Crop load and rootstock effects on maturation rate and harvest quality of cv. Braeburn apples

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Abstract — Introduction. Light crops and weak rootstocks generally increase harvested fruit diameter and quality. Besides, fruit maturation is hastened. However, crop load or rootstock effects on fruit quality were not often differentiated from maturity effect. The goal of the present study was to investigate the effect of rootstock and crop load interaction on several fruit maturation and quality variables. **Materials and methods**. Braeburn variety apple trees grafted on three rootstocks (M7, M9 and M27) in their fifth year of growth and trained to vertical axis were used. Crop loads were adjusted in early June at 12.5 and 2.5 fruits·cm^{-2} trunk cross-sectional area for heavy and light crops, respectively. Soluble carbohydrates, starch analysis and qualitative measurements were operated on 2 year-old spur fruits during four pickings. Variables evolving with maturity were studied for a same fruit ground colour. **Results and discussion**. Light crops and weak rootstocks produced higher fruit size, colour, firmness and dry matter content. Also, fruit ripening was initiated early. Nevertheless, crop load effects were less important with strong rootstocks. Fruit starch content and its relation to starch iodine index were modified by crop load. The fruit juice refractometric index was higher under light crop without modifications in total soluble sugar concentrations expressed in mg·g^{-1} fresh weight. Rootstocks had no significant effects in the composition of fruit except for glucose. **Conclusion**. Rootstocks and crop load were important to consider for an optimal harvest. In our context, ground colour seems to be a more accurate harvest criterion than starch iodine index. For a given crop load, however, the starch iodine index may give some information on fruit maturity stage. © Éditions scientifiques et médicales Elsevier SAS

***Malus* / varieties / rootstocks / yield factors / fruits / maturity / quality / starch / France**

Effets de la charge et du porte-greffe sur la vitesse de maturation et la qualité des pommes du cv. Braeburn.

Résumé — Introduction. Une faible charge en fruits et des porte-greffes de faible vigueur augmentent généralement le calibre et la qualité des fruits. Par ailleurs, la maturité est alors avancée. Cependant, les effets dus à la charge et au porte-greffe ne sont pas toujours distingués de ceux imputables à une différence de maturité. L'effet des interactions entre porte-greffe et charge sur quelques variables de maturité et de qualité des fruits à la récolte a été recherché. **Matériel et méthodes**. L'étude a porté sur des pommiers (cv. Braeburn) âgés de 5 ans et greffés sur M7, M9 et M27. L'ajustement de la charge a été effectué début juin, de façon à obtenir 12,5 fruits·cm^{-2} de surface de section du tronc pour des arbres à forte charge et 2,5 fruits pour ceux à faible charge. La qualité, les sucres solubles et l'amidon ont été analysés sur quatre récoltes effectuées sur des fruits du bois de 2 ans. Les paramètres évoluant avec la maturité ont été analysés à un stade de couleur de fond donné. **Résultats et discussion**. Une faible charge et les porte-greffes faibles ont augmenté le calibre, la fermeté, la coloration et la teneur en matière sèche des fruits, et avancé la maturité. Cependant, plus le porte-greffe est fort, moins les effets de la charge ont été importants. La charge perturbe les indications du code amidon en modifiant les teneurs en amidon et les relations entre ces teneurs et les valeurs du code. L'indice réfractométrique des jus a été plus faible pour les fruits issus de la forte charge, mais la teneur en sucres solubles a été peu modifiée. Le porte-greffe a peu influencé ces paramètres. **Conclusion**. Les effets de la charge et du porte-greffe sont importants à considérer pour une récolte optimale. Lors de notre étude, la couleur de fond a semblé être un critère de maturité plus fiable que le code amidon. Cependant, pour un niveau de charge déterminé, ce code donne également de bonnes informations. © Éditions scientifiques et médicales Elsevier SAS

***Malus* / variété / porte-greffe / facteur de rendement / fruits / maturité / qualité / amidon / France**

1. introduction

Extensive literature is available concerning the effect of tree fruit load on the quality of fruit at harvest and during storage [1–8]. Individual fruits from trees with light crop levels, in addition to being larger, heavier and firmer than fruits from heavily loaded trees, often present a higher juice refractometric index (RI) as well.

The rootstock also influences fruit quality [9–12]. Trees grafted onto weak rootstock usually produce larger, firmer fruits with a higher RI and calcium content.

Rootstock and fruit load also modify the onset of fruit maturation. Light crops and weak rootstock lead to earlier fruit maturation [9–14]. Therefore, crop loads or rootstock effects on fruit quality were often compared at a same harvest date which could correspond to different fruit maturity stages between treatments. Then, differences observed could be a maturity effect neither a rootstock or crop load effect. For example, identical storage quality of fruit from trees on M9 rootstock as stronger rootstocks could be found if fruit from the former rootstock were picked earlier [15].

Few studies have taken both rootstock and fruit load into account simultaneously and analysis of their interaction is poorly developed [1, 9]. The goal of the present study is to show the effect of rootstock and crop load interaction on several fruit maturation and quality variables.

2. material and methods

Braeburn variety trees grafted on three rootstocks (M7, M9 and M27) in their fifth year of growth and with free growing fruiting branches trained along a vertical axis were chosen in spring, 1996, in an Inra[1] experimental orchard in Montpellier, southeast France. Tree spacing were 4.5, 2.5 and 1.5 m in the rows, 6 m between the rows and tree height were 2.8, 2.0, 1.5 m for M7, M9 and M27, respectively.

Two levels of crop load were assigned in June 13 by manual thinning just after the natural fruit dropping. Four trees were available for each [rootstock × crop load] combination. In order to take into account the differences in tree volume induced by rootstocks, a ratio based on the number of individual fruits per trunk cross-sectional area (TCA) was used [16]. Heavy and light crops corresponded to 12.5 and 2.5 fruits·cm^{-2} TCA. Four pickings were carried out at weekly intervals between September 25 and October 15. Because of the lack of fruit on trees grafted on M27 rootstock, only the two first picking were carried out. For each treatment, 10 fruits from 2 year-old wood were picked at middle height and from within the periphery of the tree. Once the size, weight, ground colour (Inra chart 1 to 7, green to yellow) and the percentage of red skin were measured, a punch was used to radially remove a 0.6 g mean cylindrical cortex sample to determine sugar content. A second 0.6 g cortex sample was removed, weighed before and after drying in an oven at 85 °C and percentage of dry matter calculated. Firmness was measured on the green face of the fruits using a stand-supported, hand penetrometer (Effegi, Alfonsine, Italy). The juice refractometric index (RI) was determined with a compensated temperature hand refractometer (Sopelem, Levallois-Perret, France) fruit by fruit using the drop of juice which beaded when firmness was measured. The extent of fruit starch hydrolysis was estimated visually using iodine staining of an equatorial section of fruit, the coloured surface was compared to Eurofru chart [17], 1 = 100 % stained; 10 = 0 % stained.

The first cortex sample was weighed, then immediately frozen in liquid nitrogen and stored at –25 °C until extraction for soluble sugars using three repeated 5 mL 80 % ethanol volume. An aliquot of 250 µL of the three homogenised supernatants containing glucose, fructose and sucrose, was dried in vacuo, then dissolved in 500 µL water for quantification by enzymatic method [18]. The insoluble residue of the extract containing starch was suspended in 10 mL 0.02 N NaOH, boiled for 1 h in order to gelatinise the starch. An aliquot of 50 µL was added after stirring to 100 µL amyloglucosidase (EC 3.2.1.3, 150 U·mL^{-1}, Boehringer) in acetate buffer and incubated at 55 °C for

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1 h. The glucose thus freed was analysed enzymatically [18].

The combined four harvest results were analysed using variance analysis whenever variables did not evolve significantly over the harvests [size, dry matter content (DM %), % red colouring, firmness]. The Newman and Keuls test was used to differentiate between the groups of combinations. For variables linked to ripening, a Mann-Whitney test was run by comparing groups two by two at an identical ground colour stage, as this criterion can be considered a good maturity indicator for the Braeburn variety [19].

3. results

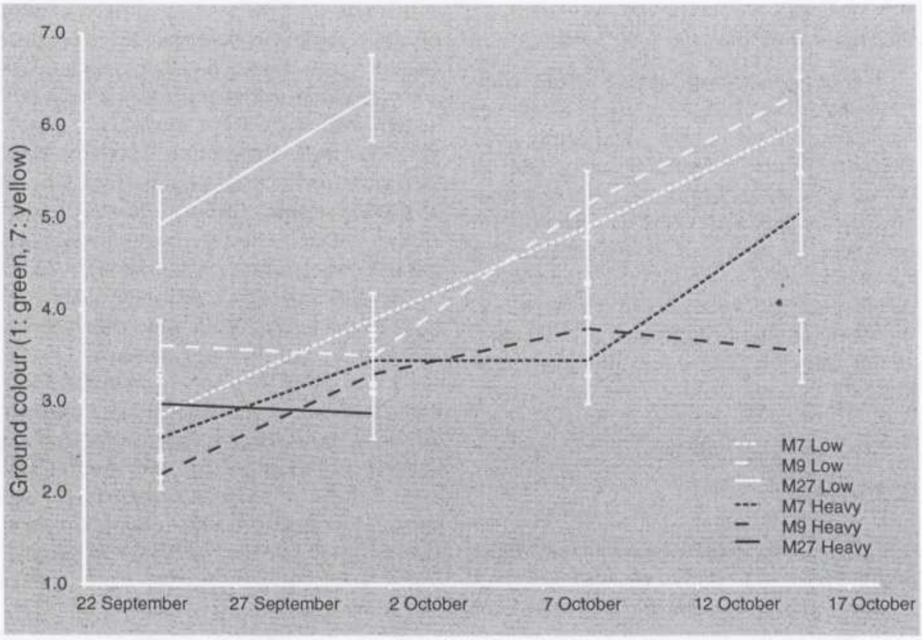
Variance analysis showed that light crops increased all the studied physical quality variables (*table I*). The rootstock also influenced the results, as trees grafted on the strongest rootstocks (M7, M9) produced fruits which were less firm, less coloured and which contained less dry matter than fruits from trees grafted onto M27 (*table I*). Interaction between crop load and rootstock was significant for three of these variables (*table I*). Fruit size was all the more affected by heavy load when the tree was grafted on weaker rootstocks (–2.8, –9.8 and –16.5 % for M7, M9 and M27, respectively). Both DM content (–13, –14.1 and –21.7 %) and firmness (–10.4, –11.9 and –16.9 %) also varied in the same way. Tree size conferred by M7 rootstock did not, however, make it possible to entirely compensate for the load effect. Even if the % of red skin presented no significant interaction between load and rootstock ($p = 0.07$) the heavy crop overall effect should be attributed to trees grafted on the strongest rootstock (*table I*).

Table I.
Effect of [rootstock × crop load] combinations on the physical characteristics of fruits.

Factor	Diameter (mm)	% red skin	Firmness ($kg \cdot cm^{-2}$)	Dry matter %
Crop Load				
Low level	85.1 a	80.1 a	9.8 a	16.3 a
Heavy level	76.8 b	73.4 b	8.5 b	13.8 b
Significance	**	*	**	**
Rootstock				
M27	80.8 b	81.6 a	10.0 a	16.0 a
M9	77.8 c	73.1 b	8.5 b	14.7 b
M7	84.4 a	75.5 ab	8.9 b	14.9 b
Significance	**	*	**	**
Interaction				
M27 × light	88.0 a	80.3	10.9 a	17.9 a
M27 × heavy	73.5 d	83.0	9.1 b	14.0 c
M9 × light	81.7 c	78.6	9.0 b	15.8 b
M9 × heavy	73.8 d	67.6	8.0 c	13.6 c
M7 × light	85.6 ab	81.4	9.4 b	15.9 b
M7 × heavy	83.2 bc	69.6	8.4 c	13.8 c
Significance	**	ns	*	**

Means within each column followed by different letters are significantly different using variance analysis and the Newman-Keuls test (ns: not significant; **: significant with $p = 0.01$; *: significant with $p = 0.05$). The four pickings are combined.

Figure 1.
Fruit ground colour variation according to the [rootstock × fruit load] combinations (bar = 5 % confidence interval).



The variation in ground colour showed that fruits from trees with light crop levels ripened earlier than that from trees with heavy crops (*figure 1*). The difference in maturation rate between fruits of the two crop loads seems all the larger as the rootstock is weaker: fruits from the M27 × light crop treatment showed pronounced earlier ripening rate compared to the other combinations and picking should be anticipated. For the set of heavily loaded trees, those grafted onto M7 had the earliest fruits.

Fruits from light cropped trees showed the same starch iodine index pattern than fruits from heavy-cropped ones (*figure 2*). On the basis of this criterion, no difference in maturity can be observed. For all the four-harvest date, fruit starch content (*figure 3*) was always statically different between heavy and low loads. Then, the relationship between the starch iodine index data and the cortex starch content of the fruit showed a significant difference between fruits from the two load treatments (*figure 4*). Fruit from the trees with the lowest load levels had higher starch contents than that from heavily loaded trees on an equivalent starch index basis. Starch regression thus began at a content level of 20 mg of starch per g of fresh weight (FW) in the first case, whereas the initial content was 10 $mg \cdot g^{-1}$ FW in the second. Starch regression comparison is, hence, operational only for a comparable level of load. Just as for the ground colour criterion, the M27, M9, M7 maturation ranking was observed for the starch index of fruits from trees with light crops levels. Fruits from heavily loaded trees were inversely ranked, according to the evolution in the ground colour.

For an efficient comparison of maturity-dependent variables as affected by rootstocks and crop loads, it is necessary to consider the fruits at an equivalent stage of ripening. The ground colour index seemed the most appropriate to use in our study to make this comparison. Quality variables were, therefore, compared on fruits with a colour range varying from 3.5 to 4.5 included. As the remaining fruits on the M27 rootstock were limited in quantity, this subject was eliminated from the analyses. Results showed that the juice refractometric index and the fruit dry matter content from the light crop treatment were much higher than those from the heavy load treatment (*table II*). Total soluble sugar content of the fruits was not modified according to the

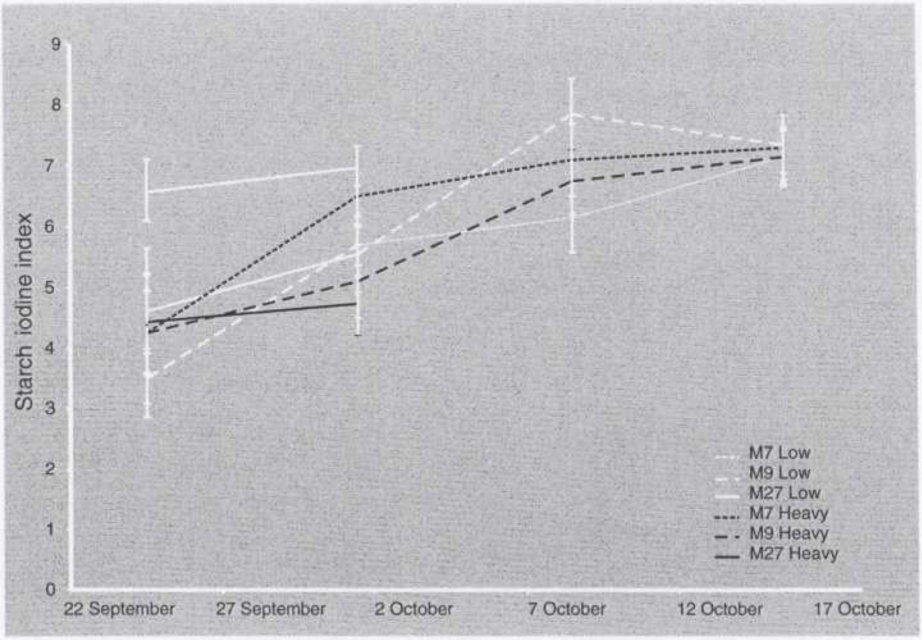


Figure 2.
Starch index variation according to the [rootstock × fruit load] combinations (bar = 5 % confidence interval).

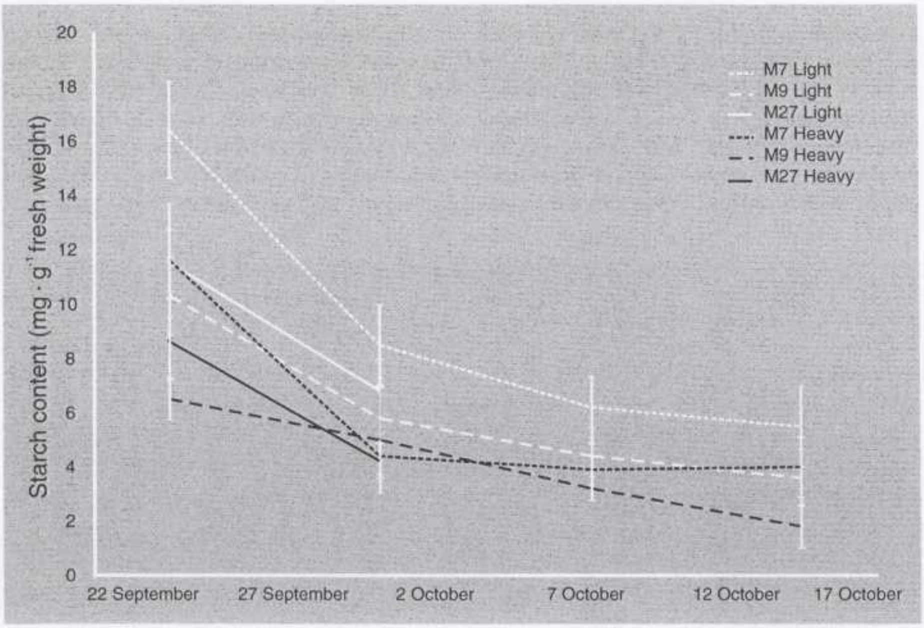


Figure 3.
Fruit starch content variation ($mg \cdot g^{-1}$ fresh weight) according to the [rootstock × fruit load] combinations (bar = 5 % confidence interval).

load. A slightly higher sucrose content for fruits from light crop trees could be observed, but a lower level of fructose offset it. Glucose was the only sugar to display any influence of rootstock on its content (*table II*).

4. discussion

Our results concerning the effects of fruit load confirm those of numerous earlier studies: a light crop level makes it possible to improve the size, the firmness and the

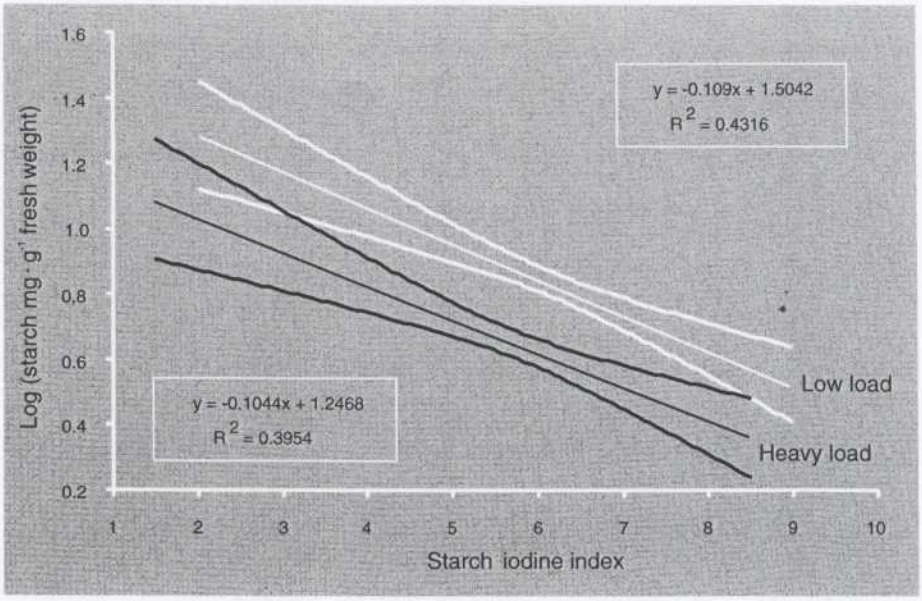


Figure 4.
Starch index – starch content relationship according to fruit load (regression fitting and confidence intervals $P = 0.05$).

dry matter content of fruits. Plotto et al. [19] refer to the ground colour as an applicable maturation indicator for the Braeburn variety. Crop load, thus, also has an effect on the maturing rate of fruit, as shown through this criterion (*figure 1*). This quickening of fruit ripening for trees with light crops levels was not always noticed in previous studies, in which ground colour and ethylene content were used as indicators of maturation [5, 7]. However, load levels were generally less extreme than in our trial. It remains interesting to note that, in the results of Volz et al. [7], the rate of starch index regression was faster in the case of heavy loads while the other maturity indicators showed no differences. This result coincides with our observations (*figure 2*):

Table II.
Fruit load and rootstock effect on the quality characteristics of fruits at the same stage of maturity (range in ground colour: 3.5 to 4.5).

Factor	Juice refractometric index	Dry matter (%)	Glucose $mg \cdot g^{-1}$ fw	Fructose $mg \cdot g^{-1}$ fw	Sucrose $mg \cdot g^{-1}$ fw	Total sugar $mg \cdot g^{-1}$ fw	*n*
Crop Load							
Low level	13.7 a	15.8 a	14.4	44.2 b	44.9 a	103.4	31
Heavy level	11.9 b	13.8 b	15.3	47.9 a	35.2 b	101.5	31
Significance	**	**	ns	*	*	ns	–
Rootstock							
M9	12.7	14.5	16.8 b	46.5	36.2	102.1	32
M7	13.0	14.7	12.7 a	46.0	43.4	102.6	30
Significance	ns	ns	**	ns	ns	ns	–

Medians within each column followed by different letters are significantly different using the Mann-Whitney test (ns: not significant; **: significant with $p = 0.01$; *: significant with $p = 0.05$). fw: fresh weight.

regression of the starch index is concomitant for the two crop loads, which does not confirm the later maturing rate of heavy load fruits observed in ground colour. Moreover, for the same starch content, the starch index value of heavy load fruits is two points below that observed for light crop fruits (*figure 4*). The difference in regression of starch index between the two loads is, consequently, lessened. Light crop fruits accumulate more starch in their cortex (*figure 3*). Starch index regression is concomitant with that of heavy crop fruits. The change, however, corresponds to more extensive and more rapid hydrolysis of starch. The starch iodine index can therefore be used as an indicator of maturity only under conditions of standard load for the different batches under comparison. Indeed, taken separately, the starch index variation of fruit from the two load levels indicate the same maturity ranking as does the colour index: M27, M9, M7 for light crops, and M7, M9 for heavy crops (*figures 1, 2*).

Our results on the rootstock effect give an overall confirmation of earlier studies: an increase in fruit firmness and of the dry matter content whenever rootstock is weaker. However, rootstock modulates the effect of fruit load significantly. The less developed the tree (i.e., weaker is the rootstock), the higher the impact of the load on the maturing and the physical qualities of the fruit. A highly developed tree shows a buffer capacity that makes it possible for it to compensate for heavy crops. This capacity could be due in part to the larger structural volume facilitating the mobilisation of more reserves at the beginning of fruit growth. Trunk cross sectional area is a common measurement to adjust crop load [16]. We were careful in our study to obtain equivalent loads for each rootstock by using this criterion. Still, even though trunk cross sectional area can be a good indicator of aerial vegetative biomass, other factors, such as source/sink relationships, can interfere to define tree load potential. Furthermore, crop loads and rootstocks can, in some cases, lead to an increase in foliar photosynthesis [20]. These factors were not measured in our study.

The effects of [rootstock × crop load] combinations on the fruit quality variables that evolve with maturation were measured at a common stage of maturity. Then, rootstock does not induce any significant differences in the composition of fruits, except as concerns glucose. Light crop level results in an increased fruit juice refractometric index without any increase in the total cortex sugar content (*table II*). The water content of heavy crop fruits is, however, higher, which contributes to a dilution of the sugars and, consequently, to a drop in juice refractometric index as compared to light crops fruits. Other authors have also noted this difference between refractometric index values and sugar contents [21].

5. conclusion

Both load and rootstock significantly influence apple quality. It is important to consider their interactions on the parameters of quality and maturation in order to ensure optimum fruit harvest. Trees with limited development, on weak rootstock, will be much more sensitive to crop loads and should be harvested earlier if they are lightly loaded. Trees on strong rootstock are less sensitive to crop loads. For the Braeburn variety, ground colour appears to be a better criterion for judging fruit maturity than starch iodine index. For a given crop load, however, the starch iodine index may give some information on fruit maturity. Therefore, starch iodine index threshold for initiating the picking should to be adapted to the load.

A question remains as to the best way of adjusting the load in relation to tree vegetative potential. Using the tree cross sectional area to estimate the volume of the tree is a practical measure to implement in orchards. Some corrections will, however, be necessary depending on the rootstock used.

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Efectos de la carga y del portainjertos en la velocidad de maduración y la calidad de las manzanas del cv. Braeburn.

Resumen — Introducción. Una baja carga de frutos y portainjertos de bajo vigor aumentan generalmente el calibre y la calidad de los frutos. Por otro lado, se adelanta la maduración. Sin embargo, los efectos debidos a la carga de frutos y al portainjertos no se distinguen siempre de los imputables a la diferencia de madurez. Se investigó el efecto de las interacciones entre portainjertos y carga en algunas variables de madurez y calidad de los frutos en la cosecha. **Material y métodos**. El estudio se realizó sobre manzanos (cv. Braeburn) de cinco años e injertados en M7, M9 y M27. El ajuste de la carga se efectuó a principios de junio para obtener 12,5 frutos·cm^{-2} de superficie de sección de tronco en los árboles de alta carga y 2,5 frutos para los de baja. Se analizó la calidad, el contenido de azúcares solubles y almidón en cuatro cosechas de frutos de árboles de dos años. Los parámetros que evolucionan con la madurez se analizaron en una fase que presentaba un color de fondo determinado. **Resultados y discusión**. Una baja carga y portainjertos poco vigorosos aumentaron el calibre, consistencia, coloración y contenido en materias secas de los frutos, y avanzaron la madurez. Sin embargo, cuanto más vigoroso era el portainjerto menores eran los efectos de la carga. La carga perturba las indicaciones del código almidón modificando los contenidos de almidón y las relaciones entre dichos contenidos y los valores del código. El índice refractométrico del jugo fue más bajo en los frutos procedentes de la carga alta, pero el contenido en azácares solubles apenas se vio modificado. El portainjertos influyó poco en estos par·metros. **Conclusión**. Es importante tener en cuenta los efectos de la carga y del portainjertos para una cosecha óptima. Durante nuestro estudio, el color de fondo se mostró como un criterio de madurez más fiable que el código almidón. No obstante, para un nivel de abundancia determinado, este código proporciona también buenas informaciones.

***Malus* / variedades / portainjertos / factores de rendimiento / frutas / madurez / calidad / almidón / Francia**