Short communication. Major macroelement exports in fruits of diverse almond cultivars

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Abstract

The amount of the major macroelements required to produce a given crop has been determined for a set of 11 almond (*Prunus amygdalus* Batsch) cultivars growing in the Middle Ebro Valley (NE Spain). A wide diversity of nutrient exports was found among the different cultivars. Although the production of kernels is the main objective when growing almonds, all the different fruit components: the mesocarp (hull), the endocarp (shell) and the seed (kernel), were taken into account. The different fruit components showed a great variation among cultivars, and the amount of fruit dry matter required for producing 1 kg of kernel ranged from 4.32 kg in 'Guara' to 10.56 kg in 'Desmayo Largueta'. Similarly, the macroelement requirements to produce a given amount of kernels varied among the different cultivars. 'Guara' has proved to be the most effective cultivar in taking advantage of the mineral elements for producing a crop, showing that this efficiency is independent of the shell type.

Additional key words: NPK-nutrition; production; *Prunus amygdalus.*

Resumen

Comunicación corta. Exportación de los macroelementos mayoritarios por los frutos de diferentes cultivares de almendro

Se determinó la cantidad de macroelementos mayoritarios necesarios para producir una determinada cantidad de cosecha en un grupo de 11 cultivares de almendro (*Prunus amygdalus* Batsch) cultivados en el Valle Medio del Ebro (NE de España). Se encontró una gran diversidad de requerimientos entre los diferentes cultivares. Aunque la producción de pepitas es el objetivo principal en el cultivo del almendro, todos los componentes del fruto se han de tener en cuenta en este cálculo: el mesocarpo (la piel), el endocarpo (la cáscara) y la semilla (la pepita). Estos tres componentes del fruto mostraron una gran variabilidad entre los cultivares y la cantidad de materia seca necesaria para producir 1 kg de pepita osciló entre 4,32 kg en 'Guara' y 10,56 kg en 'Desmayo Largueta'. Igualmente, los requisitos en macroelementos para producir una cantidad determinada de pepita varió entre los diferentes cultivares. 'Guara' mostró ser el cultivar más eficiente en la utilización de los elementos minerales para la producción de una cosecha, mostrando que esta eficiencia es independiente del tipo de cáscara.

Palabras clave adicionales: nutrición NPK; producción; *Prunus amygdalus.*

Fruit trees are fertilized to ensure optimum growth and fruit production. The amount of nutrient requirements depends on the yield potential of the cultivar, the level of available nutrients in the soil, the requirements of the crop, and the growing conditions. The vegetative growth must allow the partial renewal of the canopy but also reduce pruning needs as much as possible (Socias i Company *et al*., 1998). As a consequence, the correct management of the orchard must take into account the most adequate strategies in order to optimize input utilization since almond yields show a high variability depending on the orchard conditions (Felipe, 2000). As a result, the crop level must be maximized in relation to the inputs.

Our attention was directed to the requirements for the production of the same quantity of kernel by each cultivar. In *Prunus* species the mesocarp is the main component of the fruit as it constitutes the flesh, the basis for stone fruit consumption. In almond, however, the mesocarp, referred to as hull, is rarely considered by the grower and the industry, as it is formed by a corky flesh often rejected during harvesting and processing. As a consequence, most almond researches on fruit production and composition only include the stone, consisting of the shell (endocarp) and the kernel (seed). Thus, kernel production in the almond industry is usually referred to as shelling percentage, taking only into account the kernel and the shell.

Significant differences have been described in the relative ratios of hull, shell and kernel among diverse cultivars (Godini, 1984a). Consequently, shelling percentage, as presently defined, only gives partial information on the kernel to fruit ratio because takes into account just two of the three components. For a comprehensive sight of the fruit relationships in almond production, kernel percentage must refer to the whole fruit weight, including the three components. This variable has rarely been considered in almond (Godini, 1984b), as only the shelling percentage is normally reported because of its commercial interest. Kernel percentage as defined here, however, has a high physiological interest. The consideration of the three almond fruit components is essential to be aware of the total amount of the major macroelements removed by the almond crop, because the total removal of elements by the almond fruit is still unknown.

The determination of the nutrients required for a given crop level will give useful information to the grower, whose main aim is to obtain a profitable crop optimizing the management of the orchard inputs. However, wide differences among cultivars in transforming crop inputs to obtain a certain amount of kernel would be expected since almond cultivars show a great variability of kernel and shelling percentages. Likewise, a similar variability would be expected in their productive efficiency. As a consequence, our objective was to determine the major macroelement exports involved in the production of a given crop level in several almond cultivars under the conditions of the Middle Ebro Valley (NE Spain) since this information will allow a better knowledge of the production efficiency of the different cultivars.

Eleven almond cultivars were included in this study. Their main characteristics are described by Felipe (2000).

They include the two main traditional Spanish cultivars, 'Marcona' and 'Desmayo Largueta', as well as the main releases from different breeding programs: 'Guara', 'Moncayo' and 'Cambra' (CITA of Aragón), 'Masbovera' (IRTA, Cataluña)', 'Antoñeta' and 'Marta' (CEBAS, Murcia), and 'Ferragnès' and 'Lauranne'(INRA, France), including the main Californian cultivar, 'Nonpareil', as control. The rootstock for all cultivars was the peach × almond hybrid INRA GF 677. During the years of study, 2009 and 2010, the orchard was 10-11 years old, therefore the trees were in full production. The experimental design was of three completely randomized replicates per cultivar, and the unit plot was a single tree with the neighboring trees as borders.

The experimental orchard was located in Alcañiz (Teruel province, Spain), at 480 m above sea level, at the geographical coordinates of 41.02 N and 0.08 W (XUTM:730613-30 and YUTM:4557052-30). The orchard was on a plain alluvial soil of the entisol type with an A/C profile and a silty-clay-loam texture. Leaf N concentrations were determined in mid July, with an average of 2.14% dry weight, a normal value for almond. The average rainfall was 462 mm and supplementary water was supplied by drip irrigation, with four drippers per tree, of 4 L hr^{-1} of reasonable quality water (EC = 1.26 dS m^{-1}). The irrigation was programmed according to the FAO methodology (Allen *et al*., 1998), using the average data from a weather station and a class A evaporation pan in the same orchard. The annual water requirement reached 1,072 mm, covered with the effective rain (0.7 × Total Rain) plus irrigation. Annual fertilizer application followed the usual ratios in the region for the crop level observed. It was the equivalent of 90-22-112 kg ha^{-1} of N, P, and K respectively, through the irrigation water, twice a week from March through September. No deficiency symptoms were observed on the trees.

To assure sample uniformity, 100 fruits were collected from the central part of the tree canopy, from all four directions at the phenological stage between J and K (Felipe, 1977), coincident with harvest maturity for each cultivar. For each sample the dry weight of each fruit component, hull, shell and kernel, was obtained. Samples were dried in an oven at 60ºC until constant weight. The different major macro-elements were analytically determined according to the official EU methods (Kodad *et al*., 2004).

The analyses were repeated over two consecutive years. The values of each year were statistically analyzed, applying the analysis of variance of the mean

values after angular transformation. The Fisher's LSD test was applied when significant differences were determined.

The data recorded included the weight of the three components of the almond fruit, the hull, the shell and the seed, and are reported in Table 1. The results of the two years follow the same trend and the values of the kernel and shelling percentages followed the same mean separation for all cultivars. As a consequence, the average values are considered for discussion. The first noteworthy observation is the wide diversity of dry matter required to produce 100 kg of kernel among the different cultivars studied. 'Guara' has shown to be the most efficient cultivar as it requires less than half the dry matter (41%) to produce a fruit crop as 'Desmayo Largueta', the least efficient cultivar in this sense.

Similarly a high variability was observed for the shelling percentage, ranging from 22.8% in 'Marcona' to 67.1% in 'Nonpareil', with a difference of 44.3% and a ratio of 2.94 between the extreme values. This range of variability was much narrower when the kernel percentage was considered over the whole fruit, ranging from 9.5% in 'Desmayo Largueta' to 23.2% in 'Guara', since the difference was of 13.7% with a ratio of 2.44 between the extreme values. In addition, the order of the cultivars changed completely, as shown by 'Nonpareil', the cultivar with the highest shelling percentage (67.1%), but with one of the lowest kernel percentages (9.7%). These variations respond to the general trend observed in different shell hardness (Go-

dini, 1984b), as cultivars with a very soft shell also have a very thick hull. This inverse relationship between shell and hull is particularly noteworthy for 'Nonpareil', a cultivar with the lowest amount of endocarp, but with the highest amount of mesocarp. As a result, although the dry weight of the shell represents half of that of the kernel, the dry weight of the hull is ten times higher. This difference places 'Nonpareil' in the lower positions in Table 1.

Concerning the chemical composition of the different fruit elements, most studies have been restricted to the kernel. The differences in composition among cultivars are much smaller than the differences in the dry matter content of each fruit component (Saura-Calixto & Cañellas, 1982). These authors showed that the N content is very low in the hull and the shell (0.43 and 0.16 g/100 g of dry matter (DM) respectively), whereas it is very high in the kernel (4.85 g/100 g of DM) confirming that the protein fraction is mostly restricted to the seed. The differences were much lower for P with the lowest amount again in the shell (0.13, 0.02 and 0.45 g/100 g of DM for hull, shell and seed). However, the hull showed the highest K content (2.15, 0.16 and 0.86 g/100 g of DM for hull, shell and seed). This fact stresses the importance of leaving the hulls on the soil surface at harvest to favor the return of this element to the soil. This return is easily accomplished with several harvesting machines, which transfer the fruits after shaking to a bin through a de-hulling helicoidal appliance, thus dropping most hulls onto the ground.

Table 1. Dry matter required in each of the fruit components in different almond cultivars for the production of 100 kg of almond kernel (two years average)

Cultivar	Weight of the different fruit components (kg)				Index of kernel dw production[1]	Kernel[2] (%)	Shelling[3] (%)
	Mesocarp (hull)	Endocarp (shell)	Seed (kernel)	Whole fruit			
Guara	165 a[4]	167 b[4]	100	432 a[4]	41	23.1 f[4]	37.5 c[4]
Masbovera	172 a	243 c	100	515 a	49	19.4 e	29.2 ab
Cambra	183 a	250 c	100	544 a	51	18.4 e	28.6 ab
Antoñeta	293 b	218 bc	100	611 ab	58	16.4 d	31.4 b
Lauranne	388 b	204 bc	100	692 b	66	14.5 c	32.9 b
Ferragnès	505 c	214 bc	100	818 bc	78	12.2 b	32.9 b
Moncayo	475 bc	302 d	100	877 c	83	11.4 b	24.9 a
Marta	495 c	284 cd	100	879 c	83	11.4 b	26.0 a
Marcona	584 c	338 d	100	1,022 d	97	9.8 a	22.8 a
Nonpareil	898 e	49 a	100	1,047 d	98	9.7 a	67.1 d
D. Largueta	665 d	291 cd	100	1,056 d	100	9.5 a	25.6 a

[1] Ratio of the total fruit dry weight for 100 kg of kernel taking 'Desmayo Largueta' as the 100 reference. dw: dry weight. [2] Kernel percentage of the total fruit weight. [3] Kernel percentage of the weight of shell and kernel. [4] Values followed by the same letter within a column were not significantly different at $p \leq 0.05$ by Fisher's LSD test.

With the composition of the different fruit components it was possible to estimate the major macroelement exports by the fruits for the amount of 100 kg of almond kernels (Table 2). N removal is the least variable among the different cultivars, probably because N content is high in the kernel and low in the other fruit components and the N exports were determined for the same amount of kernel in all cultivars. Because of the importance of N in tree growth and protein accumulation in the kernel, up to 4.85% of dry weight, the ratio of N required by each cultivar to produce a given amount of crop was calculated in relation to 'Desmayo Largueta'. 'Guara' was again the most efficient cultivar, with an index of 71, whereas the least efficient cultivar was 'Nonpareil' with an index of 107 (Table 2). The same pattern of variation was observed for the other two elements, since for the production of 100 kg of kernels 'Guara' removed 0.6 kg of P and 4.6 kg of K, whereas the removals by 'Nonpareil' were 1.4 kg of P and 20.0 kg of K.

These results have been obtained under the particular conditions of the Middle Ebro Valley in NE Spain. However, the stability of the almond fruit composition over different environments (Kodad *et al.*, 2010) shows that the efficiency of a given cultivar is maintained independently of the orchard growing conditions. In this sense, 'Guara' has proved to be the most efficient cultivar in taking advantage of the mineral elements for the kernel production of a crop, whereas the soft-shell cultivar 'Nonpareil' was among the least efficient, together with 'Marcona' and 'Desmayo Largueta'.

Acknowledgements

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Table 2. NPK removal (kg) by the whole fruit per 100 kg of almond kernels (two years average)

Cultivar	N[1] (kg)	Index for N[2]	P[1] (kg)	K[1] (kg)
Guara	5.8 a	71	0.6 a	4.6 a
Masbovera	6.0 a	73	0.6 a	5.0 a
Cambra	6.1 a	74	0.7 a	5.4 a
Antoñeta	6.5 ab	79	0.7 a	7.5 b
Lauranne	6.8 abc	84	0.8 ab	9.5 b
Ferragnès	7.4 b	90	1.0 bc	12.0 c
Moncayo	7.4 bc	90	1.0 bc	11.5 c
Marta	7.4 bc	91	1.0 bc	12.0 c
Marcona	7.9 c	97	1.1 bc	14.0 d
Nonpareil	8.7 d	107	1.4 d	20.0 e
Desmayo Largueta	8.2 c	100	1.2 c	15.6 d

[1] Values followed by the same letter within a column were not significantly different at $p \leq 0.05$. [2] Ratio of the N removal of each cultivar in relation to 100 for 'Desmayo Largueta'.