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Pomegranate (*Punica granatum* L.) a dry pericarp fruit with fleshy seeds

Pablo Melgarejo[a,*], Dámaris Núñez-Gómez[a], Pilar Legua[a], Juan J. Martínez-Nicolás[a], Mª Soledad Almansa[b]

[a] Production Plant and Microbiology Department, Miguel Hernández University, Ctra. Beniel 3.2 Km, 03312, Orihuela, Alicante, Spain
[b] Plant Biology Department, Miguel Hernández University, Ctra. Beniel 3.2 Km, 03312, Orihuela, Alicante, Spain

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ABSTRACT

Background: Recently, pomegranate has established itself as a functional food of increasing interest, both economically and within the scientific community, which has generated a significant increase in publications focused mainly on its characteristics, benefits, and nutritional composition.
Scope and approach: However, despite those papers maintaining scientific rigor, failures and/or errors of interpretation are evidenced concerning basic botanical concepts regarding the pomegranate fruit. Given this, and as a way of contributing to the homogenization of knowledge, this short communication defines the concepts of "seed", "aril", and "testa" as specifically applied to the pomegranate fruit by recovering historical botanical publications.
Key findings and conclusions: The literature studied showed incorrect usage of botanical terms regarding pomegranate parts. The pomegranate seed is the whole grain. It is composed of sarcotesta, sclerotized mesotesta, tegmen, nucela, and embryo with cotyledons, and constitutes the edible portion of this complex fruit called balausta. The whole pomegranate seed cannot be called aril, because it is exariled or without aril seed.

1. Pomegranate: a complex and relevant fruit

The pomegranate tree origin extends from the Balkans to the Himalayas. It is one of the fruit trees grown since ancient times, presenting great genetic diversity. Its existence has been known for thousands of years, and different people had cultivated the pomegranate, including the Phoenicians, Greeks, Arabs, and Romans (Melgarejo & Salazar, 2003).

Over the last few years, the pomegranate tree, especially its fruit, has experienced a growing interest, both economically and within the scientific community. This interest has been motivated not only by its pleasant organoleptic properties, and/or by the consolidation of new crops in different countries around the world, but also by being a functional product of great interest due to its benefits to human health, since it is rich in antioxidants, minerals, and vitamins, among other compounds useful to prevent some diseases (Melgarejo & Salazar, 2003; Rajaei & Yazdanpanah, 2015; Seeram, Schulman, & Heber, 2006).

Thereby, this incipient pomegranate consumption has led to an increase in world production, which has grown from 3000 thousand tons in 2011 (Melgarejo & Valero, 2012) to 5954 thousand tons in 2017 (National Horticulture Board, 2017). This increase was motivated, as mentioned above, by the pomegranate's high nutritional value and its considerable health benefits, as well as the significant increase in scientific publications over the last 30 years. Although these articles carry out a thorough analysis, with technical quality, scientific scientific rigor, and good methodological foundation, interpretation failures and/or errors are evidenced regarding basic botanical concepts about the pomegranate fruit.

The main objective of this work is to highlight, objectively and respectfully, the main botanical etymological errors expressed in most of the scientific articles published about the pomegranate fruit, as well as to make a brief explanatory contextualization of these concepts, based on botanical bibliography references. The objective is to contribute to quality, integrated, and multidisciplinary scientific knowledge. Therefore, regardless of the main objective of the scientific paper and/or area of study related to the pomegranate fruit, all the botanical concepts were conserved, recognized, and referenced appropriately.

2. Problem contextualization and motivation for undertaking this study

In order to be able to accurately define and label the concepts concerned with this paper, different bibliographic references were

* Corresponding author.
E-mail address: pablo.melgarejo@umh.es (P. Melgarejo).

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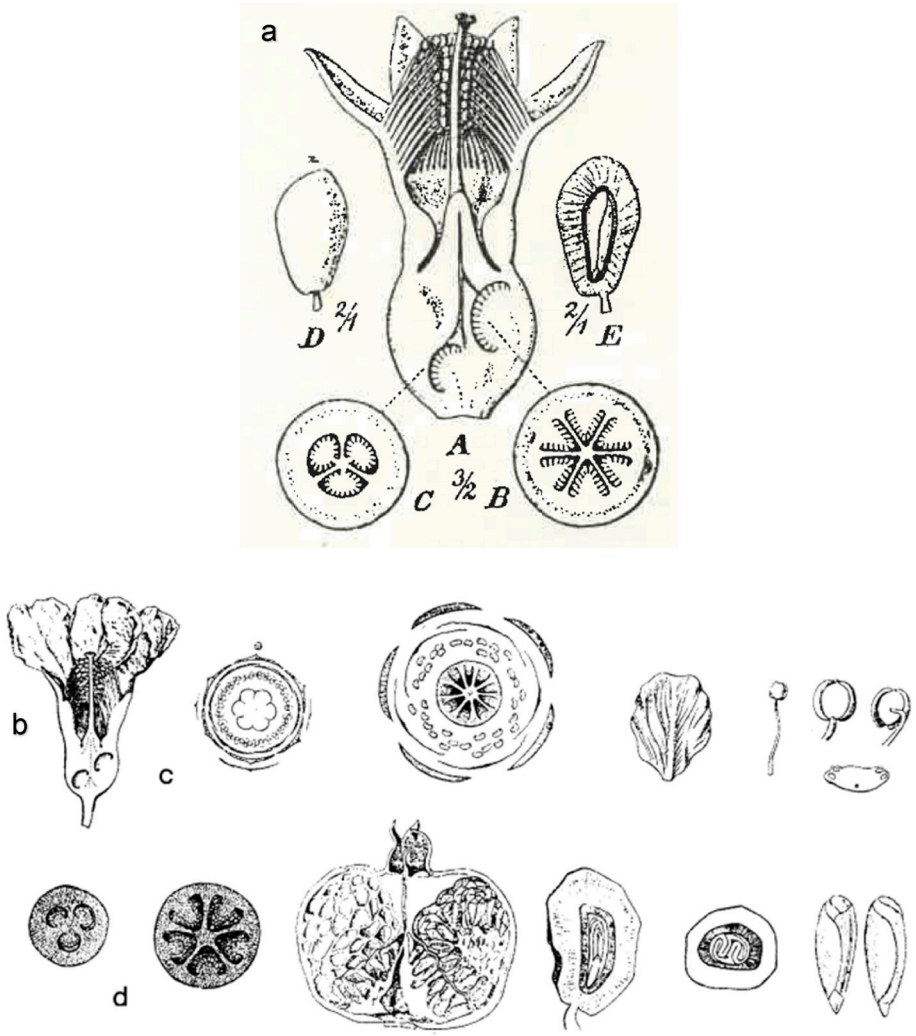

Fig. 1. *Punica granatum* diagrams.
a. Longitudinal section of the flower (A); cross-section of the ovary in its upper part (B), and its lower part (C); seed (D) and the longitudinal section of the seed (E) (Font Quer, 1953).
b. Illustration of the flower (Goldberg, 1989).
c. Representation, from left to right, of two cross-sections at different heights, complete and sectioned petals and stamens (Goldberg, 1989).
d. Fruit: from left to right, eight carpels overlapping planes, a cross-section of the whole fruit, a longitudinal section, and a cross-section of the seed and the cotyledons inscribed in each other (Goldberg, 1989).

consulted as well as specialized public and private collections related to the botanical characterization of the pomegranate fruit (*Punica granatum* L.).

As a way of supporting the botanical foundation of the claims presented in this communication, historical documents were prioritized as a central pillar for botanical concept definitions. Regarding allusive references of etymological errors, recent papers were prioritized, highlighting the relevance of the topic discussed. Thus, this work aims to revive the ancient botanical terminology, currently forgotten and/or unknown to a large number of authors.

Recently, our research group read in the Food Chemistry Journal the article entitled “Comparing the effects of thermal and non-thermal technologies on pomegranate juice quality: A review” written by Putnik et al. (2019). Although the document undertook a precise review focused on the specific quality parameters of the pomegranate juice preserved using thermal and non-thermal technologies, the mentions of different parts of the pomegranate fruit caught our attention. In this paper, both in the introduction and the conclusions sections, the authors separated the edible part of the fruit into “*arils*” and “*seeds*”, referring to the outer pulpy coat as *aril* and the “woody part” as *seed*. Although the distinction between *seed* and *aril* is generally used for pomegranate fruit parts differentiation, especially in articles focused on the biochemical, nutritional, pharmaceutical, medical and/or similar functionalities of the pomegranate fruit, *botanically*, they are incorrect terms.

Motivated by this publication, a specific bibliographic review was carried out. As a result, interpretative differences in basic botanical concepts of the pomegranate fruit were identified in numerous articles. It was found in these papers that the etymological errors were not the same, once different incorrect nomenclature was found. In general, based on the numerous scientific articles published in international journals, the terms that presented the greatest confusion, and therefore misused, were “*seed*” and “*aril*".

Given this, three types of etymological errors were identified as frequently used and accepted by the scientific community, regardless of the area of study.

These were as follows:

i. Use of the term “aril” to refer to the whole pomegranate seed (Adiletta et al., 2017; Belay, Caleb, Mahajan, & Opara, 2018; Fashi,

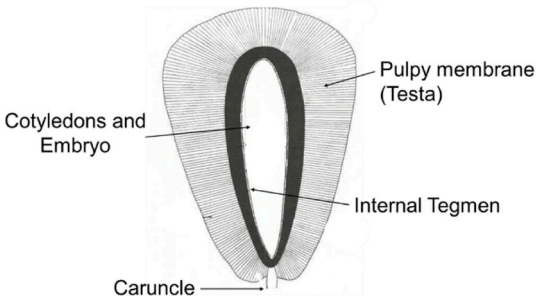

Fig. 2. Longitudinal section diagram of a *Punica granatum* seed in which the radially elongated cells of the pulpy membrane (testa) can be observed surrounding the cotyledons and embryo (adapted from Kozlowski, 1972; and Fahn, 1985).

Naderloo, & Javadikia, 2019; Franklin et al., 2019; Jaiswal, DerMarderosian, & Porter, 2010; Mukama, Ambaw, & Opara, 2019).

ii. Name only the inner part of the pomegranate seed "seed" (Hou et al., 2019; Kulkarni & Aradhya, 2005; Loizzo et al., 2019).

iii. Specific differentiation between "seed" and "aril" of the pomegranate fruit, where in this case, the term "aril" refers exclusively to the pulp or juicy membrane of the seed (Bonesi, Tundis, Sicari, & Loizzo, 2019; Karimi, Sadeghi, & Kokini, 2017; Viswanath, Sridevi, Venkataramudu, Rajesh Naik, & Ravindra Kumar, 2019; Özcan et al., 2019).

Regarding these commonly made mistakes, the authors and/or references are much more numerous than mentioned above. However, since the given references are mere examples, it was not considered necessary to add more, given that the main objective of this work is to help the understanding and correct etymological use of the terms previously mentioned, and not to highlight the mistakes of other scientists colleagues.

Thereby, to explain these contradictions, the authors resorted to botany, which is the science for the study of plants, including their structure, properties, and biochemical processes. It was also included plant classification and the study of plant diseases and its interactions with the environment. The principles and findings of botany have provided the base for such applied sciences as agriculture, horticulture and forestry.

3. Pomegranate fruit parts: a botanical characterization

Pomegranate, *Punica granatum* L., is a dicotyledonous plant belonging to the *Rosidae* subclass, *Myrtales* Order, and *Punicaceae* family. The name Pomegranate comes from the Latin word *Pomum*, meaning Apple, and *granatus,* meaning full of seeds. The botanical name derived from old French: *Pomegrenate* or full-of-seeds apple (Goor & Liberman, 1956; Graham, Crisci, & Hoch, 1993; Mertens-Talcott, Jilma-Stohlawetz, Rios, Hingorani, & Derendorf, 2006; Still, 2006).

In pomegranate general, it is a large shrub or small deciduous tree considered to be extremely long-lived (Morton, 1987). Its root is superficial, knobbly, strong, reddish, grows to become widespread. Its branches are alternate and open, with medium thickness, and sometimes with terminal spines. The leaves are opposite, whole, smooth, without stipules, and with short petioles. The flowers (Fig. 1), solitary or in groups of up to seven, have the thalamus in the form of a spinning top, holding between 5 and 9 petals and sepals; which are hermaphroditic with more than 300 stamens inserted in the calyx and eight carpels located on two superimposed planes (Agustí, 2010).

The pomegranate fruit, called balausta, is a pulpy berry of approximately 6–12 cm in diameter, crowned by the persistent calyx; thick skin, leathery, with coloration that can vary from reddish yellow to green with reddish areas and even scarlet red depending on the variety (Fig. 1). The fruit inside is full of seeds or grains of prismatic shape, and a pulpy cover called testa, woody tegmen, without albumin, straight embryo, and cotyledons inscribed in each other (Fig. 1) (Agustí, 2010; Fahn, 1985; Font Quer, 1953; Goldberg, 1989; Melgarejo & Martínez Valero, 1989). *Each grain is the edible portion of the fruit, and it constitutes the pomegranate seed* (Fahn, 1985; Goldberg, 1989; Melgarejo & Salazar, 2003).

In this sense, but earlier in history, Miller (1768, 1785), Harvey and Sonder (1862), and Köhler (1883) described the pomegranate fruit as "*divided into several cells (carpels) by membranous partitions (carpellary membranes), which are full of rounded succulent seeds*". Besides this, other authors described the pomegranate seeds more specifically as *"(…) large, angled seeds, testa with juicy pulp; foliaceous cotyledons, spirally rolled up, biauriculated at the base (…)"* (Standley & Williams, 1962; Thomas, 1897). It is possible to notice that all authors agreed to highlight the seed as pulpy; and based on this idea, Kozlowski (1972) and Fahn (1985) made a specific schematic design of the pomegranate seed, in which the pulpy membrane of the seed, also called testa, was unequivocally identified, as shown in Fig. 2.

In 1926, Netolitzky conducted an anatomy pomegranate seed study and claimed that the seed testa is composed of an external pulpy membrane named sarcotesta. The sarcotesta term is applied to the pulpy and edible part of the seed coat. It presents attractive colors and can be considered a clear adaptation of the seeds to the zoochory. The sarcotesta is always followed, inwards, by a hard sclerotized layer as a protection against animal digestion (Boesewinkel & Bouman, 1984).

According to botanists, the sarcotesta can have three different origins. Regarding pomegranate seeds, the sarcotesta comes from the outer layer of the testa, in which epidermal cells grow radially with an elongated shape (Fig. 2) (Boesewinkel & Bouman, 1984; Eames & MacDaniels, 1925; Kozlowski, 1972).

Certainly, it is possible to imply that there is a lack of anatomical knowledge about the pomegranate seed, which is not fully understood, and its concepts are unclear. Many authors (Ali Redha, Hasan, & Mandeel, 2018; El-Beih, Ramadan, El-Husseiny, & Hussein, 2019; Paul, Banerjee, Goon, & Saha, 2018) call "*aril*" to the pulpy part of the seed, when, in fact, the pomegranate seed is considered as exariled or without aril (Corner, 1976; Netolitzky, 1926), so they are referring to the edible pulpy part of the testa.

The term "*aril*" was defined by Gaertner (1788) as an ancestral integument annexed to the hilum that envelops, totally or partially, to the seed. Years later, Corner (1976) defined it as pulpy structures that grow from some parts of the ovule or funiculus, after fertilization, and that cover part or all of the seed. It is considered a facilitating adaptation in endozoochory.

More recently, Pujari and Rane (2015), after a thorough microscopic work carried out regarding the pomegranate seeds development, effectively distinguished its different parts, such as testa, tegmen, endosperm, nucela, cotyledons, and embryo (Fig 3).

According to these authors and others previously mentioned, the pomegranate seed can be defined as a reproductive structure that has a fleshy outer testa called sarcotesta (a single layer of translucent and pulpy columnar cells) and an internal sclerotic testa called mesotesta (hard and thick-walled) (Fig. 4). The walls of mesotesta cells, during maturation, are thicker in the seeds of hard-seed pomegranate varieties when compared with the soft-seed ones. So, it could be affirmed that these sclerotized cells provide the hardness that is appreciated when the seeds are chewed. In the interior of the mesotesta, it is possible to find the tegmen, which is constituted by two yellowish-brown membranous epidermal layers (Fig. 4) (Boesewinkel & Bouman, 1984; Fahn, 1985; Pujari & Rane, 2015). Following the above descriptions, and aiming to clarify the concepts presented, the general structure of the pomegranate fruit was summarized in Fig. 5.

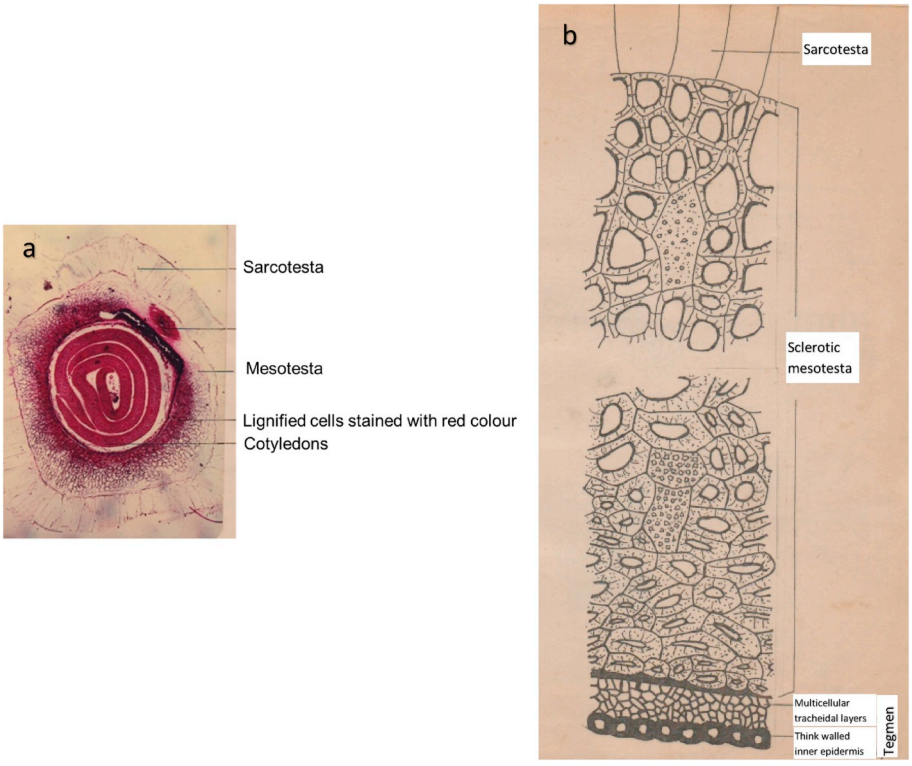

Fig. 3. Microphotograph of the cross-section (a) and partial scheme of a longitudinal section (b) of the pomegranate seed, with emphasis on its different parts, 120 days after the anthesis (×450) (Pujari & Rane, 2015).

4. Etymological conclusions

Based on the evidence and the literature presented in this communication, it is clear that most authors wrongly refer to the pomegranate seed and/or its parts. Given this, it can be concluded that:

- The pomegranate seed is the whole grain. It is composed of sarcotesta, sclerotized mesotesta, tegmen, nucela and embryo with cotyledons, and constitutes the edible portion of this complex fruit called balausta.
- The external testa, fleshy or pulpy, is composed of a single layer of radial cells called sarcotesta and cannot be confused with aril.
- The whole pomegranate seed cannot be called aril, because it is exariled.
- The sclerotized mesotesta is the one that brings hardness to the pomegranate seeds.
- The sarcotesta and the mesotesta together constitute the seed testa or outer covering.
- The tegmen or inner coat is composed of two yellowish-brown membranous layers.

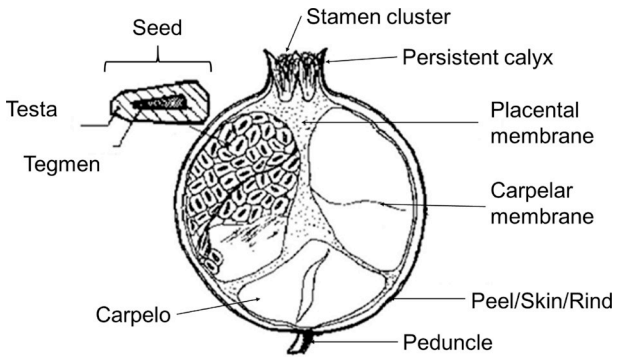

Fig. 5. Pomegranate fruit parts highlighting the seeds with the inner part (tegmen) and the outer membrane (testa), the fleshy part from where the juice is extracted (Adapted from Melgarejo & Salazar, 2003).

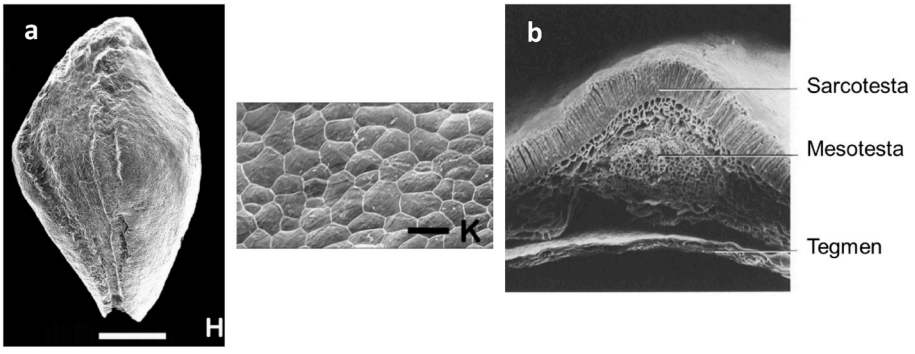

Fig. 4. SEM photographs of *Punica granatum* seed. (a) Raphal face, sarcotesta and outermost layers of the mesotesta removed; scale bar = 1 mm (H) and sarcotesta surface, raphal face; scale bar = 50 μm (K) (Graham & Graham, 2014). (b) Partial longitudinal seed section showing different layers (Adapted from Boesewinkel & Bouman, 1984).

- The inner portion of the seed constituted by the mesotesta, tegmen, and embryo with its cotyledons and other structures, cannot be denominated seed and/or woody part.

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Declaration of competing interest

None.

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