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# Summary

Pomegranate *(Punica granatum* L.) has gained global recognition not only for its nutritional and sensory attributes but also for the exceptional richness of its bioactive compounds. Alongside the expansion of pomegranate cultivation and processing, large quantities of by-products—mainly peels and seed press residues—are generated, representing more than half of the fruit's original mass. These by-products, once considered waste, are now recognized as valuable sources of polyphenols, particularly ellagitannins, flavonoids, and phenolic acids, which exhibit strong antioxidant, antimicrobial, anti-inflammatory, and other health-promoting properties.

This book provides a comprehensive overview of pomegranate cultivation and global distribution, the chemical composition of its major by-products, and the pre- and post-harvest factors influencing their bioactive profiles. Particular emphasis is placed on extraction techniques for polyphenols, including conventional and emerging green technologies, as well as on recent advances in encapsulation strategies aimed at improving the stability, bioavailability, and controlled release of sensitive compounds. The biological activities of pomegranate peel extracts are critically discussed, together with their growing applications in food systems, packaging, and plant disease control. By integrating agronomic, biochemical, technological, and functional perspectives, this work highlights the potential of pomegranate by-products as sustainable, high-value ingredients for the food and health-related industrie.

# Introduction

The pomegranate *(Punica granatum* L.), originating from Central Asia, has undergone extensive geographical expansion and genetic diversification, resulting in thousands of genotypes and hundreds of cultivated varieties. Currently, pomegranate production is concentrated in Mediterranean regions, Asia, and the Americas, with a marked increase in global output driven by growing consumer demand for functional and health-promoting foods. Alongside this growth, industrial processing of pomegranate into juices and ready-to-use products generates substantial amounts of by-products, mainly peels and seed press residues, which are often underutilized.

These by-products are now recognized as valuable sources of polyphenols, dietary fibers, and micronutrients, with chemical compositions influenced by cultivar, edaphoclimatic conditions, fruit maturity, and post-harvest handling. Among them, the pericarp stands out due to its exceptionally high polyphenol content, dominated by ellagitannins with strong antioxidant capacity. However, the instability of these compounds during processing, storage, and digestion limits their direct application.

To overcome these challenges, significant research efforts have focused on optimizing extraction methods and developing encapsulation strategies to preserve bioactivity, improve stability, and enable controlled release. In parallel, increasing attention is

being paid to the incorporation of pomegranate by-products into food systems, packaging materials, and plant disease control as part of sustainable valorization approaches. This work synthesizes current knowledge on pomegranate by-products, with particular focus on polyphenol recovery, encapsulation technologies, and their technological and biological applications.

# 1 Cultivation and Distribution of Pomegranate *(Punica granatum* L.)

## 1.1 Origin and Genetic Variability

The pomegranate *(Punica granatum* L.) is a tree species native to Central Asia. Over time, its cultivation has expanded to regions characterized by warm climates and low precipitation (Holland et al., 2009). As a result of its widespread dissemination, the pomegranate has developed considerable genetic variability. Currently, more than 5,000 genotypes, sometimes including duplicates, are maintained in germplasm banks, and approximately 500 distinct cultivars have been described (Vincent et al., 2019). Certain pomegranate varieties exhibit notable drought tolerance, although this trait varies depending on the genotype(Adiba et al., 2021).

## 1.2 Global Production and Distribution

Today, pomegranate is cultivated on all continents, although production is concentrated in specific countries: India, Iran, Turkey, the United States (California), Egypt, Chile, Morocco, Algeria, Peru, and Spain (Kahramanoglu and Usanmaz, 2016). Pomegranate cultivation is experiencing substantial growth, with several countries reporting significant increases in production over the past decade. According to official data, Turkey recorded a 45% increase in production between 2015 and 2021, Peru saw a 360% rise during the same period, and Mexico's production increased by 84% between

2015 and 2020. India and Spain also experienced notable growth, with increases of 41% (2015–2019) and 28% (2015–2019), respectively. In Algeria, pomegranate cultivation has expanded significantly due to the National Agricultural Development Program (PNDA), which facilitated the recovery of agricultural land. Production rose from 717,063 tons in 2012 to 790,374 tons in 2014, with yields increasing from 7.83 t/ha to 8.42 t/ha (Meziane et al., 2016).

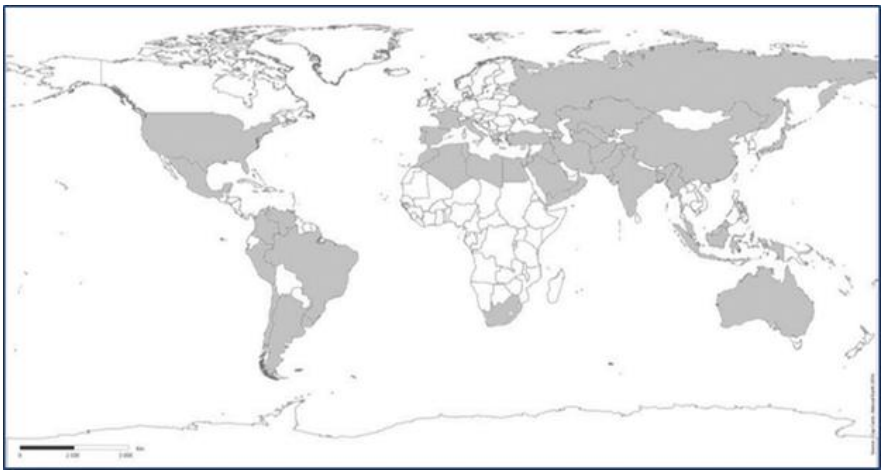

**Figure 1.** Worldwide distribution of pomegranate cultivation, with producing countries highlighted in gray (Lamotte, 2023).

## 1.3 Pomegranate

The pomegranate is a berry-shaped fruit, with color varying according to cultivar, ranging from red, pink, or purple to shades of yellow or green (Khadivi et al., 2020). Its outer layer, or pericarp, consists of the exocarp and a spongy, whitish-yellow mesocarp,

which protects the locules containing the edible seeds. The seeds contain a juicy portion known as the aril, which surrounds an internal structure (Figure 2) Khad (Khadivi et al., 2020).

The anatomy of the pomegranate is subject to varying interpretations in the literature. Indeed, the term “pomegranate seed” is sometimes used to refer to the aril, whereas “seed” refers to the internal part of the seed. Furthermore, the terms rind or peel are used inconsistently, sometimes indicating only the exocarp or the entire pericarp.

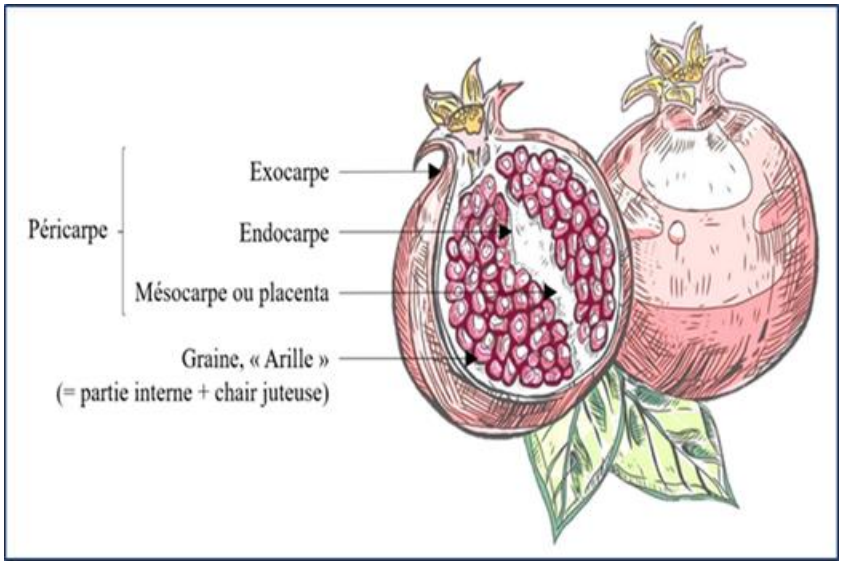


**Figure 2.** Different Parts of the Pomegranate.

The growing interest in the dietary use of pomegranate is attributable both to its organoleptic qualities and to its nutritional properties, which have been increasingly highlighted in recent years. These characteristics are closely linked to the bioactive compounds

and nutrients present in the edible fraction of the fruit, i.e., the seeds, as well as in juices extracted from the whole fruit or solely from the seeds (Dhineshkumar and Ramasamy, 2016). Among the major functional molecules are natural sugars, organic acids, phenolic antioxidants, micronutrients, and lipids (da Silva et al., 2013).

Pomegranate is marketed in various forms: whole, deseeded, or processed into derivative products such as juice (Stiletto and Trestini, 2021). In certain producing countries, the combination of harvest seasonality and the growing demand for nutrient-dense foods drives processing activities, thereby ensuring the year-round availability of pomegranate products (Rymon, 2011). During processing into ready-to-use seeds or juice, different types of by-products are generated. For whole seeds marketed commercially, the pericarp is separated and constitutes the main by-product. In contrast, for juice production, pomegranates are either pressed in their entirety or after seed extraction.

During pomegranate pressing, different by-products are generated depending on the method used. When the whole fruit is pressed, a single by-product is obtained: the press cake. In contrast, when only the seeds are pressed, two by-products are produced: the pericarp and the seed press cake. These distinctions are particularly important, as pressing the whole fruit or only the seeds affects the bioactive compound content of the juice, which also leads to variations in the resulting by-products (Rinaldi et al., 2013).