Efficient Sampling to Determine the Distribution of Fruit Quality and Yield in a Commercial Apple Orchard

M. Martinez
Faculty of Life Sciences
University of Copenhagen
Frederiksberg
Denmark

D. Wulfsohn and I. Zamora
Dayenú Ltda
San Fernando, Region de O'Higgins
Chile

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Abstract

In situ assessment of fruit quality and yield can provide critical data for marketing and for logistical planning of the harvest, as well as for site-specific management. Our objective was to develop and validate efficient field sampling procedures for this purpose. We used the previously reported 'fractionator' tree sampling procedure and supporting handheld software (Gardi et al., 2007; Wulfsohn et al., 2012) to obtain representative samples of fruit from a 7.6-ha apple orchard (*Malus ×domestica* 'Fuji Raku Raku') in central Chile. The resulting sample consisted of 70 fruit on 56 branch segments distributed across 36 trees for yield estimation. A sub-sample of 56 fruit (one per branch segment) was removed; and, individual fruit mass, firmness and contents of malic acid, soluble solids and starch were measured in the laboratory. The data also were used to obtain an imprecise, but unbiased, estimate of yield. Estimated marketable yield was 295.8±50.2 t. Field and packinghouse records indicated that of 348.2 t sent to packing (52.4 t or 15% higher than our estimate), 263.0 t was packed for export (32.8 t less or -12% error compared to our estimate). The estimated distribution of caliber compared very well with packinghouse records. The distributions of sample fruit maturity measurements were used to estimate the proportion of fruit meeting exporter quality standards.

INTRODUCTION

In situ evaluation of fruit quality and maturity is important for market planning and for orchard block management by growers. Few descriptions can be found in the literature of sampling protocols for obtaining fruit samples from across an orchard, as opposed to postharvest sampling from storage boxes or from conveying systems and sorters. A number of methods based on random sampling and/or systematic sampling have been studied for sampling fruit for large-scale yield forecasts or for research (e.g., Jessen, 1955; Allen, 1972; Forshey and Elfving, 1979; De Silva et al., 2000). An Australian protocol for maturity evaluation of apples from an orchard or block recommends that at least 20 apples be picked by selecting five trees "at random" (and in another version, five "typical trees") within the orchard block, picking four apples of similar size from each tree at eye level (alternatively, from the zone within the tree to be picked), including a mix of fruit from "the inside and outside of the canopy and from a North, South, East and Westerly direction" (Chennel et al., 2002; Murphy et al., 2012). Damaged fruit are not included in the sample.

To obtain a statistically representative sample of a predefined population (e.g., undamaged fruit within the zone of the trees to be harvested) requires essentially that two conditions are met: (1) Fruit are sampled with uniform (constant) probability and (2) that the sample size is large enough to adequately represent the variability in the population. The selection of trees or fruit that "appear representative" of the orchard or tree is one reason for very high errors in some yield forecast protocols (Wulfsohn et al., 2012 and references therein). Humans are also notoriously poor at selecting things "at random" but require a well-defined way to label trees and fruit and the use of a random number table or generator.

Wulfsohn et al. (2012) evaluated a general methodology for sampling fruit from many species of fruit trees. The procedure was an application of nested systematic sampling and included procedures for defining and labeling (ordering) sampling units. Wulfsohn et al. (2012) demonstrated the potential of this approach for obtaining accurate estimates of yield from relatively small samples of fruit (e.g., several hundred apples to achieve accuracies better than 10%). Because the procedure provides uniform samples of fruit, it also can provide "representative" samples for quality evaluation in an orchard. With a judicious selection of sampling parameters at each level, the procedure will yield fruit from different zones of trees (heights aboveground and position in the canopy) without any need for the surveyor to apply personal preferences while sampling. In this paper, we applied the methodology to evaluate the distribution of size and quality of apples in a commercial orchard.

MATERIALS AND METHODS

We used the 'fractionator' sampling procedure (Wulfsohn et al., 2006, 2012) and the BranchSampler software (Gardi et al., 2007) to obtain representative fruit samples of the main cultivar, 'Fuji Raku Raku', from a 7.6 ha apple orchard near Molina, Chile, at the start of harvest in April 2011. The procedure was an application of multilevel nested systematic sampling (Fig. 1). The sampling units were defined as follows with sampling periods (intervals or spacings between adjacent samples) as indicated: (level 1) rows with a sampling period of 7, (level 2) trees-within-rows with a period equal to 35 trees, (level 3) primary branches on trees with a sampling interval of 9, and (level 4) branch-segments-within-branches using a period of 6. The first sample location at each level was determined by a uniform random integer in the range $[1, k_j]$ where k_j = sampling period for level j. Fruit were counted on the final sampling units (branch-segments) and then (level 5) one fruit selected randomly. BranchSampler was used to generate random integers and sampling locations, and for data input. Sampling periods were selected to obtain a large enough sample to reliably estimate the distributions of fruit caliber and quality. The data were also used to obtain an unbiased but imprecise (given the small sample size), estimate of total yield based on the predefined uniform sampling probability (given by the product of inverse periods) and total fruit number. A semi-empirical model was used to predict the uncertainty on the estimate (Wulfsohn et al., 2012). Sampled fruit were taken to the laboratory for measurements of mass (using a 0.1 g precision balance), flesh firmness (using a Güss Fruit Texture Analyzer with a 11 mm penetrometer), malic acid content (using titration with NaOH), soluble solids content (sucrose, using a Quick Brix 60, digital refractometer, Metler, Toledo) and starch index (using an iodine test). Estimated yield and caliber distribution were compared with field and packinghouse records of yield and calibers of the fruit that were packaged for export.

RESULTS AND DISCUSSION

The sample consisted of 70 fruit counted on 56 branch segments distributed on 36 trees obtained in 2.5 h by a two-person team. As shown in Figure 1, the sampling procedure produced 40 trees; however, four of these trees did not yield samples because of the small size and low vigor of these trees (e.g., if the number of fruit-bearing branches on the tree is less than the branch period, etc.). Furthermore, we did not sample the north - most nine rows of the eastern block (see Fig. 1) because these rows were being harvested at the time of our survey. Our estimate of yield was adjusted to account for these missing rows, which can be considered a source of systematic error in the final estimate (there exists a possibility that the vigor and yield of these rows is different compared to the rest of the block). Visibly defective and very small fruit were excluded from the samples. Marketable yield was estimated as 295.8±50.2 t. Field and packinghouse reports indicated that the total yield from the 7.6 ha orchard was 401.2 t. Of this, 348.2 t were of fresh-fruit market quality (national and export) and sent to packing. Finally, 267.0 t was packed for export. The tonnage exported also depends on the amount of fruit destined for export markets based on earlier market projections and pre-sales, and may be smaller than the actual amount of export-quality fruit. The value of 348.2 t corresponds most directly to the population of fruit we defined for the sampling and, therefore, to our yield estimate. The error of -52.4 t agrees well with the model-predicted SE of 50.2 t.

Figure 2 shows the estimated distribution of caliber compared with packinghouse records (all calibers calculated or adjusted based on an 18.2 kg box). The two distributions compare very well considering the sample size of only 56 fruit. Other sources of differences in the distributions may be inexact overlapping of caliber-mass ranges for different box sizes, and probably more importantly, differences in the two 'populations' compared because (1) we did not obtain samples of fruit from about 11% of the orchard area (9 rows) and (2) the fruit packaged for export is a subset of fruit of marketable quality.

The estimated distributions of fruit firmness, SSC, starch and malic acid content are shown in Fig. 3. Fruit quality distributions were compared with the exporter's standard for export and the proportion of fruit falling with these ranges determined as summarized in Table 1. No standard for malic acid is defined. Red cultivars like 'Fuji Raku Raku' are also graded based on color, which we did not measure for our samples. Other than fruit caliber and color class, no fruit quality data are collected during packing. We therefore cannot compare or estimated distributions with the real distribution of these quality properties.

More intensive sampling should be used for precise yield estimation and for creating maps of quality and yield (see Aggelopoulou et al., 2010; Wulfsohn et al., 2012).

CONCLUSIONS

The 'fractionator' protocol provided a straightforward and efficient procedure to obtain representative samples of fruit in an orchard. Seventy fruit counted on 56 branch segments distributed across 40 trees from a 7.6 ha 'Fuji Raku Raku' apple orchard resulted in an estimation of marketable yield with an error of about -17%. This error was within the model-predicted range of error for the estimator. A sample of 56 fruit produced an estimated distribution of caliber similar to the distribution of the fruit packaged for export. Distributions of other quality parameters provided estimations of the proportion of fruit meeting export quality standards established by the industry.

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Tables

Table 1. Harvest maturity parameters for Chilean grown 'Fuji' apples destined for immediate export and estimated percentage of fruit in orchard meeting the normative at the time of harvest.

Variable	Standard	Range in sample	% of export quality
Firmness (kg)	6.4 - 9.1	5.9 - 10.4	86%
Soluble solids (°Brix)	>12.0%	12.1-18.6	100%
Starch index (10-scale)	5 - 7	4 - 10	43%

Figures

Fig. 1. Nested systematic sampling was used at (1) row, (2) tree-in-row, (3) branch-on-tree, (4) segment-in-branch levels, and random sampling at the (5) fruit-on-segment stage. Location labels show the number of branch segments (the final sampling level) sampled on each tree in the sample.

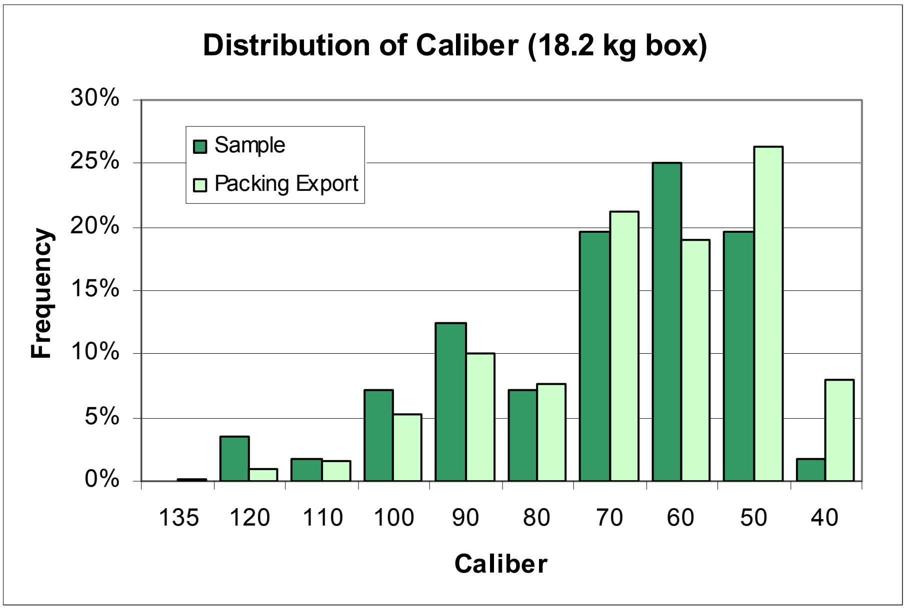

Fig. 2. Comparison of size distribution estimated from a sample of 56 fruit with size distribution of fruit packaged for export.

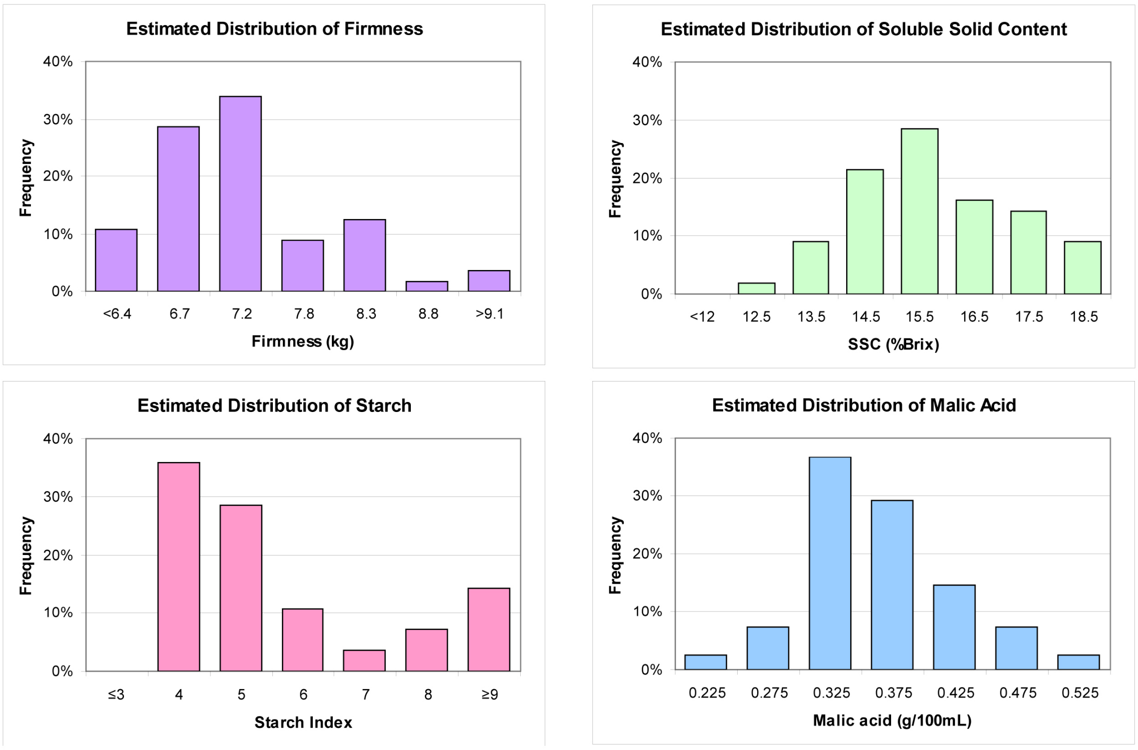

Fig. 3. Estimated distributions of flesh firmness, SSC, starch content and malic acid content of apples at the start of harvest.