-Ciocalteu colorimetric method (Singleton and Rossi, 1965) as modified by Valois et al. (2006) and reported as milligrams gallic acid equivalents/100 g fruit on a fresh weight basis. The VCEAC was based on the reduction of absorbance at 734 nm on a BrandTech Scientific ultraviolet/Vis diode-array spectrophotometer (Essex, CT) after the extracted sample was added to a solution containing free radical generating 2,2′-Azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) as diammonium salt (Kim et al., 2002). Values are reported as milligrams VCEAC/100 g fruit on a fresh weight basis.

*Statistical analyses.* All data were analyzed with a mixed model to assess the long-term effects of each production system using the PROC MIXED procedure of SAS 9.1 (Cary, NC). The mixed model included year (2004 to 2007), treatment (IFP and OFP), and their interactions as fixed effects for dry matter content, sensory evaluations, fruit mineral concentrations, total phenolic concentrations, and antioxidant capacity. For the IEC, blush, starch, firmness, TA, SSC, and SSC:TA, the statistical mixed models also included the harvest timing (1 to 4) as a fixed effect. For the 2007 postharvest evaluations, the statistical model included treatment (IFP and OFP), harvest timing (1, 2, or 3), and day (1 or 7) as fixed effects. Block, treatment × block, and, when the harvest effect was included, treatment × block × year were random effects. The IEC data were log-transformed as a result of skewed distributions and then presented as back-transformed means. Main effects, interactions, and treatment effects within interactions were considered significant when $P \leq 0.05$.

## Results

*Maturity and quality measurements.* Fruit maturity and quality measurements were not consistently different between treatments, but interactions among treatments, year, and harvest timing were found for some harvest measurements (Table 1). The IFP-grown fruit weighed more in 2005 and 2006, but OFP-grown fruit weighed more in 2007. This corresponded with the average fruit size from all harvested fruit (data not shown). The IEC of fruit was not different between treatments, and the starch index was only different in 2005 when OFP-grown apples had less starch hydrolysis compared with those from the IFP system. The IFP-grown apples were more highly blushed in 2007, but this did not result in a greater percentage of fruit graded into the most highly valued marketing category (U.S. Extra Fancy) (Federal Register, 2002). Apples from the IFP system were firmer than OFP-grown apples at the first two harvests in each year, but in 2004, OFP-grown fruit was firmer at the fourth harvest. The SSC of fruit was not different between treatments. Titratable acidity was higher in fruit from the OFP system in 2006 and 2007. Fruit from the OFP system had a higher sugar-to-acid ratio (SSC:TA) in 2004, but IFP-grown apples had a higher SSC:TA ratio in 2006 and 2007. In 2007, IFP-grown apples had lower dry matter content, but the difference was less than

Table 1. Average fruit weight, internal ethylene concentration (IEC; shown as back-transformed means), starch index, blush, firmness, soluble solids concentration (SSC), titratable acidity (TA), the SSC:TA ratio, and dry matter content of apples from integrated (IFP) or organic fruit production (OFP) systems at harvest over 4 years.[z]

| Year | Harvest | Treatment | Avg fruit wt (g) | IEC ($\mu L \cdot L^{-1}$) | Starch (1–8) | Blush (%) | Firmness (N) | SSC (°Brix) | TA ($g \cdot mL^{-1}$) | SSC:TA | Dry matter content (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2004 | 1 | IFP | N/A | 0.1 | 1.4 | 71 | 88.3 | 11.4 | 0.492 | 23.3 | |
| 2004 | 1 | OFP | N/A | 0.1 | 1.7 | 67 | 86.4 | 11.3 | 0.482 | 23.6 | |
| 2004 | 2 | IFP | N/A | 0.2 | 2.1 | 77 | 83.4 | 12.0 | 0.476 | 25.3 | |
| 2004 | 2 | OFP | N/A | 0.5 | 2.0 | 78 | 82.0 | 12.2 | 0.442 | 27.5 | |
| 2004 | 3 | IFP | N/A | 5.2 | 2.8 | 80 | 85.0 | 12.7 | 0.503 | 25.2 | |
| 2004 | 3 | OFP | N/A | 7.7 | 2.9 | 81 | 83.7 | 12.2 | 0.449 | 27.1 | |
| 2004 | 4 | IFP | N/A | 12.4 | 3.3 | 94 | 78.8 | 12.9 | 0.435 | 29.7 | |
| 2004 | 4 | OFP | N/A | 30.6 | 3.6 | 95 | 81.6 | 13.4 | 0.429 | 31.2 | |
| 2005 | 1 | IFP | 155 | 17.9 | 3.9 | 89 | 85.3 | 12.0 | 0.577 | 20.9 | |
| 2005 | 1 | OFP | 141 | 4.4 | 3.2 | 97 | 84.5 | 12.4 | 0.564 | 22.0 | |
| 2005 | 2 | IFP | 160 | 23.8 | 4.2 | 99 | 80.9 | 12.8 | 0.554 | 23.1 | 15.8 |
| 2005 | 2 | OFP | 137 | 11.1 | 3.9 | 99 | 81.2 | 12.5 | 0.512 | 24.7 | 15.4 |
| 2006 | 1 | IFP | 133 | 0.7 | 1.3 | 80 | 87.6 | 11.2 | 0.464 | 24.2 | |
| 2006 | 1 | OFP | 120 | 1.1 | 1.5 | 73 | 86.2 | 11.6 | 0.508 | 22.7 | |
| 2006 | 2 | IFP | 134 | 12.1 | 2.1 | 90 | 85.5 | 12.1 | 0.424 | 28.6 | |
| 2006 | 2 | OFP | 121 | 14.7 | 2.5 | 86 | 83.7 | 12.1 | 0.466 | 26.1 | |
| 2006 | 3 | IFP | 143 | 40.5 | 3.8 | 96 | 80.8 | 13.2 | 0.408 | 32.5 | 14.9 |
| 2006 | 3 | OFP | 131 | 34.1 | 4.3 | 94 | 80.4 | 13.2 | 0.472 | 27.9 | 14.5 |
| 2007 | 1 | IFP | 124 | 0.6 | 1.1 | 73 | 87.2 | 11.4 | 0.442 | 25.7 | |
| 2007 | 1 | OFP | 138 | 0.3 | 1.0 | 62 | 85.9 | 11.4 | 0.536 | 21.5 | |
| 2007 | 2 | IFP | 137 | 0.8 | 1.8 | 85 | 86.4 | 11.9 | 0.453 | 26.3 | |
| 2007 | 2 | OFP | 148 | 0.4 | 1.5 | 78 | 83.7 | 11.7 | 0.508 | 23.1 | |
| 2007 | 3 | IFP | 148 | 21.5 | 3.3 | 95 | 80.9 | 12.1 | 0.415 | 29.2 | 13.7 |
| 2007 | 3 | OFP | 153 | 18.0 | 2.8 | 93 | 81.1 | 12.0 | 0.452 | 26.5 | 14.4 |
| Year | | | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| Harvest | | | *** | *** | *** | *** | *** | *** | *** | *** | |
| Treatment | | | ** | NS | NS | NS | NS | NS | NS | NS | NS |
| Harvest × treatment | | | NS | NS | NS | NS | *** | NS | NS | NS | |
| Year × treatment | | | *** | NS | * | * | NS | NS | *** | *** | * |
| Treatment effects within the year × treatment interaction | | | | | | | | | | | |
| 2004 | | | | | NS | NS | | | NS | * | |
| 2005 | | | *** | | * | NS | | | NS | NS | NS |
| 2006 | | | ** | | NS | NS | | | ** | *** | NS |
| 2007 | | | ** | | NS | * | | | ** | *** | * |
| Treatment effects within the harvest × treatment interaction | | | | | | | | | | | |
| Harvest 1 | | | | | | | * | | | | |
| Harvest 2 | | | | | | | * | | | | |
| Harvest 3 | | | | | | | NS | | | | |
| Harvest 4 | | | | | | | * | | | | |

[z] Significance levels of the main effects (year, harvest, or treatment), interactions, and treatment effects within an interaction are at the bottom of the table. Each value represents the mean of a 10-apple subsample from four replicated blocks within each treatment.

NS, *, **, ***Nonsignificant or significant differences at $P \leq 0.05$, 0.01, or 0.001, respectively.

N/A = data not available.

1% and probably had little influence over the other measurements taken in this experiment.

*Year 2007 poststorage evaluations.* Apples from the OFP system were consistently firmer and had greater SSC, TA, and SSC:TA than those from the IFP system after 9 weeks of storage at 0.5 °C in 2007 (Table 2). Harvest × treatment and day × treatment interactions for firmness resulted from differences in magnitude between IFP-grown and OFP-grown apples at the various test intervals. Overall, the OFP-grown apples weighed ≈20 g more than IFP-grown apples at the second harvest that year.

*Sensory evaluations.* In the triangle test, consumer panelists were able to correctly distinguish the two treatments in all years. This difference started at 58% correct judgments in 2005 but dropped to 52% in 2006 and then to 48% in 2007 compared with a one-in-three chance of a random correct selection. Treatment effects were not significant for the hedonic/intensity tests, and treatment effects within interactions were not consistent (Table 3). For example, OFP-grown apples were judged sweeter in 2005, IFP-grown apples were judged sweeter in 2006, and no difference was found in 2007. Apples from the OFP system were judged to have better overall flavor and better overall acceptability in 2005 and to have crisper and firmer flesh in 2007. The largest difference between the treatments was for overall appearance in 2006. In that year, there were more blemishes observed by the panelists on the OFP-grown apples as a result of a high incidence of sooty blotch [a fungal complex that includes *Peltaster fruticola* (Johnson, Sutton & Hodges), *Leptodontium elatius* (G. Mangenot) De Hoog, *Geastrumia polystigmatis* Batista & M.L. Farr], flyspeck [*Schizothyrium pomi* (Mont. & Fr.) Arx], and other production-related cosmetic defects (e.g., scarfskin and russeting) on OFP-grown apples.

*Fruit mineral concentration.* Concentrations of potassium (2004 and 2005) and calcium (Ca) (all years) were higher in IFP-grown than OFP-grown fruit (Table 4). The magnesium–to-calcium ratio was highest in the OFP-grown fruit, probably because of the lower Ca concentrations. No other nutrient concentrations were found to be different between the treatments over the 4 years.

*Total phenolic concentrations and antioxidant capacity.* The TP concentrations and VCEAC were not different between fruit from the two growing systems (Table 5). However, the TP concentrations for both treatments increased from 2004 to 2005 to 2006 to 2007.

## Discussion

Increases of IEC, starch indices, and SSC and the decreases of firmness and TA during the sequential harvests indicated a rapid ripening period for 'Liberty' apples. Fruit changed from under- to overripe within a 1-week interval, indicating that the proper harvest timing of 'Liberty' was critical for the comparative fruit quality evaluations that were conducted. In 2004, 2006, and 2007, fruit maturity advanced at the same rate in both systems. In 2005, the OFP-grown fruit appeared to have delayed maturity compared

Table 2. Measurements of average fruit weight, firmness, soluble solids concentration (SSC), titratable acidity (TA), and the SSC:TA ratio of apples from integrated (IFP) or organic fruit production (OFP) systems in 2007 after 9 weeks of storage at 0.5 °C.$^z$

| Harvest | Day | Treatment | Avg fruit wt (g) | Firmness (N) | SSC (°Brix) | TA ($g \cdot mL^{-1}$) | SSC:TA |
|---|---|---|---|---|---|---|---|
| 1 | 1 | IFP | 143 | 57.9 | 12.6 | 0.401 | 32.0 |
| 1 | 1 | OFP | 152 | 64.6 | 13.0 | 0.434 | 30.0 |
| 1 | 7 | IFP | 149 | 54.5 | 12.6 | 0.344 | 37.4 |
| 1 | 7 | OFP | 152 | 58.3 | 13.1 | 0.363 | 36.5 |
| 2 | 1 | IFP | 140 | 52.8 | 12.7 | 0.320 | 39.6 |
| 2 | 1 | OFP | 161 | 64.1 | 13.5 | 0.393 | 34.5 |
| 2 | 7 | IFP | 140 | 52.1 | 12.8 | 0.277 | 46.1 |
| 2 | 7 | OFP | 160 | 61.0 | 13.4 | 0.330 | 40.6 |
| 3 | 1 | IFP | 158 | 52.4 | 12.6 | 0.334 | 37.6 |
| 3 | 1 | OFP | 155 | 59.2 | 13.5 | 0.404 | 33.5 |
| 3 | 7 | IFP | 153 | 47.8 | 12.7 | 0.307 | 42.1 |
| 3 | 7 | OFP | 156 | 53.7 | 13.7 | 0.350 | 39.5 |
| Day | | | NS | *** | NS | *** | *** |
| Harvest | | | ** | *** | NS | *** | *** |
| Treatment | | | * | ** | * | *** | *** |
| Harvest × treatment | | | *** | *** | NS | NS | NS |
| Day × treatment | | | NS | * | NS | NS | NS |
| Treatment effects within the day × treatment interaction | | | | | | | |
| 1 | | | | *** | | | |
| 7 | | | | ** | | | |
| Treatment effects within the harvest × treatment interaction | | | | | | | |
| 1 | | | NS | ** | | | |
| 2 | | | *** | *** | | | |
| 3 | | | NS | ** | | | |

$^z$Significance levels of the main effects (day, harvest, or treatment), interactions, and treatment effects within an interaction are at the bottom of the table. Each value represents the mean of a 10-apple subsample of four replicated blocks within each treatment.

NS, *, **, ***Nonsignificant or significant differences at $P \leq 0.05$, 0.01, or 0.001, respectively.

with IFP-grown fruit. For that reason, in 2005, we compared IFP-grown apples from the first harvest with OFP-grown apples from the second harvest for measurements of mineral content, sensory evaluations, TP, and VCEAC.

In the present study, firmness, SSC, TP, and VCEAC were not consistently different between the production systems; however, higher TA and lower SSC:TA were found in OFP-grown apples in 2006 and 2007 and the percentage red blush was greater for IFP-grown apples in 2007. In other comparative systems studies (Briviba et al., 2007; DeEll and Prange, 1992; Lamperi et al., 2008; Peck et al., 2006; Reganold et al., 2001; Róth et al., 2007; Weibel et al., 2000), results have been mixed and did not match our results, suggesting that there are too many factors involved to consistently attribute fruit quality differences to a particular production system. Reports from comparative systems studies in other perennial fruit production systems have also shown ambiguous results for phytochemical content (reviewed by Zhao et al., 2006). Growing region and cultivar appear to more strongly affect fruit quality than production system (Lamperi et al., 2008; McGhie et al., 2005).

Many interrelated biotic and abiotic factors can influence fruit maturity and quality by altering carbohydrate and water balance in the plant. However, although we found occasional treatment differences in yields, fruit size, pest damage, and weed pressure (Peck, 2009), we did not find clear relationships to fruit quality. Crop loads are known to affect maturity and quality (Awad et al., 2001; Francesconi et al., 1996), but in our experiment, yields were similar between treatments in 2005 when maturity was different between systems; and no maturity effects were detected in 2007 when IFP system yields were significantly greater than those of OFP (data not shown). The IFP-grown fruit were larger in 2005 and 2006 (by 18 and 13 g, respectively), and OFP-grown fruit was 10 g larger in 2007, but there did not appear to be a strong relationship between fruit size and the other measurements, perhaps because these fruit size differences were small and fruit from both treatments would have mostly been within the same U.S. Department of Agriculture size grading range (Federal Register, 2002). Pest and disease pressure were greater for OFP (data not shown), which affected crop quality in terms of cullage and marketability, but there did not seem to be much effect on the internal fruit quality. Likewise, kaolin clay (Surround® WP; Engelhard Corporation, Iselin, NJ), which has been shown to sometimes effect fruit quality (Glenn et al., 2001, 2005; Schupp et al., 2002; Wand et al., 2006), was applied between 173 and 575 kg a.i./ha/year for OFP pest control and did not consistently cause greater fruit size or increase peel color as reported in other studies (Glenn et al., 2001, 2005). Additionally, the increase in SSC and firmness that was reported by Merwin (2003) when apple trees were grown in a competitive groundcover as was the case in our OFP system was not found in the present study.

Poststorage quality was evaluated only in 2007; fruit from the OFP system were consistently firmer and had higher SSC, TA, and SSC:TA ratios than IFP-grown fruit. Despite our best efforts to match fruit size, the OFP-grown apples from the second harvest sampling were ≈20 g heavier. However, although smaller apples tend to be firmer than larger apples, the OFP-grown apples at this harvest sampling were both larger and firmer than IFP-grown apples. Peck et al. (2006) and Reganold et al. (2001) also reported that apples grown under OFP systems had better storage life than those from IFP systems, but this effect may not be consistent (Róth et al., 2007). Higher fruit Ca concentrations have been associated with greater flesh firmness

Table 3. Consumer sensory panel ratings of apples from integrated (IFP) or organic fruit production (OFP) systems at harvest over 3 years.$^z$

| Year | Treatment | Sweetness (1–9) | Tartness (1–9) | Overall flavor (1–9) | Firmness (1–9) | Crispness (1–9) | Juiciness (1–9) | Overall acceptability (1–9) | Appearance (1–9) |
|---|---|---|---|---|---|---|---|---|---|
| 2005 | IFP | 5.7 | 5.7 | 5.9 | 7.0 | 6.9 | 6.9 | 6.4 | N/A |
| 2005 | OFP | 6.3 | 6.0 | 6.4 | 6.9 | 6.8 | 6.9 | 6.8 | N/A |
| 2006 | IFP | 6.4 | 6.2 | 6.4 | 7.0 | 7.0 | 6.9 | 6.7 | 6.5 |
| 2006 | OFP | 6.1 | 6.0 | 6.2 | 7.0 | 6.9 | 6.9 | 6.5 | 5.5 |
| 2007 | IFP | 6.2 | 5.9 | 6.1 | 6.8 | 6.8 | 6.7 | 6.4 | 6.6 |
| 2007 | OFP | 6.1 | 6.2 | 6.3 | 7.2 | 7.0 | 6.9 | 6.6 | 6.6 |
| Year | | NS | NS | NS | NS | NS | NS | NS | ** |
| Treatment | | NS | NS | NS | NS | NS | NS | NS | * |
| Year × treatment | | *** | NS | ** | NS | * | NS | * | *** |
| Treatment effects within the year × treatment interaction | | | | | | | | | |
| 2005 | | *** | | ** | | NS | | ** | |
| 2006 | | * | | NS | | NS | | NS | *** |
| 2007 | | NS | | NS | | ** | | NS | NS |

$^z$Significance levels of the main effects (year or treatment), interactions, and treatment effects within an interaction are at the bottom of the table. Each value represents the mean of at least 48 independent observations of four replicated blocks within each treatment.

NS, *, **, ***Nonsignificant or significant differences at $P \leq 0.05$, 0.01, or 0.001, respectively.

N/A = data not available.

Table 4. Mineral concentrations of apple flesh (dry weight basis) from integrated (IFP) or organic fruit production (OFP) systems at harvest over 4 years.$^z$

| Year | Treatment | C (%) | N (%) | C:N | P (%) | K (%) | Ca (%) | Mg (%) | Al (μg·g$^{-1}$) | B (μg·g$^{-1}$) | Cu (μg·g$^{-1}$) | Fe (μg·g$^{-1}$) | Mn (μg·g$^{-1}$) | Zn (μg·g$^{-1}$) | N:Ca | N:P | Mg:Ca | Mg + K:Ca |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2004 | IFP | 40.2 | 0.11 | 359 | 0.047 | 0.50 | 0.028 | 0.022 | 1.3 | 20.2 | 5.2 | 5.5 | 1.9 | 3.6 | 4.2 | 2.4 | 0.82 | 19 |
| 2004 | OFP | 40.1 | 0.11 | 377 | 0.045 | 0.45 | 0.023 | 0.020 | 1.2 | 19.5 | 4.6 | 5.3 | 1.6 | 2.8 | 4.9 | 2.4 | 0.88 | 21 |
| 2005 | IFP | 39.1 | 0.13 | 302 | 0.072 | 0.74 | 0.023 | 0.024 | 2.2 | 27.9 | 2.3 | 15.9 | 2.1 | 5.0 | 5.9 | 1.8 | 1.08 | 34 |
| 2005 | OFP | 38.8 | 0.13 | 298 | 0.067 | 0.68 | 0.016 | 0.021 | 2.4 | 32.4 | 2.0 | 16.8 | 2.0 | 5.3 | 9.8 | 2.0 | 1.38 | 52 |
| 2006 | IFP | 40.8 | 0.11 | 373 | 0.052 | 0.49 | 0.024 | 0.023 | 4.0 | 19.5 | N/A | 11.9 | 3.8 | N/A | 5.0 | 2.1 | 1.00 | 23 |
| 2006 | OFP | 40.7 | 0.10 | 395 | 0.054 | 0.51 | 0.021 | 0.024 | 3.7 | 19.3 | N/A | 8.2 | 2.2 | N/A | 5.1 | 1.9 | 1.16 | 26 |
| 2007 | IFP | 40.4 | 0.11 | 383 | 0.051 | 0.48 | 0.029 | 0.022 | 0.0 | 9.1 | 1.9 | 6.5 | 1.3 | 12.2 | 3.8 | 2.1 | 0.78 | 17 |
| 2007 | OFP | 40.1 | 0.13 | 343 | 0.050 | 0.50 | 0.028 | 0.024 | 1.7 | 9.7 | 4.4 | 6.9 | 1.3 | 17.3 | 4.5 | 2.5 | 0.84 | 19 |
| Year | | *** | NS | * | *** | *** | ** | NS | *** | *** | ** | ** | NS | *** | ** | * | *** | *** |
| Treatment | | NS | NS | NS | NS | NS | * | NS | NS | NS | NS | NS | NS | NS | NS | NS | ** | NS |
| Year × treatment | | NS | NS | NS | NS | ** | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Treatment effects within the year × treatment interaction | | | | | | | | | | | | | | | | | | |
| 2004 | | | | | | * | | | | | | | | | | | | |
| 2005 | | | | | | * | | | | | | | | | | | | |
| 2006 | | | | | | NS | | | | | | | | | | | | |
| 2007 | | | | | | NS | | | | | | | | | | | | |

$^z$Significance levels of the main effects (year or treatment), interactions, and treatment effects within an interaction are at the bottom of the table. Each value represents the mean of a pooled sample of 10 apples of four replicated blocks within each treatment.

NS, *, **, ***Nonsignificant or significant differences at $P \leq 0.05$, 0.01, or 0.001, respectively

N/A = data not available.

(Ferguson and Boyd, 2002), but in the current study, greater Ca was observed in IFP-grown fruit, not OFP-grown fruit, although in 2007, the difference was small (Table 4). Differences between the results in our study and others may reflect different cultivars or growing regions. However, detecting differences in ‘Liberty’, a rapidly ripening cultivar, was significant.

Although the triangle test panelists consistently discriminated between fruit from the two growing systems, there was no obvious basis for this distinction. Red lighting and equally sized apple slices made it unlikely that panelists were able to visually identify the slice that was different. Additionally, panelists were instructed to identify the fruit that tasted different regardless of appearance. Panel scores showed that the eating quality of apples from both systems was rated favorably (greater than 5 on hedonic and intensity scales) by consumers.

There were a few correlations between fruit quality measured by laboratory instruments and rated by the sensory panelists. In 2005, when OFP-grown apples were judged by panelists to be sweeter, the SSC:TA ratio was greater for OFP-grown apples; in 2006, when IFP-grown apples were judged to be sweeter, the SSC:TA ratio was greater for IFP-grown apples. The SSC:TA ratio was also greater for IFP-grown apples in 2007, but the difference between treatments was smaller than in previous years and was apparently below the level of differentiation for most sensory panelists (Harker et al., 2002a). In all years, panelists reported similar firmness ratings between treatments, which were also confirmed by objective firmness measurements. Flesh firmness differences may need to be greater than 6 N for trained panelists to detect fruit texture differences (Harker et al., 2002b). The greater crispness reported by panelists in 2007 was not consistent with penetrometer measurements taken at harvest, but crispness is a different textural attribute than firmness and is more difficult to relate to penetrometer measurements (Harker et al., 2002b).

The 1-point difference in the 2006 overall appearance test was a strong indication that cosmetic blemishes on the OFP-grown apples were less acceptable to consumers than the mostly unblemished IFP-grown fruit. This could be a serious impediment to OFP in the northeast United States because of increased likelihood that apples grown under this system will be blemished. Yue et al. (2006) found that 75% of the consumers surveyed at a large midwestern university (undergraduate students were excluded) were willing to pay a premium for organic apples given identical appearance to conventionally grown apples. However, only 28% of the survey participants were willing to pay a premium when organic apples with cosmetic imperfections (such as sooty blotch/flyspeck damage) were compared with unblemished conventional fruit; and that premium was less than half the premium given to unblemished organic apples. In that study, less than 5% of the

Table 5. Total phenolic concentration and antioxidant activity of unpeeled apples (fresh weight basis) from integrated (IFP) or organic fruit production (OFP) systems at harvest over 4 years.[z]

| Year | Treatment | Total phenolics (mg GAE/100 g fruit) | Antioxidant capacity (mg VCEAC/100 g fruit) |
|---|---|---|---|
| 2004 | IFP | 76.4 | 241.0 |
| 2004 | OFP | 79.2 | 227.4 |
| 2005 | IFP | 82.4 | 137.0 |
| 2005 | OFP | 74.5 | 153.8 |
| 2006 | IFP | 150.7 | 225.9 |
| 2006 | OFP | 157.3 | 239.7 |
| 2007 | IFP | 137.9 | 232.4 |
| 2007 | OFP | 144.6 | 223.3 |
| Year | | *** | *** |
| Treatment | | NS | NS |
| Year × treatment | | NS | NS |

[z] Significance levels of the main effects (year or treatment) and interactions are at the bottom of the table. Each value represents the mean of a pooled sample of 10 apples of four replicated blocks within each treatment.

NS, *, **, ***Nonsignificant or significant differences at $P \leq 0.05$, 0.01, or 0.001, respectively.

GAE = gallic acid equivalent; VCEAC = vitamin C-equivalent antioxidant capacity.

sampled population was primarily interested in organic produce and willing to purchase blemished organic apples for a premium similar to unblemished apples.

Our study of fruit maturity and quality during a 4-year transition period from conventional to IFP-grown and OFP-grown apple systems showed that differences were small if present and that internal fruit quality was rarely different between the apple-growing systems. The major impact of the management systems was fruit finish. For OFP to be broadly implemented in the northeast United States, better fruit finish must be achieved because in a supermarket environment, cosmetic blemishes might be paramount and detract from sales. However, consumers may be prepared to purchase fruit with lesser visual quality if organic is a strong purchasing motivation. Although many consumers are motivated to purchase organic foods for their putative compositional quality, our study suggests that for ‘Liberty’ apples, this perception might be incorrect. Other factors such as relative price, pesticide residues, potential enteropathogens, and the externalities of the system might be more valid motivations to purchase or avoid apples labeled as either organic or IFP.

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