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Shell hardness in almond: Cracking load and kernel percentage

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ABSTRACT

Shell-cracking load was measured in a sample of 54 almond cultivars, most of them from the autochthonous germplasm of Majorca (Spain), through a compression test. The shell-cracking load ranged from 58 N in 'Nonpareil' to 1415 N in 'Alzina', showing the large variability of shell hardness in almond nuts, distributed in 21 mean groups. The results confirmed the suitability of this method for estimating shell hardness due to its reproducibility and small variance within cultivars. Although shell hardness has been traditionally correlated with shelling percentage, our results show that shell hardness may be an independent variable due to its weak correlation with shelling percentage, nut weight and kernel weight. Additionally, our results show that the hardness scores in almond need to be revised.

1. Introduction

The almond nut is a drupe consisting of three main components: the outer hull, the intermediate shell and the inner kernel. The hull is a fibrous layer consisting of the pericarp and the mesocarp, equivalent to the flesh of the stone fruits, and splitting at maturity to show the shell. The shell consists of the endocarp, primarily composed of cellulose, hemicellulose and lignin. The shell contains the seed or kernel, which is the commercial part of the fruit (Socias i Company et al., 2017). Consequently, attention has mostly been directed to the study of the almond kernel, being the hull and the shell somehow neglected due to their lower economic importance, although the interest on their possible utilisation is continuously increasing (Ledbetter, 2008).

The hardness of endocarp or shell shows a very large variability among cultivars, from very soft paper shells to very hard stony shells. Their morphology is also very variable, with a large diversity of shape, size, and the presence of different modifications, such as wrinkles and pores, a more or less pronounced keel at the ventral suture, or a sting at the apex (Socias i Company et al., 2017). When almond descriptors were defined, Gülcan (1985) characterized nine states of expression for softness of shell (1 extremely hard, 3 hard, 5 intermediate, 7 soft and 9 paper) defined by easiness of shell cracking, from easy cracking with hands to nuts difficult to break with a hummer. On the other hand, shell hardness has been related to shelling percentage, from less than 20% in stony shells to more than 60% in paper shells. Consequently, five classes have also been considered according to shelling percentage (SP): very hard (SP: < 30%), hard (SP: 30–40%), semi-soft (SP: 40–50%), soft (SP: 50–60%) and paper (SP: > 60%) (Batlle et al., 2017). Both traits have an important genetic determinism, present continuous variation and are affected by environment (growing conditions, year, location, etc.), usual characteristic of quantitative traits, although a qualitative component has also been suggested for their inheritance (Grasselly, 1972). Moreover, the International Union for the Protection of New Varieties of Plants (UPOV) has expressed shell hardness as the resistance of the stone to cracking, with five states of expression (1 absent or very weak, 2 weak, 3 medium, 4 strong, and 5 very strong) (UPOV, 2017).

The preference for each shell type depends on the growing conditions and the prevalent industry in the region. In the Mediterranean region hard shells are preferred since these cultivars seem more adapted to non-irrigated conditions and more resistant to depredation by birds and rodents, and to penetration by insect larvae damaging the kernel. Furthermore their nuts can be stored for a long time with reduced problems of getting rancid or excessively dry, thus allowing their commercialization along the season. The Mediterranean shelling plants are consequently adapted to hard shells, using knocking hammers and being completely different from shelling plants for soft shells, using solid rubber rollers as it happens in California and other countries growing similar cultivars, including most growing regions of the southern hemisphere (Verdú et al., 2017).

The endocarp may be used as firewood because of a very high heating power, sometimes in the same processing plants to heat water for blanching kernels. It is also utilised in obtaining chipboards and active carbon and, reduced to powder, to polish some metals and as a natural wool colorant. New ways of research aim at increasing its

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possible utilization, such as organic inclusions in porous ceramic bodies, as additives in drilling of new wells, and as a substrate in soilless or hydroponic culture (Ledbetter, 2008; Socias i Company et al., 2013). Almond shell carbohydrates are mainly cellulose and hemicellulose, but it also contains tannins, pectin and mucilage, constituting a potential source of industrial chemicals (Saura Calixto et al., 1988; Schirra, 1997). The high xylan content of almond shells makes them a suitable substrate for the production of xylose (Pou-Llinás et al., 1990), furfural (Quesada et al., 2002) or for fractioning into cellulose, pentosans, and lignin (Martínez et al., 1995). More commonly, almond shells are considered a waste product and are composted, used as mulch, plowed back into the orchard, or used as a fuel. Several potential antimicrobial compounds have been reported associated with almond shells (Sachdiva, 1968; Bhatia, 1977), which could affect orchard soil ecology if allowed to form in significant quantities in new almond cultivars.

Shell hardness is a function of the proportion of cellulose, hemicellulose and lignin, as the main components of the shell, but also of the shell morphology, the fiber content and the outer shell adherence (Ledbetter, 2008). Shell hardness refers to the resistance of shell to be broken by hand or using a hammer (subjectively scored) or with a texturometer (objectively scored). Percentage of kernel is a complex trait resulting of the proportion between the dry kernel mass and the whole nut dry mass (kernel plus shell). Both traits, related to the almond nut, are very important for industrial processing. Shell hardness and percentage of kernel are usually related, since usually the higher the kernel percentage, the lower the shell hardness, and vice versa. Since shell hardness has shown a high correlation with kernel percentage, it has been often expressed as kernel percentage because kernel percentage is easily measured, although this correlation is not absolute. However, both traits are different and it is possible to find hard thin shelled cultivars with high kernel percentage, a desirable trait combination from the breeding and industry points of view. Among the hard shell cultivars, those producing nuts with thin hull and shell would be interesting for breeding and production since they would be more efficient in the use of inputs, such as macroelements, required to produce a given amount of crop (Alonso et al., 2012). Also, production of these cultivars would imply transport savings, since for a given kernel mass the volume of nuts would be lower.

The knowledge of the shell hardness is essential for a really effective cracking process. However, the objective measurement of shell hardness by a texturometer has not been clearly explained (Barbera et al., 1987; Ballester, 1998) or has been studied in a reduced number of genotypes (Ledbetter, 2008; Altuntas et al., 2010; Shirmohammadi and Fielke, 2017; Oliveira et al., 2017) or in genetically similar populations, such as full sibs (Ballester, 1998; Romero et al., 2017), thus not sufficiently reflecting the variability of the species. These measurements, in addition, may not fully reflect the real shell hardness, especially when soft-shell cultivars are tested (Ledbetter, 2008; Shirmohammadi and Fielke, 2017). Consequently, our objective was the analysis of the shell hardness of a group of almond cultivars by a new objective method in order to infer its adequate utilization in the measurement of shell hardness in almond.

2. Material and methods

2.1. Plant material

This study included 54 almond cultivars, most of them from the autochthonous germplasm of the island of Majorca (Spain), although some foreign cultivars were also included as references (Table 1). Each cultivar is represented by three trees in the Sa Canova (Sa Pobla, Majorca) collection, grafted on the rootstock INRA GF-677, maintained according to the commercial management of almond orchards. Most of the cultivars come from the collection established in the Granja Experimental de la Ciutat de Mallorca during the years 1950s and 1960s, increased by further introductions by Joan Rallo. In addition, some samples were obtained from singular trees, identified by own prospection and growing in their original location, and a few foreign cultivars from other collections. The almond germplasm of Majorca is considered highly diversified (Estelrich, 1907), showing at the same time several peculiar traits (Fernández i Martí et al., 2009, 2015; Kodad et al., 2010).

The study was carried out with the crop of 2017. The almond nuts were collected once ripe, when the mesocarp was fully dry, split to show the inner endocarp, and easy peduncle abscission (Felipe, 1977). Samples of 100 nuts were collected from the ensemble of the different trees of each cultivar. Previously to any measurement, the nuts were placed at room temperature until constant moisture (≈ 6%) since uniform moisture is essential for hardness measurements because breaking force may decrease with increasing moisture content in almond (Shirmohammadi and Fielke, 2017) as well as in other nuts and grains, such as pistachio (Razavi and Edalatian, 2011) and oat (Zhao et al., 2017).

2.2. Shell-cracking load

Shell-cracking load (SCL) was measured with the compression test instrument Z100 of Zwick (Ulm, Germany), equipped with a charge cell of 100 KN (Fig. 1). The shell cracking load was estimated in ten nuts per cultivar. Each single almond nut was placed on a stationary metal plate at the base of the Z100 instrument such that the suture plane of the nut was parallel to the metal plate, and perpendicular to the direction of the compression force (Fig. 1). Compression of the nut was then begun from above applying firstly a pre-charge of 2 N, and then a compression speed of 25 mm min^{-1}. Thus, the almond nut received the compression force perpendicularly to the transversal section. Shell-cracking load was defined as the force needed to crack the nut shell and was assessed by the maximum force during the compression test.

The end of the measurements was considered when the compression force reached 60% of the maximum value measured during the assay, with a limit of 3 mm (Fig. 2), because previous assays indicated that after this run the shell already cracked in hard-shell cultivars. For soft-shell cultivars, the end of the measurement was decided when after a sharp decrease a continued force was observed at the screen, followed by an ascendant force, when load was not applied any more to the shell, but to the kernel.

2.3. Kernel percentage

A random sample of 50 nuts from each cultivar was weighted in an AND Fx-2000 electronic balance (Japan). Once cracked, the kernels were also weighted and the shelling percentage (SP) obtained. The average mass of nuts (NM) and kernels (KM) were also obtained.

2.4. Statistical analysis

All statistical analyses were performed with Version 9.1 of SAS (SAS Institute, 2004). The analysis of variance with the PROC GLM procedure was applied to evaluate the genotype effect on the shelling strength variable. The mean separation was performed using Duncan test at P = 0.05. Simple linear regressions among the cultivar shell-cracking load (SCL), as dependent variable, and the cultivar shelling percentage (SP), nut mass (NM) and kernel mass (KM), as independent variables were performed using the PROC REG procedure.

3. Results and discussion

A large variability for shell-cracking load was observed among the cultivars studied, ranging from 58 N in 'Nonpareil' to 1415 N in 'Alzina', widely distributed among the different cultivars, giving rise up to 21 mean groups (Table 1). This distribution is much wider than any previously described in almond, showing that the ensemble of the cultivars