CORRELATIONS BETWEEN FRUIT SIZE AND FRUIT QUALITY IN APPLE TREES WITH HIGH AND STANDARD CROP LOAD LEVELS

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ABSTRACT

In 2004, a trial was carried out to determine the relationships between fruit size and other fruit quality parameters in order to assess whether small size is correlated with poor fruit quality in apples. The trial was carried out in two commercial orchards near the town of Scurelle in the middle of Valsugana valley in Trentino Alto Adige region. 'Golden Delicious' (Clone B) and 'Red Chief' (*Malus* × *domestica* Borkh.) trees were cultivated under heavy and standard crop loads. Half of the trees of each cultivar were hand thinned to obtain a heavy crop load of about eight fruits per square centimeter TCSA, and the other half were thinned to obtain a standard crop load of about six fruits per square centimeter TCSA. At harvest, fruits were counted, and fruit diameter, fruit weight, flesh firmness, total soluble solids (TSS) content and titratable acidity were recorded. Correlation and regression analysis were also performed in order to determine the relationships among fruit quality parameters. In cultivars, fruit size and fruit weight were lower with heavy cropping trees than with standard cropping trees. On the other hand, TSS content and flesh firmness were higher with heavy cropping trees. With both cultivars and at both crop load levels, there was a slightly negative correlation between fruit size and TSS content, and a more negative correlation between fruit weight and flesh firmness. The only strong positive correlation found was between fruit size and fruit weight. All of the parameters evaluated in this trial were weakly correlated with each other, except for size and weight. Fruits from heavy cropping trees were smaller, firmer, and had a higher TSS content, which indicates that a moderate increase in crop load does not affect fruit quality.

Key words: apple, fruit load, flesh firmness, sugar content, acidity, thinning

INTRODUCTION

To apple growers, fruit size is strongly correlated with profits. Size, together with shape and colour, is one the most important fruit quality characteristics to consumers (Schotzko, 1985). Apple growers all over the world use chemical or hand thinning to reduce crop load so that, at harvest time, their apples will be larger and more attractive to consumers (Williams, 1985).

On June 1, 2008, new European Union Commission regulations will come into full effect (EC 85/2004, amended by Commission Regulation EC 1238/2005). According to these new regulations, apples will be divided into three categories depending on either diameter or weight: Extra, Class I and Class II. The new regulations lower the minimum size and weight requirements for each category, and lower the minimum size requirements for commercial apple sale. Italian apple producers, including growers in the main apple-producing region of Trentino Alto Adige, fear that the new regulations will lower EU marketing standards and reduce quality for consumers.

Lightly thinned trees bear heavier crops of smaller fruits. Apples from trees with a heavy crop load tend to have lower total soluble solids content, lower titratable acidity, reduced flesh firmness, and altered background colour (Blank et al., 1986; Hansen, 1989; Greene et al., 1989; Johnson, 1992; 1994; Gottfried, 2000). However, the correlations between apple size and other fruit quality parameters are not clear and are the subject of ongoing discussion (Link, 2000).

The aim of this study was to assess whether small size is correlated with poor fruit quality in apples. A trial was carried out to determine the relationships between fruit size and other fruit quality parameters. To increase the amount of small fruits, the apple trees in this study were cultivated under heavy and standard crop load levels. The heavy crop load level was about 30% more than the standard crop load level. The fruit quality of apples from heavy and standard cropping trees was compared to each other.

MATERIAL AND METHODS

In 2004, a trial was carried out in two commercial orchards near the town of Scurelle in the middle of Valsugana valley in Trentino Alto Adige region. Scurelle lays 375 meters above sea level at a latitude of 46º 04' N and a longitude of 11º 31' E. The soil was an acidic sandy loam with high content of organic matter.

The experiment was carried out on four-year-old 'Golden Delicious' (Clone B) trees grafted on M9 rootstock, and on six-year old 'Red Chief' trees grafted on M26 rootstock (*Malus* × *domestica* Borkh.). The 'Golden Delicious' trees were planted 1.0 × 3.5 meters apart for a density of 2860 trees per hectare. The 'Red Chief' trees were planted 0.8 × 3.5 meters apart for a density of 3570 trees per hectare. The trees were planted in an east-west

orientation and were trained as slender spindles. Fertilizers, herbicides, pesticides, and drip irrigation were applied as required and in accordance with local recommendations.

For each cultivar, eighteen plants growing in a single row were selected on the basis of uniform growth habit and bloom density. At the beginning of the vegetative growth season, the trunk cross-sectional area (TCSA) of every plant was measured 15 cm above the scion-graft union.

Approximately forty days after full bloom, the June fruit drop had ended and the king fruitlets were about 15 mm in diameter. The fruits remaining on each tree were counted. Half of the trees of each cultivar were hand thinned to obtain a heavy crop load of about eight fruits per square centimeter TCSA, and the other half were thinned to obtain a standard crop load of about six fruits per square centimeter TCSA. In all cases, thinning was carried out by leaving the king fruitlet and one or more lateral fruitlets in every cluster, if necessary.

Table 1. Trunk cross-sectional area (TCSA), yield efficiency, mean fruit number per tree, and cumulative yield of 'Golden Delicious and 'Red Chief' apple trees carrying standard and high crop load

	Golden Delicious		Red Chief	
	standard load	high load	standard load	high load
TCSA [cm^2]	12.67 a	13.24 a	13.84 a	13.92 a
Yield efficiency (fruits cm^{-2} TCSA)	5.89 b	7.97 a	5.21 b	6.97 a
Fruits per trees	74.6 b	105.5 a	72.1 b	97.0 a
Yield [t ha^{-1}]	45.7	48.7	47.1	45.9

For each cultivar and row, values followed by the same letter are not significantly different according to Student's t-test ($p \leq 0.01$)

At harvest, four plants with crop load levels close to the desired values were selected for each cultivar. All fruits were counted, weighed and measured (Tab. 1). Fruits were divided into size classes in 5.0 mm increments (50-55, 55-60, etc.). Titratable acidity was measured in five replicates of ten fruits from each size class. Titratable acidity was measured using a DL-50 titrator (Mettler Toledo GmbH, Switzerland). Flesh firmness and total soluble solids content (TSS) were measured in all of the remaining fruits of each size class. Total soluble solids content was measured with an automated Pimprenelle analyzer (Satop Giraud Technologie, Cavillon, France).

Data were statistically elaborated using one-way analysis of variance (ANOVA), followed by means separation by Tukey's multiple-range test. Data were treated as a completely randomized design, treating all parameters

as independent variables. Differences between crop load levels were analyzed using Student's t-test.

Correlation and regression analysis were also performed in order to determine the relationships among fruit quality parameters.

RESULTS

Heavy crop load affected fruit size distribution in both 'Golden Delicious' and 'Red Chief' (Fig. 1 and 2). With 'Golden Delicious', there was an increase in the proportion of fruits in the 65-70 mm size class. With 'Red Chief', there was an increase in the proportion of fruits in the 60-65 mm size class. With both cultivars, there was a decrease in the proportion of fruits in the >75 mm size class.

With both cultivars, mean fruit weight and size were significantly lower in heavy cropping trees. On the other hand, flesh firmness and TSS content were higher (Tab. 2).

With both cultivars and at both crop load levels, there was a slightly negative correlation between fruit size and TSS content, and a more negative correlation between fruit weight and flesh firmness (Tab. 3). The only strong positive correlation found was between fruit size and fruit weight. Regression analysis was also performed, but none of the tested regression models fit the data satisfactorily (data not shown).

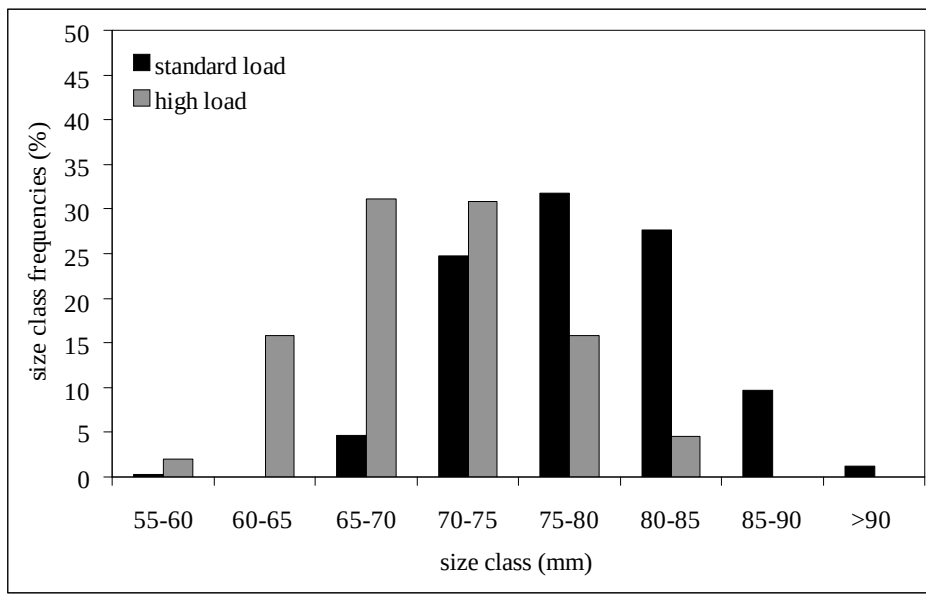

Figure 1. Size class frequencies of 'Golden Delicious' fruits picked from trees carrying standard and high crop load levels

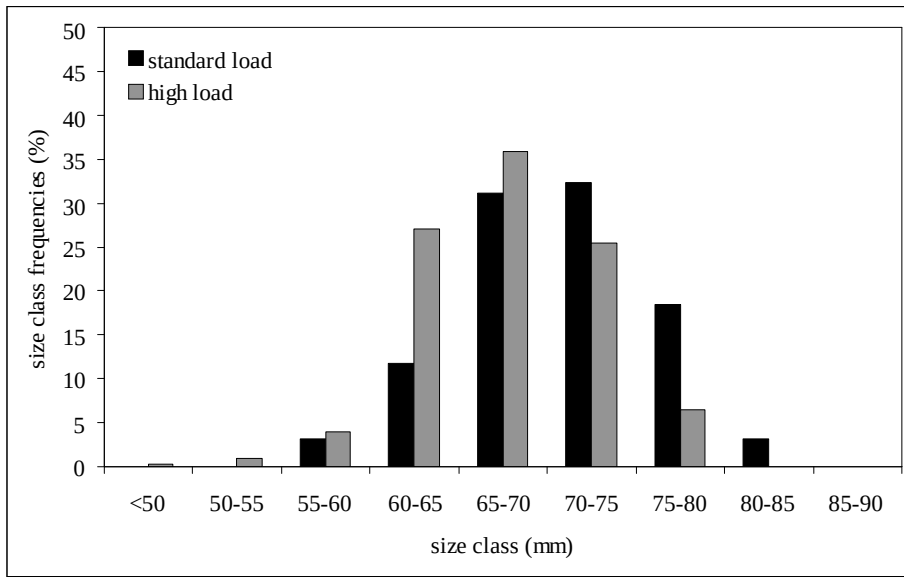

Figure 2. Size class frequencies of 'Red Chief' fruits picked from trees carrying standard and high crop load levels

Table 2. Effects of crop load on quality parameters of apple fruits picked from 'Golden Delicious' and 'Red Chief' trees carrying standard and high crop load

Parameter	Golden Delicious		Red Chief	
	standard load	high load	standard load	high load
Fruit weight [g]	214.4 a	161.1 b	183.1 a	132.6 b
Fruit size [mm]	78.10 a	70.04 b	73.73 a	65.14 b
TSS content [°Brix]	13.67 a	14.40 b	11.63 a	12.14 b
Flesh firmness [kg cm^{-2}]	7.03 a	7.79 b	7.65 a	8.34 b

For each cultivar and row, values followed by the same letter are not significantly different according to Student's t-test ($p \leq 0.01$)

With 'Golden Delicious', fruits in the size classes from 65 to 85 mm had a higher TSS content with heavy cropping trees than with standard cropping trees. Fruits in all size classes under 80 mm had a higher titratable acidity with heavy cropping trees than with standard cropping trees (Tab. 4).

With 'Red Chief' trees, fruits in the size classes from 55 to 65 mm had a higher TSS content and were more firm with heavy cropping trees than with standard cropping trees. On the other hand, there were no differences in titratable acidity between heavy cropping trees and standard cropping trees (Tab. 5).

Table 3. Correlations between size and weight, total soluble solids, and flesh firmness of apple fruits picked from 'Golden Delicious' and 'Red Chief' trees carrying standard and high crop load

Parameter	Golden Delicious		Red Chief	
	standard load	high load	standard load	high load
Fruit weight	0.971 (282)	0.977 (374)	0.956 (283)	0.515 (378)
TSS content	-0.17 (226)	-0.120 (289)	-0.156 (221)	-0.401 (319)
Flesh firmness	-0.569 (226)	-0.666 (289)	-0.514 (221)	-0.768 (319)

All correlation are statistically significant at the $p \leq 0.05$ level (sample size is reported in brackets)

Table 4. Flesh firmness, total soluble solids, and titratable acidity of 'Golden Delicious' fruits of different size picked from trees carrying standard and high crop load levels

Fruit size [mm]	Flesh firmness [kg cm^{-2}]		TSS content [°Brix]		Titratable acidity [meq $100g^{-1}$]	
	standard load	high load	standard load	high load	standard load	high load
55-60	– [(1)]	8.79 a	–	–	–	–
60-65	–	8.499 ab	–	14.5 a	–	10.57 a
65-70	7.54 ab^x	8.14 abc^y	13.5 a^x	14.5 a^y	9.05 a^x	11.13 a^y
70-75	7.55 a^x	7.61 bcd^x	13.5 a^x	14.4 ab^y	7.57 ab^x	9.87 a^y
75-80	7.12 bc^x	7.31 cd^x	13.7 a^x	14.4 ab^y	7.90 ab^x	9.90 a^y
80-85	6.75 cd^x	6.69 d^x	13.5 a^x	13.9 b^y	7.73 ab^x	6.64 b^x
85-90	6.39 d	–	13.9 a	–	7.23 b	–

Within each column and each row, means with same letter (a,b,c,d and x,y, respectively) are not significantly different according to Tukey's test and t-test, respectively ($p \leq 0.05$)
[(1)]Values excluded from statistical analysis for inadequate sample size

Table 5. Flesh firmness, total soluble solids, and titratable acidity of 'Red Chief' fruits of different size picked from trees carrying standard and high crop load levels

Fruit size [mm]	Flesh firmness [kg cm^{-2}]		TSS content [°Brix]		Titratable acidity [meq 100g^{-1}]	
	standard load	high load	standard load	high load	standard load	high load
50-55	–[(1)]	9.84 a	–	13.2 a	3.70 a^{x}	3.57 a^{x}
55-60	8.27 a^{x}	9.36 a^{y}	11.4 bc^{x}	12.7 a^{y}	4.18 a^{x}	4.33 a^{x}
60-65	8.00 ab^{x}	8.59 b^{y}	11.0 c^{x}	12.2 a^{y}	4.44 a^{x}	4.48 a^{x}
65-70	8.19 a^{x}	8.37 b^{x}	12.2 a^{x}	12.1 ab^{x}	4.73 a^{x}	4.35 a^{x}
70-75	7.80 ab^{x}	7.74 c^{x}	11.7 b^{x}	11.9 b^{x}	4.50 a^{x}	4.22 a^{x}
75-80	7.37 bc^{x}	7.10 d^{x}	11.6 bc^{x}	11.5 b^{x}	4.65 a^{x}	4.63 a^{x}
80-85	7.19 c	–	11.4 bc	–	4.43 a	–

Within each column and each row, means with same letter (a,b,c,d and x,y, respectively) are not significantly different according to Tukey's test and t-test, respectively ($p \leq 0.05$)
[(1)]Values excluded from statistical analysis for inadequate sample size

With 'Golden Delicious', flesh firmness was highest in fruits smaller than 70 mm with the heavy cropping trees, and in fruits smaller than 75 mm with the standard cropping trees. TSS content was highest in fruits smaller than 80 mm with the heavy cropping trees. Titratable acidity was highest in fruits smaller than 80 mm with the heavy cropping trees, and in fruits smaller than 85 mm with the standard cropping trees (Tab. 4)

With 'Red Chief', flesh firmness was highest in fruits smaller than 60 mm with the heavy cropping trees, and in fruits smaller than 75 mm with the standard cropping trees. TSS content was highest in fruits smaller than 70 mm with the heavy cropping trees, and in fruits between 65 and 70 mm with the standard cropping trees. There was no significant difference in titratable acidity between heavy cropping trees and standard cropping trees (Tab. 5).

DISCUSSION

Fruit size and fruit weight were lower with heavy cropping trees than in standard cropping trees. With 'Golden Delicious', fruit size was 11% lower and fruit weight was 25% lower. With 'Red Chief', fruit size was 12% lower and fruit weight was 28% lower.

Thinning may stimulate fruit growth by affecting the rate and duration of cell division, by promoting cell enlargement, or by stimulating the production

of intercellular spaces (Goffinet et al., 1995). However, in our trial, thinning reduced overall fruit size mainly by changing the fruit size distribution. Thinning usually increases fruit size more by reducing the number of the smallest fruits than by increasing the size of the remaining fruits (Forshey and Elfving, 1977).

Both 'Golden Delicious' and 'Red Chief' are classified as large-fruited cultivars according to the new European Union Commission regulations (EC 85/2004, amended by Commission Regulation EC 1238/2005). In our trial, fruit size was larger with 'Golden Delicious' than with 'Red Chief'. Because fruit weight is a quantitative parameter, environmental conditions probably affected fruit growth and development (Leibhard et al., 2003; Corelli-Grappadelli and Lakso, 2004; Comai et al., 2005).

To be classified as Extra according to the new European regulations, 'Golden Delicious' apples have to measure at least 60 mm in diameter or weigh at least 90 grams. 'Red Chief' apples have to measure at least 65 mm in diameter or weigh at least 110 grams.

Even though crop load level affected fruit size distribution, high crop loads should not reduce profits margins. The number of fruits meeting the new European Union requirements would be only slightly lower than with lower crop loads.

TSS content, titratable acidity and flesh firmness were higher with heavy cropping trees than with standard cropping trees. With both cultivars and both crop load levels, fruit quality parameters were best and fruit size was the largest in the small and medium size classes.

In an earlier study, TSS content was 2 to 3% higher in fruits from hand-thinned 'Golden Delicious' trees. However, there was no apparent correlation between TSS content and fruit size. TSS content was essentially the same in both large fruits and small fruits (Link, 2000).

In our trial, hand thinning was performed late in the season, when fruit growth depends more on cell enlargement than on cell division (Lakso et al., 1995). In several apple varieties, cell volume and fruit size have been reported to be lower in heavy cropping trees (Martin and Lewis, 1952). There is as also a positive correlation between fruit size and the proportion of intercellular spaces (Ruess and Stösser, 1993). In our trial, apples in the smaller size classes had a higher TSS content probably because of lower cell volume and a lower proportion of intercellular spaces.

In 'Golden Delicious', titratable acidity has been previously reported to be both positively and negatively correlated with fruit weight and crop load level (Link, 1967; 2000). In our trial, titratable acidity was highest with heavy cropping trees, probably because of differences in acid metabolism between heavy cropping trees and standard cropping trees.

In our trial, flesh firmness was clearly higher with heavy cropping trees than with standard cropping trees. This agrees well with previous reports that flesh firmness is negatively correlated with mean fruit weight and crop load level (Johnson, 1992; 1994).

All of the parameters evaluated in our trial were weakly correlated with each other, except for size and weight. Therefore, no single parameter can reliably predict fruit quality. Fruits from heavy cropping trees were smaller, firmer, and had a higher TSS content. Although further research is needed, our data indicate that a moderate increase in crop load does not affect fruit quality.

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ZALEŻNOŚĆ POMIĘDZY WIELKOŚCIĄ OWOCÓW A ICH JAKOŚCIĄ DLA DRZEW O ZRÓŻNICOWANYM POZIOMIE PLONOWANIA

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STRESZCZENIE

Doświadczenie przeprowadzono w roku 2004 w celu zbadania zależności pomiędzy wielkością owoców, a innymi parametrami jakości jabłek. Drzewa 'Golden Delicious' (klon B) i 'Red Chief' (*Malus* × *domestica* Borkh.) uprawiano w systemie zróżnicowanego plonowania (dwa poziomy: 6 i 8 owoców na cm^2 powierzchni przekroju poprzecznego pnia, określone jako standardowe i wysokie plonowanie). Po zbiorze określano masę i wielkość owoców, dzielono na klasy wielkości co 5 mm (50-55, 55-60 itd.) i analizowano jędrność miąższu owoców, ogólną zawartość ekstraktu i kwasowość miareczkową. Przeprowadzono także analizę korelacji i regresji w celu zbadania zależności pomiędzy parametrami jakościowymi owoców. Wysokie plonowanie drzew redukowało średnią wielkość i masę owoców oraz zwiększało zawartość cukrów i jędrność miąższu u obu odmian. W przypadku obu odmian i obu poziomów plonowania wystąpiła negatywna korelacja pomiędzy wielkością owoców a zawartością ekstraktu i pomiędzy masą owoców i jędrnością miąższu. Silną pozytywną korelację obserwowano jedynie pomiędzy wielkością owoców, a ich masą. Wyniki wskazują, że wszystkie badane parametry są słabo ze sobą związane z wyjątkiem zależności między wielkością a masą. Owoce z drzew o wysokim plonie były mniejsze, ale miały wyższą jędrność miąższu i zawartość ekstraktu, co wskazuje na to, że umiarkowane zwiększenie plonu nie wpływa negatywnie na jakość owoców.

Słowa kluczowe: jabłka, masa owoców, jędrność miąższu, zawartość cukrów, kwasowość, przerzedzanie