

# The introduction of *Citrus* to Italy, with reference to the identification problems of seed remains

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**Abstract** While some consensus exists about the roles of southwestern China and northeastern India in the origin and diversification of the genus *Citrus*, the scarcity of its archaeological remains, as well as some methodological limits in unequivocally identifying taxa, do not facilitate reconstruction of the tempo and mode of spread of the genus towards other areas, notably the Mediterranean.

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Recent discoveries of archaeobotanical macro-remains (seeds and fruits) and pollen records from some important Italian sites in the Vesuvius area and Rome can be used to shed new light on this history. However, due to their morphological variability and the changes derived from the preservation processes, *Citrus* seeds appear difficult to recognise. In this paper, we present criteria to facilitate their precise identification, based on the observation of the morphology of modern seeds, and most of all the seed-coat patterns. The reference material consisted of “archaic” varieties of *C. medica* L. (citron), *C. × limon* (L.) Burm. f. (lemon) and seeds of *C. × aurantium* L. (bitter or Seville orange), *C. × aurantiifolia* (Christm.) Swingle (lime) and *C. reticulata* Blanco (tangerine, mandarin orange). Considering the fact that the general morphology of seeds, especially when mineralised, can confuse the identification of *Citrus* with Maloideae types, we also add criteria for the recognition of *Cydonia oblonga* Mill. (quince), *Malus domestica* Borkh. (apple), *Pyrus communis* L. (pear), *Sorbus aria* (L.) Crantz (whitebeam) and *S. domestica* L. (service tree). The observation of the keels and cell patterns was mostly useful to identify new material from Pompeii and Rome dating from the 3rd/2nd century B.C. and the Augustan period around the beginning of the Common (Christian) Era as *C. medica* L. (citron) and *C. cf. × limon* (L.) Burm. f. (possible lemon). The classical Greek and Latin sources helped us to understand the use and status of citrus fruits in the ancient world and, in combination with all available archaeobotanical remains compiled in this paper, have allowed us to discuss the spread of *Citrus* from its regions of origin to the eastern Mediterranean and then within the Mediterranean.

**Keywords** Lemon · Citron · Western Mediterranean · Archaic period · Roman period

## Introduction

### Problems and aims of the study

The centre of origin of *Citrus* L. (Rutaceae) is, at the moment, generally considered to be in northeastern India (Asouti and Fuller 2008) and southwestern China (Gmitter and Hu 1990). In fact, wild *Citrus* and its wild relatives spontaneously grow in Yunnan province, but it is difficult to ascertain if these wild taxa are truly indigenous or whether they were introduced a long time ago by human agricultural activities (Gmitter and Hu 1990). The role of this area in the origin and diversification of the genus *Citrus* seems to be well established, but the material reported so far is still too sparse to trace a reliable history of the chronology and mode of spread of the genus towards other areas, notably the Mediterranean (Zohary et al. 2012, pp. 146–147).

Some theories have been suggested, mostly based on designation and etymology: either an ancient acclimatisation in Egypt (Loret 1891), or a route to Europe via Palestine (Isaac 1959), or via Persia and Greece (Loret 1891; Tolokowsky 1938). The argument has reached a limit, because the scarcity of the archaeobotanical remains, as well as the limitation in unequivocally identifying taxa, leaves the problem unsolved. The common view is that the only *Citrus* known in antiquity was *C. medica* L. (citron). *C. × limon* (L.) Burm. f. (lemon) and *C. × aurantium* L. (sour or Seville orange) were supposed to have been imported by the Arabs towards the 10th century A.D. and *C. × sinensis* (L.) Osbeck (sweet orange) by the Portuguese around the 16th century A.D. (Ramón-Laca 2003).

Some recent finds in Italy have raised the question of an earlier introduction, notably for the lemon. This relies nevertheless on the possibility of identifying the archaeobotanical remains. This proves far from simple, due to the multiplicity of the phenotypes, and the probability that archaeological specimens do not correspond with known modern varieties.

In the following, we will attempt to synthesise the ancient knowledge of *Citrus* spp., fruit and tree, according to classical sources, iconography and archaeological discoveries dating from after the 2nd millennium cal B.C. Then we will describe new archaeobotanical finds from the Campania region and Rome in southern Italy, and the possibility of identifying them as closely as species, using present-day reference material. The aim of this later section is not to make intraspecific distinctions within the genus *Citrus* but to confirm the presence of several *Citrus* types among the archaeological specimens. Consequently, at this stage of the work, biomorphometry has not been performed. Finally, we will introduce the question of the diffusion agents and acclimatisation in the western

Mediterranean. All the data given in the text refer to absolute/solar years B.C./A.D. The nomenclature we are referring to for the *Citrus* species is found in Appendix 1 (ESM).

### Description of the plant in classical sources

Greek and Latin texts provide descriptions of *Citrus* fruit or trees and also information about their cultivation, uses and properties. In spite of the diversity of names, descriptions are quite similar from one text to the next. Ancient writers tend to repeat what their predecessors wrote, especially in the case of an “exotic” plant such as the *Citrus* fruit. Not every writer had actually seen it, or they may have seen the tree without identifying it. Of course, these names are not scientific ones; the problem of identifying the species that could be grown in the western Mediterranean during antiquity is still present.

The first description is made by the Greek Theophrastus (ca. 372–287 B.C.) who referred in his *Historia Plantarum* to a peculiar tree from Media and Persia (*Hist. Plant.* 4.4.2–3) (Andrews 1961, p. 39; Amigues 1988). He describes its seeds (*Hist. Plant.* 1, 11, 4), then its flowers, which are characteristic of the genus: “those which have a sort of distaff (i.e. the pistil) projecting from the middle are fertile, while those which do not are sterile” (*Hist. Plant.* 1, 13, 4). The tree’s identification criteria are the leaves, “comparable with the ones of the oriental strawberry tree and the walnut tree”, and the thorn, “as those of the pear tree or the fire-thorn, but smooth and very sharp and robust” (*Hist. Plant.* 4, 4, 2). Plinius (Pliny) (A.D. 23–79) also mentions the thorns (*Nat. Hist.* 12, 15) (Rackham 1952–67), and Vergilius (Vergil) (ca. 70–19 B.C.) compares the leaves with those of a laurel (*Georgica* 2, 131) (Volk 2008). According to several writers, the tree bears fruits the whole year (Theophrastus *Hist. Plant.* 4, 4, 2; Dioscorides, *De Materia Medica* 1, 115, 5 (Wellmann 1958); Plinius, *Naturalis Historia* 12, 15; Servius, *Commentarii in Vergilii Georgica* 2, 127).

The first description of the fruit is from Dioscorides (ca. A.D. 40–90): elongated shape, wrinkled and golden yellow skin, fragrant and similar to a pear (*Mat. Med.* 1, 115, 5). Galenus (Galen) (A.D. 129—ca. 200) describes it more precisely. The fruit is divided into three parts: the inner part, which contains the seeds and is acid; the flesh, which is juicy and refreshing; and the skin, which has “acrid oil” (*Simp. Med.* 8, 19; *De alimentorum facultatibus* 2, 37) (Kühn 1965). As Galenus names the middle part “flesh” (Greek *sarx*), and the inner part *sperma* (seed), and as he says that every part is sour, we can imagine a *Citrus* fruit whose middle part (the albedo) was well-developed: this is the case of the citron, and this description has probably led Loret (1891) to his hypothesis. According to

him, Dioscorides also describes a citron, because the “wrinkled skin” he mentions is characteristic of this fruit. Gargilius Martialis (Martial) (ca. A.D. 200—ca. 260) also mentions a fruit divided into three parts (Maire 2001), using the same words as Galenus (*Medicinae ex oleribus et pomis* 45), so it is unclear whether Gargilius Martialis describes the same fruit that he really had seen, or whether he was using Galenus’ work.

One can observe an evolution in the way how Greek and Latin writers cite the plant. Theophrastus uses the periphrasis *melea persike*, “Persian apple tree” (*Hist. Plant.* 1, 11, 4), or *melea medike*, “Median apple tree” (*Hist. Plant.* 1, 13, 4); then most of the Latin authors use the word *citrus* to name the tree, and *citrium* or *malum citrium* for the fruit (André 1985, p. 68), and Greek authors writing after the 1st century A.D. also use the words *kitrea* and *kitrion*. However we find in Plinius’ *Naturalis Historia* both the periphrasis *malus Assyria* (*Nat. Hist.* 12, 15), as well as names built on the root *citr*—(*Nat. Hist.* 15, 47; 15, 110; 23, 105; 16, 107).

#### Biology, taxonomic classification and phylogeny within the genus *Citrus*

The taxonomy of citrus fruits appears quite complicated, because of their complete inter-fertility as well as the forming of adventitious nucellar embryos. The six genera belonging to the sub-family Aurantioideae of the Rutaceae which are considered as the “true” citrus fruits, are very close and interfertile, so the genus *Citrus* itself is characterized by a wide diversity. Consequently, taxonomic classification is difficult due to the reproductive biology of the genus. Many *Citrus* types reproduce asexually by a process called nucellar embryo formation: many embryos initiate directly from nucellar cells, and these embryos are genetically identical to the parent plant (Mabberley 1997; Moore 2001). Seeds are also produced asexually by facultative apomixis, which is replacement of the normal sexual reproduction by asexual reproduction, without fertilisation. This process, through abnormal meiosis, gives rise to embryos which have the same genetic makeup as the mother plant. Thus, when a *Citrus* seed is planted, the resulting tree is often genetically identical to the tree from which it came, and these reproductive processes stabilize and perpetuate hybrid taxa. Sexual compatibility between *Citrus* and related genera favour natural hybridization, giving rise to a wide range of subspecies. The high frequency of bud mutation, the beneficial ones potentially propagated by grafting, further reinforces the possibility for diversification within the genus. Since apomixis generates offspring which are genetically identical to the parent plant, so that the characters of the hybrids are maintained through seedling and stable hybrid lines, they could be considered as real microspecies (Mabberley 1997;

Moore 2001). Moreover, *Citrus* taxa have been cultivated for a long time and their centre of origin is not precisely known: as well as the wide diversity within the genus, these elements make their classification based on morphological and geographical criteria difficult.

In fact, the “classical” classifications (Swingle and Reece 1967; Tanaka 1977) have been revealed as inadequate in appropriately assessing past “species”. Those classifications, depending on what is given a “species” status according to anatomical and morphological criteria, include respectively 16 and 162 types. Further classifications from Scora (1975) and Barrett and Rhodes (1976), based on 146 morphological and biochemical characters, suggest that only *C. medica* L. (citron), *C. maxima* (Burm.) Merr. (syn. *C. grandis* (L.) Osbeck) (pomelo) and *C. reticulata* Blanco (mandarin, tangerine) should be considered “true species”. The other cultivated ones more probably represent hybrids arising from cross-breeding or natural events, and therefore indicated with an × between the genus and the species name.

Recent work in genetics has revealed that species status within the genus *Citrus* is problematic, due to biological characteristics. Within the Rutaceae, the subfamily Aurantioideae is divided into subtribes including the Citrinae, which comprises a group of six genera, all having lemon or orange-like fruits: *Citrus*, *Clymenia*, *Eremocitrus*, *Fortunella*, *Microcitrus* and *Poncirus* (Moore 2001). The genus *Citrus* is composed of the subgenera *Eucitrus* (common cultivated fruit) and *Papeda* (non edible fruit), according to Swingle and Reece (1967), while phylogenetic dendrograms obtained from separate DNA marker technologies show that they do not cluster completely (Pang et al. 2007; Uzun et al. 2009).

Recent phylogenetic investigations based on SSRs molecular (Barkley et al. 2006) and AFLP markers (Pang et al. 2007) support these original suggestions and the parental species of important hybrids such as *C. × limon* (L.) Burm. f. (lemon), *C. × sinensis* (L.) Osbeck (sweet orange) or *C. × paradisi* Macfad. (grapefruit) have been potentially identified, using RAPD, SCAR and cpDNA markers (Nicolosi et al. 2000), or RAPD and RFLP (Federici et al. 1998).

In the light of the previous considerations, the probability of being able to identify archaeobotanical remains to species level, using morphological characters, appears quite low.

On the one hand, *Citrus* is characterized by wide diversity, with abundant natural hybridization, providing many different phenotypes, which suggests a good number of species or subspecies. On the other hand, because of the asexual type of reproduction, exchange of genes is often prevented, and the biological concept of speciation (Willis 2002) is difficult to apply to the genus *Citrus*. Considering the high degree of variability due to natural hybridization

occurring within the genus, we may easily imagine that there were various species growing in the past. They were probably different from the ones we know today, and furthermore, some of the ancient species most probably do not grow nowadays. Species determination from wall-paintings and Greek and Latin literary sources is clearly problematic and even archaeobotanical remains are always difficult to identify, unless they are preserved by desiccation or waterlogging. Considering these elements all together, it seems important to re-examine the data, and to evaluate the degree of accuracy that archaeological remains and literary sources may provide.

Current knowledge on the presence of *Citrus* from on-site archaeobotanical evidence

The main archaeological discoveries of *Citrus* remains, mainly seeds, are summarized in Appendix 2 (ESM) and mapped (Fig. 1). Only the most ancient finds have been quoted, up to the 4th century A.D., as this paper is dealing with the question of early spread. The new Italian discoveries will be presented in the [Materials and methods](#) section below. The data have been arranged chronologically.

Finds of *Citrus* macroremains are quite rare, and the main reason for this scarcity is the fact that *Citrus* seeds are difficult to identify, due to their morphological variability and the changes arising from the preservation processes, mainly carbonisation and mineralisation, but also fragmentation. Those processes affect the preservation of the seed coat and

make it more difficult to see the characteristic features (see section “[Elaboration of new determination criteria](#)”). Whereas carbonised seeds are very rarely encountered, mineralised seeds are often found (Appendix 2, ESM). In permineralised material, minerals fill the cell lumina and intercellular spaces, but do not completely replace the cell walls (Taylor et al. 2009, p. 25). The process is fast and usually involves calcium phosphate (McCobb et al. 2003; Shillito and Almond 2010). Most *Citrus* remains are mineralised seeds, in which either the cells of the seed coat have been individually “fossilised”, or there is only a “moulding” of the inner space of the seed. On such casts, the characteristic crests and the testa ornamentation do not remain visible (see section “[Elaboration of new determination criteria](#)”). In addition, the general morphology of seeds, when mineralised, can confuse the identification of *Citrus* with Maloideae.

Waterlogged and desiccated macroremains provide better identification possibilities (Appendix 2, ESM); they, however, are only rarely found, or under special circumstances as in deserts).

The earliest evidence of *Citrus* seeds comes from northern India, from the early 2nd millennium B.C. site of Sanghol in Punjab, but the identification as *C. × limon* (L.) Burm. f. is not supported by a description of the criteria used, as underlined by Asouti and Fuller (2008). The second macroremain evidence comes from Sanganakallu in Karnataka province, in southwestern India, where wood charcoal dating to 1400–1300 B.C. was identified (Asouti and Fuller 2008; Kingwell-Banham and Fuller 2012).

**Fig. 1** Location of the sites cited in Appendix 2, ESM



However, wood remains do not provide unequivocal identification criteria. The structures allow a sure identification of the genus, but are not characteristic enough to identify the species (Fahn et al. 1986; Greguss 1959; Schweingruber 1990).

The earliest European finds come from the eastern Mediterranean region. Some possibly mineralised seeds were found in Hala Sultan Tekke, Cyprus, possibly dating back to 1200 B.C., but they have not been directly dated to confirm their age (Hjelmqvist 1979, p. 117). Another early Mediterranean find comes from cremation grave 158 of the Phoenico-Punician necropolis of Monte Sirai, southern Sardinia (6th century B.C.); there, the use of highly symbolic materials such as beebread (*Ambrosia*), and *Citrus* (Botto and Salvadei 2005) for libations and offerings to the dead was revealed by chemical analysis of organic residues which were found in an *oenochoe* (a wine jug). Polyphenols, namely polymethoxyflavanones, were detected (Garnier, personal communication). Those compounds, quite stable, are hardly known in natural environments and are specific to citrus fruits. Because of the complete absence of sugars, one can suggest that this matter had been obtained from *Citrus* fruit skin.

New research has brought to light more evidence from the 1st millennium B.C. It comes from the city of Cumae (Kyme) in southwestern Italy, near Naples, today Cuma—Fusaro, one of the earliest Greek Euboean colonies, which played a major role in the transfer of Greek cultural influence to Etruscan and Roman civilisations. There, *Citrus*-type pollen was found in samples from core C VIII from the ancient lagoon at the foot of the archaeological site. The six available radiocarbon dates calibrate the sequence between the first half of the 8th century B.C. and the 15th–17th centuries A.D. 70 pollen grains of *Citrus* have been counted. The first one appears at 896–657 B.C., at the depth of 6.56 m, the type then being continuously recorded in silty layers until the top of the core (Bui Thi Mai and Girard 2010). When this pollen type is found in rather large quantities, considering the insect pollination character of *Citrus* and its poor pollen production and dispersal, one must consider the possibility that the trees had been cultivated locally. This might indicate that *Citrus* trees were cultivated in southern Italy at such an early period. One may suggest that these remains are evidence of “attempts” to acclimatise this taxon. More pollen evidence is recorded from the harbour of Carthage, North Africa, where *Citrus* fruit cultivation is suggested during the 4th century B.C. (Van Zeist et al. 2001). Somewhat more recent pollen evidence is recorded from southern Italy, especially from the Campania region and Pompeii (Appendix 2, ESM). Six pollen grains of *Citrus* (“lemon or citron”, Gröger et al. 2002, p. 251) have been recorded in the upper part of Zone 3 (Roman period) in section 3 of the lake core AV 14 K2 from Averno (Gröger et al. 2002). Archaeobotanical investigations in Pompeii have revealed *Citrus* pollen in the House of

Hercules and Ebe’s Wedding, 1st century A.D. (Mariotti Lippi 2000).

However, the species *C. medica* and *C. × limon* cannot be separated on the basis of pollen grains. The 4/5 colporate grain types including *C. medica* L. type, are found in all genera of the Citrinae group sharing a coarsely reticulate sculpturing, and also in exotic genera such as *Oxanthera*, *Aegle* and *Feronia* (Grant et al. 2000).

Another early southern Italian find, a *Citrus*-like fruit, was discovered in a funerary offering dating back to the 6th century B.C. on the southern Italian island of Ischia, but this was re-identified as Maloideae, using a micro-CT scan and SEM to characterize its structural morphology (Coubray et al. 2010).

From the Roman period, there are several finds of macroremains (Appendix 2, ESM). *Citrus* wood remains have been identified by Hueber in the Villa of Poppaea at Oplontis near Pompeii (Jashemski et al. 2002, p. 102). Mineralised seeds were also found at Pompeii, in other contexts. One single mineralised seed originates from the second phase of the House of Hercules and Ebe’s Wedding and dates from the first half of the 2nd century B.C. (Ciaraldi 2007, Fig. 43, p. 113). Another pip comes from a pit dug into the kitchen floor of the House of the Vestals, phase 3, and dates back to the second half of the 2nd century B.C. (Ciaraldi 2007, Fig. 61, p. 139). The only known carbonised seed remain of *Citrus* type comes from the area of the temple of Venus in Pompeii (Fiorentino and Marinò 2008).

The city of Pompeii has also yielded some frescoes and mosaics in which *Citrus* fruit trees have been identified. The trees are depicted with realism and precision, which has led some to believe that their painters had seen the real trees. In some cases, lemons or lemon trees could indeed be recognized, as for example on a mosaic from the Bath of Diocletian Museum in Rome (Jashemski 2002, p. 102), or on a wall-painting from the House of the Fruit Orchard in Pompeii (Jashemski 2002, p. 101; Borgogino 2006, pp. 31–32). On the other hand, some orange and round fruits are questionably argued to represent oranges as in the Mosaic from Naples (Tolkowsky 1938, pp. 100–101), and a fresco from Pompeii (Borgogino 2006, p. 35). Nevertheless, this evidence indicates that *Citrus* trees grew and produced flowers and fruit in the Pompeii region towards the 1st century A.D.

Desiccated and therefore very well preserved *Citrus* remains have been found in Egypt, in remote desert locations (Roman quarry settlements, oasis; Van der Veen, various works, see Appendix 2, ESM). *Citrus* fruit could have been cultivated there, as a garden plant (Thanheiser et al. 2002).

To summarize, the cultivation of *Citrus* trees seems to have been established in the Campania region of southern Italy by the beginning of the 1st century A.D., but the introduction of the genus is potentially much more ancient

and was probably attempted several times after the 6th–5th century B.C.

## Materials and methods

### New discoveries of *Citrus* macroremains

Recently, five mineralised and one carbonised seed were recovered in Pompeii from a well, archaeologically dated back to the 3rd–2nd centuries B.C., in the pre-Roman Samnites levels under the Roman temple of Venus (Fig. 2). For the description of sampling and recovery techniques as well as the archaeological context, see Fiorentino and Marinò (2008).

In the centre of Rome, in a votive deposit sealed under the floor of the Carcer-Tullianum, a Roman building used as a prison and located in the northern part of the Forum Romanum, 13 seeds and a fragment of skin belonging to *Citrus* have been found (Fig. 3, identified by A. Celant). The material, forming one single sample of approx. 20 l, was retrieved from a small rectangular pit covered by the stone floor and it was washed using sieves with 4, 2, and 0.5 mm mesh sizes. Plant remains were picked out under the stereomicroscope. Seeds were AMS dated to 2003 ± 45 B.P. (LTL8303A; 2σ calibration 120 B.C.—A.D. 90), most probably corresponding to the Augustan period (27 B.C.—A.D. 14). The seeds were uncharred (waterlogged), partly swollen because of waterlogging, and superficially covered by mineral concretions.

### Elaboration of new identification criteria using present-day reference material

For a reliable identification of *Citrus* seeds we applied the following procedure: First of all, photographs and SEM images were made of the *Citrus* seed types which could possibly be found in archaeological contexts earlier than the medieval and modern periods, and also some of the Maloideae taxa. The scanning electron microscope used for this study is part of the electron microscopy service of the Direction des Collections (Museum National d'Histoire Naturelle of Paris). It is a TESCAN-VEGA-II-LSU model which allows both conventional and variable-pressure microscopy. In order to avoid having to coat the samples with carbon or gold, the SEM observations were performed in low vacuum mode with a residual gas pressure in the analysis chamber of 20 Pa (nitrogen) and an accelerating voltage of 20 kV. These secondary electron micrographs were taken with an Everhart–Thornley detector adapted and dedicated to variable pressure mode (LVSTD device).

The reference material consists of “archaic” varieties of two types of *C. medica*: *C. medica* var. “Etrog” and

**Fig. 2** *Citrus* seeds from Pompeii; **a** general view of the seeds recovered from the temple of Venere, Pompeii, 3rd–2nd centuries B.C.; **b** SEM photograph of a seed; **c** SEM photograph of the coat of a *Citrus* seed (magnification 80×); **d** SEM photograph of the seed coat (180×), compared to the SEM photograph of the seed coat of *C. medica* “Etrog” at the same magnification; **e** SEM photograph of the seed coat (480×); **f** SEM photograph of the seed coat of *C. medica* “Etrog” modern seed (180×); photos by V. Zech-Matterne, S. Pont, MNHN Paris

*C. medica* var. “Diamante” and two varieties of *Citrus* × *limon*: “Frost Eureka” and “Femminello”, from the collection “agrumes et apparentés” INRA-CIRAD de la station INRA de San Giuliano, Corsica, France. Additional material has been collected by Jacob Morales, Gran Canaria, for the following taxa: *C. × aurantium*, *C. reticulata* and *C. × aurantiifolia* (see Appendix 1, ESM, for scientific denominations and synonyms). We added some species out of the reference collection of the UMR 7209 of the National Museum for Natural History laboratory in Paris: *C. × limon* (unknown variety collected in Pompeii) and some Maloideae types: *Cydonia oblonga* Mill., *Malus domestica* Borkh., *Pyrus communis* L., *Sorbus aria* (L.) Crantz and *S. domestica* L.

For each taxon, we took photographs of ten seeds in order to show the intraspecific variation, and detailed pictures of lateral and dorsal view, on which one can observe the epidermis features, the ventral or dorsal crests as well as the embryo zone. SEM pictures have been taken at several enlargements to show the cell arrangement. For systematic description, the following references have been used: shape according to IPGRI descriptors for the genus *Citrus* (1999), descriptions of the surface following Berggren (1969) and the terminology of the SACDBT group [Chart 1; Taxon 11–5 (1962)].

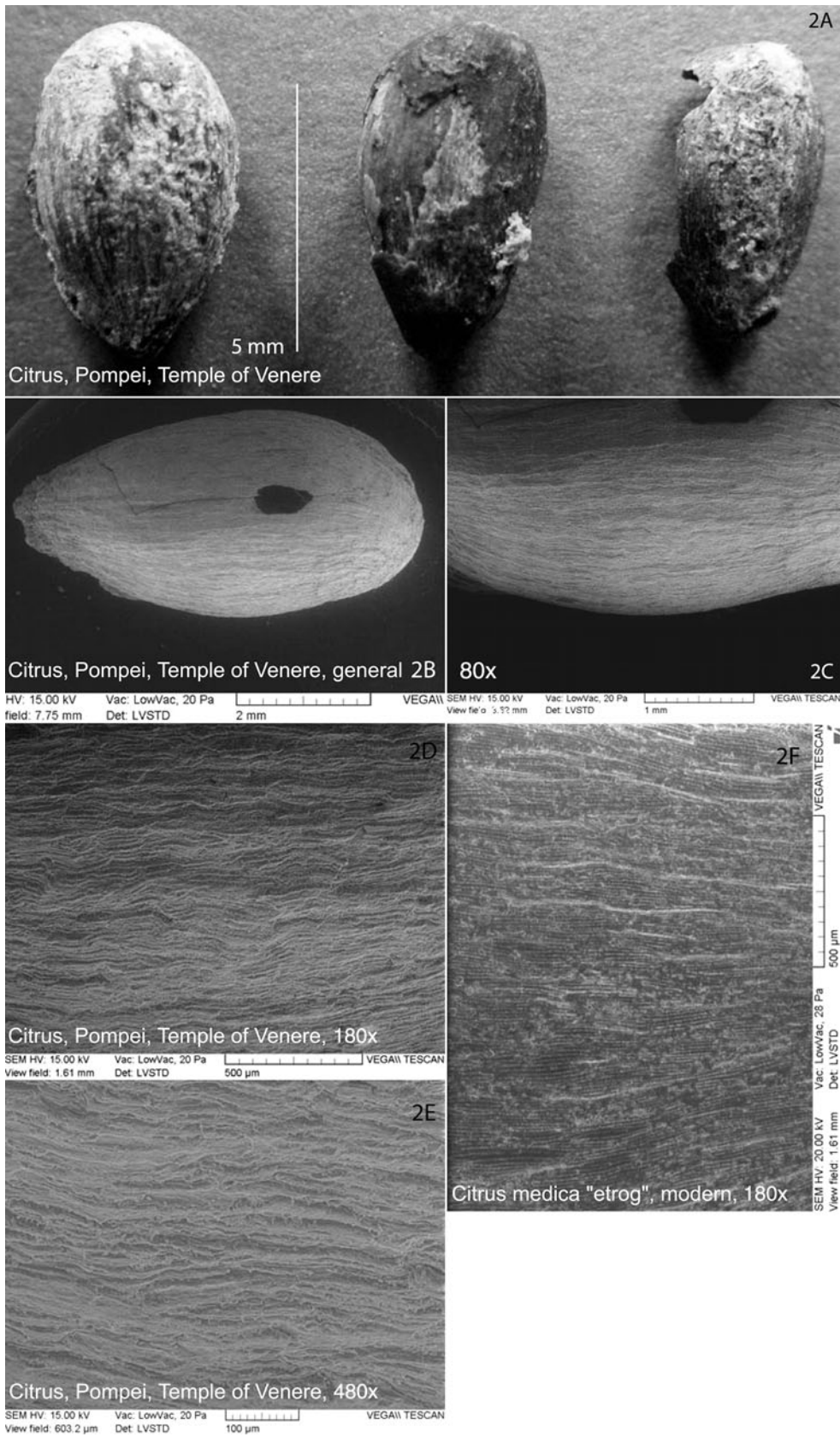
The following descriptions refer to the general shape, dimensions, presence/absence of lateral crests and epidermal cell patterns and are listed in Table 1. The criteria are defined according to Fig. 4.

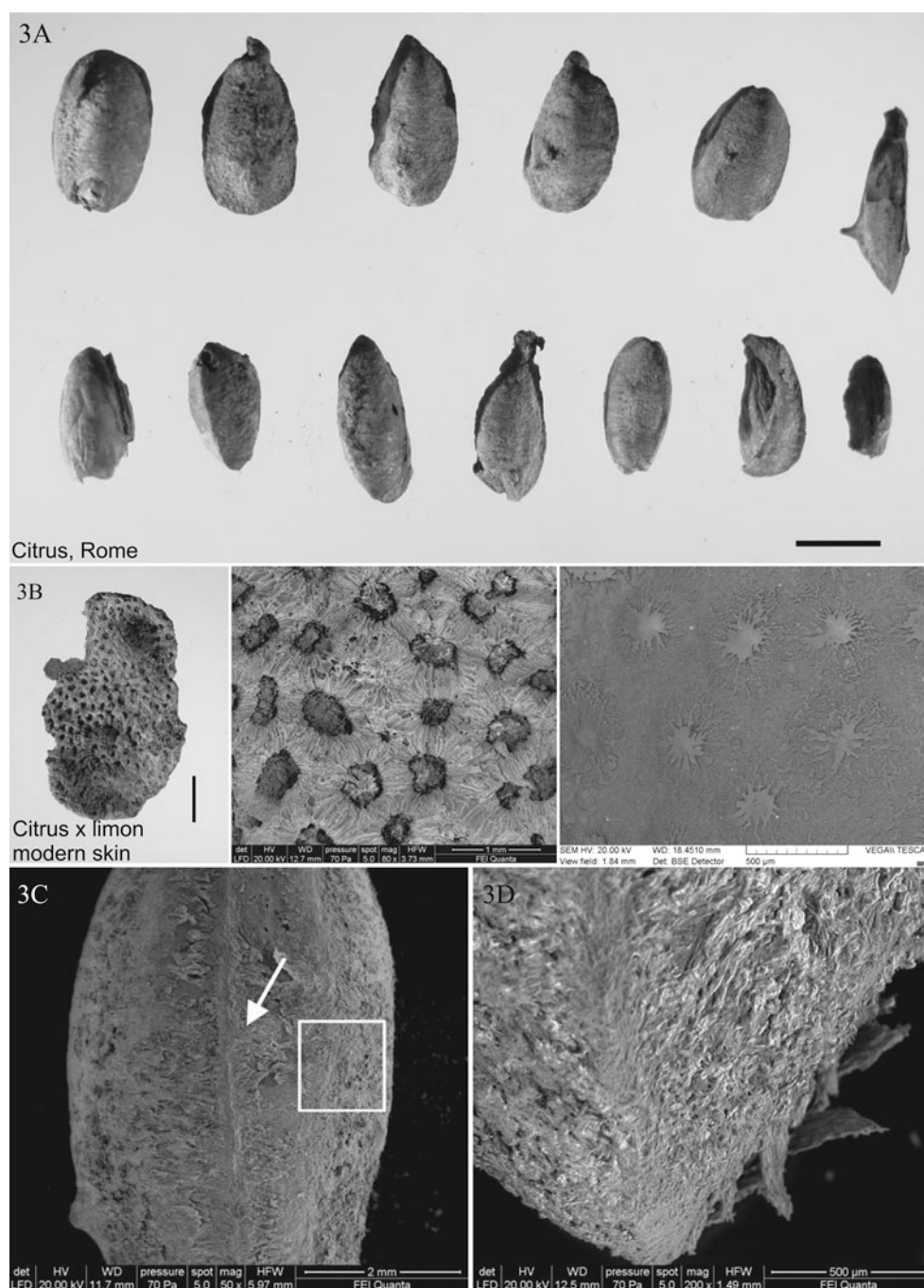
## Results

### Description of the general characteristics of the seeds of different modern *Citrus* taxa (Fig. 5)

The following description is based on modern seeds of *C. × limon* “Frost Eureka” and “Femminello”; *C. medica* “Etrog” and “Diamante”; *C. × aurantium*, *C. reticulata* and *C. × aurantiifolia*.

The polyembryonic seeds of the *Citrus* members are covered by a thin and brown inner coat and a mucilaginous thick and yellow outer coat. As in other dicotyledonous seeds, the radicles are at the micropylar end of the seed and the cotyledons at the chalazal end (Schneider 1968).





**Fig. 3** *Citrus* seeds from Rome. **a** seeds of *C. cf. × limon* from the Forum Romanum; **b** skin fragment of *Citrus* from the Forum Romanum (left; scale bars are 5 mm) and detail of the star-like features in SEM (middle); skin fragment of a modern *C. limon* (right);

**c** SEM photograph of the coat of a *Citrus* seed, the arrow indicates the crest, the irregular pattern of the surface is visible in the square; **d** SEM photograph of the embryo of a *Citrus* seed; photos by A. Celant

The shapes and dimensions of the seeds appear to be quite variable between the different “species”/morphotypes, but also at an intraspecific range (Fig. 5A–G). All the shapes described in IPGRI are represented in our material. The lateral sides are straight to regularly convex. The apex is truncated or more or less rounded. A lopsided beak is sometimes present on this side, as in *C. medica*

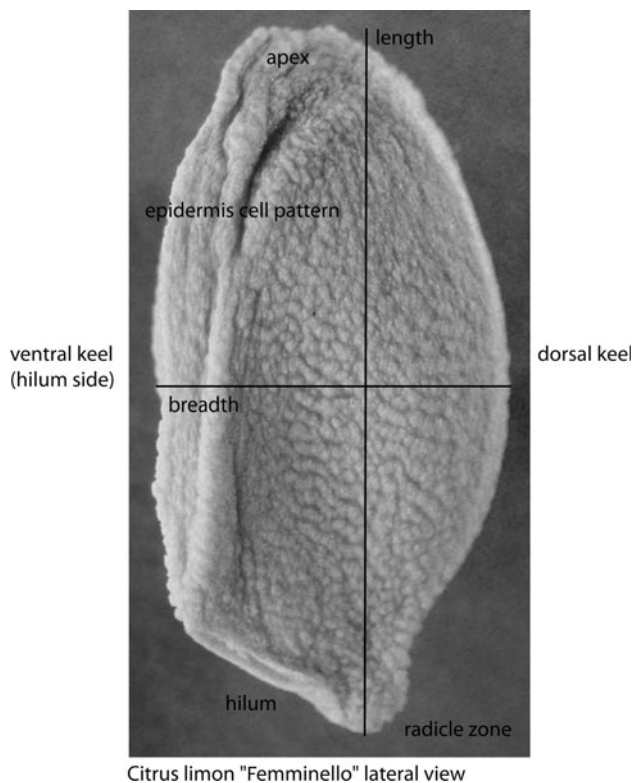
“Diamante” (Fig. 5D1). The base is usually pointed or lopsided. The hilum appears at the pointed base. The shape of the hilum is like a short fissure, in an oblique position with regard to the base extremity (Fig. 5H). Sometimes the base points to the hilum side and sometimes the other way. Either a crest can be seen on the hilum side (also called “ventral” side in the figures), or both ventral and dorsal



**Table 1** Criteria used for the differentiation of the different *Citrus* and Maloideae types

Criteria	<i>Citrus</i>	Maloideae
General shape	Quite variable (all IPGRI shapes represented); cross section rounded or polygonal	Globular/elongated; cross section rather thick with the exception of <i>Sorbus domestica</i> flattened in cross section
Shape of the embryo	Base pointed or lopsided; apex truncated or more or less rounded	Base pointed; <i>S. aria</i> embryo located on a lopsided beak; apex rounded, occasionally slight prominence
Crests/keels <sup>a</sup>	Ventral crest or keel always present; dorsal keel occasionally present in <i>C. × limon</i> and <i>C. × aurantiifolia</i>	Occasionally ventral crest
Seed surface (80–180×)	<i>C. medica</i> and <i>C. × limon</i> : cells arranged in fascicles	<i>Malus</i> : juxtaposition of long ranges of elongated cells <i>Pyrus</i> : reticulate pattern punctuated with small dimples <i>Cydonia</i> : reticulate-foveate net-pattern <i>Sorbus domestica</i> : scalariform outer layer structure <i>S. aria</i> : sulcate fibre structure covered by a scalariform outer layer
Seed surface (ca. 500×)	<i>C. medica</i> : cells chained in longitudinal and parallel lines (sulcate to ribbed pattern); <i>C. × limon</i> : cells irregular and anarchic (rugose to ruminant); other species: seed coat pitted with small protrusions	

<sup>a</sup> Crest: prominent and sharp—keel: smoother; inflection in the curvature



**Fig. 4** Lateral view of a seed of *C. × limon* var. “Femminello” showing the criteria used in the paper for archaeological seed identifications: general shape in lateral view, dimensions, presence/absence of ventral/dorsal crests, morphology of the apex and embryo zone, epidermis cell patterns; photos by V. Zech-Matterne

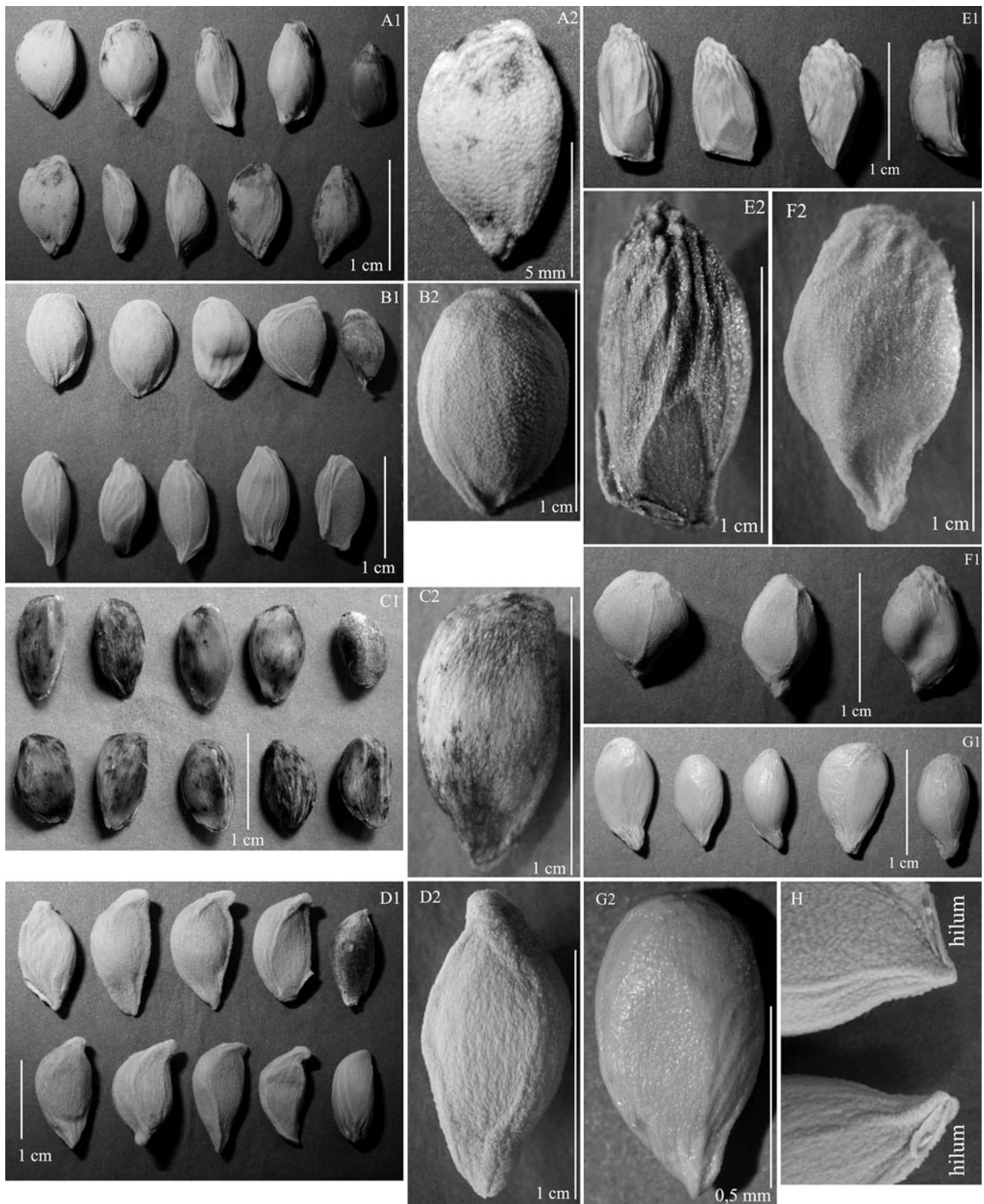
keels are present, the main one systematically positioned on the hilum side (“ventral side”). Occasionally, longitudinal nerves can be observed on the testa. Dimensions of 10 (5) modern seeds have been measured (Appendix 3, ESM).

Description of the general characteristics of the seeds of different Maloideae taxa (Fig. 6)

The seeds are pointed on the embryo side and rounded on the other side. On the rounded edge, a prominence can sometimes be seen, especially on the *Pyrus* seeds, (Fig. 6B1/2). The embryo of *Sorbus aria* is located on a lopsided base (Fig. 6E1/2). The seeds of *Cydonia oblonga* (Fig. 6C1/2) and *S. domestica* (Fig. 6D1/2) appear to be more globular than the seeds of the other species, which are more elongated. *S. domestica* has flattened seeds in cross-section, whereas the seeds of all other species are rather thick. The hilum is positioned on the pointed base. Its shape is also like a longitudinal and oblique aperture, visible on the pointed base (Fig. 6F, G).

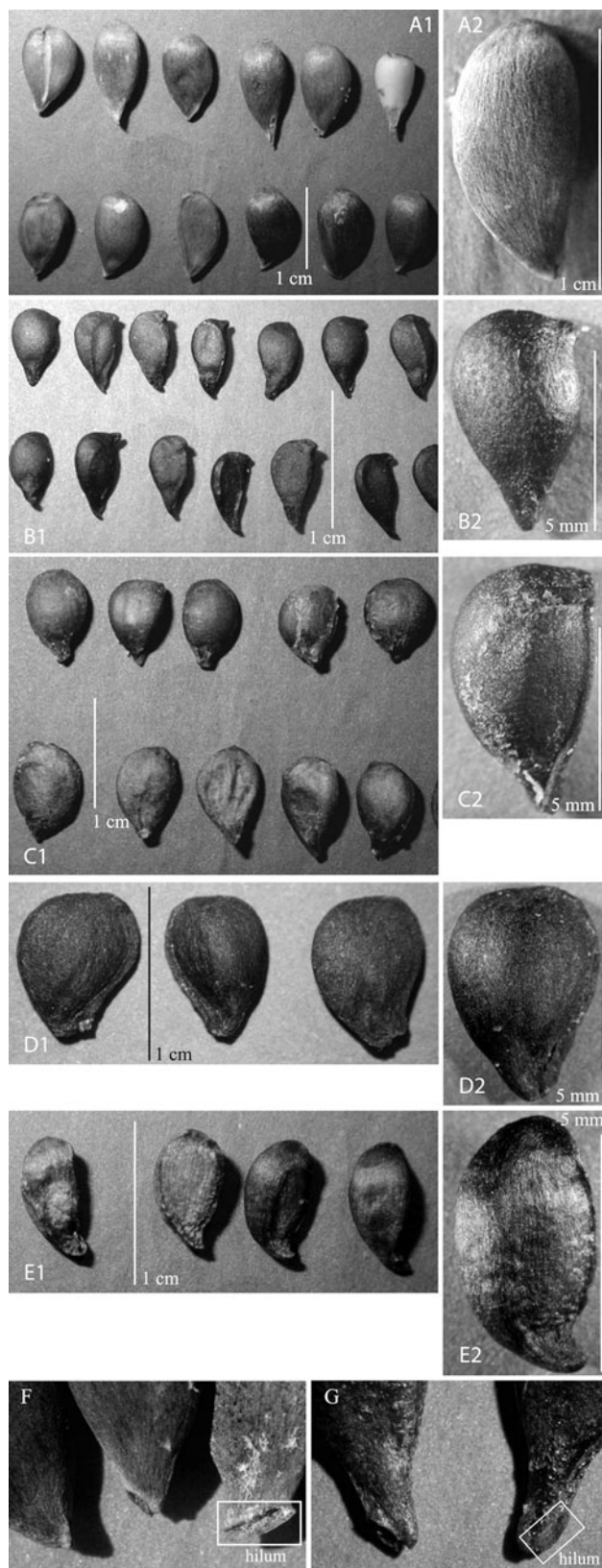
The presence/absence of crests/keels (Fig. 7)

The presence of both a ventral and a dorsal keel in the cross-section view has been noted only for *Citrus*, especially *C. × limon* (Fig. 7K a, b) and *C. × aurantiifolia* (Fig. 7K c, E). The main keel is positioned on the hilum side (“ventral side”) (Fig. 7A1/2). The *C. medica* type and other species of *Citrus* show a prominent ventral crest



**Fig. 5** General characteristics of the *Citrus* taxa. **A1/2** *C. × limon* “Frost Eureka” intraspecific variability and lateral view of the seed; **A1** upper right specimen: the epidermis of the seed has been removed in order to show the inner part; intraspecific variability and lateral

view of the seeds of **B1/2**, *C. × limon* “Femminello”; **C1/2** *C. medica* “Etrog”; **D1/2** *C. medica* “Diamante”; **E1/2** *C. × aurantium*; **F1/2** *C. reticulata*; **G1/2** *C. × aurantiifolia*; **H** hilum of *C. × limon* “Femminello”; photos by V. Zech-Matterne



◀ **Fig. 6** General characteristics of the Maloideae species; intraspecific variability and lateral view of the seeds of **A1/2** *Malus domestica*; **B1/2**, *Pyrus communis*; **C1/2** *Cydonia oblonga*; **D1/2** *Sorbus domestica*; **E1/2** *Sorbus aria*; **F** hilum of *Malus domestica*; **G** hilum of *Pyrus communis*; photos by V. Zech-Matterne

occasionally absent from *Pyrus* and *Cydonia*, as well as *Sorbus domestica*, and most of the time *Malus* (Fig. 7F) does not have any crest at all. The compression of several seeds in the fruit flesh creates an imprint that gives the idea that a crest was present.

The cell patterns of *Citrus taxa* (Fig. 8)

At magnifications of 80× and 180×, the cells of *C. medica* (Fig. 8B1) and *C. × limon* (Fig. 8A1) are both arranged in fascicles. They are much more regular and marked in *C. medica*. At a magnification of 488×, the cells of this latter species (Fig. 8B2) are chained in longitudinal and parallel lines in a sulcate to ribbed pattern, while their shape and arrangement appear to be irregular and anarchic, rugose to ruminant in *C. × limon* (Fig. 8A2). The patterns in other *Citrus taxa*, *C. reticulata*, *C. × aurantium* and *C. × aurantiifolia*, are less clear and seem to be pitted, with small protrusions (Fig. 8C–E).

The cell patterns of the Maloideae taxa (Fig. 9)

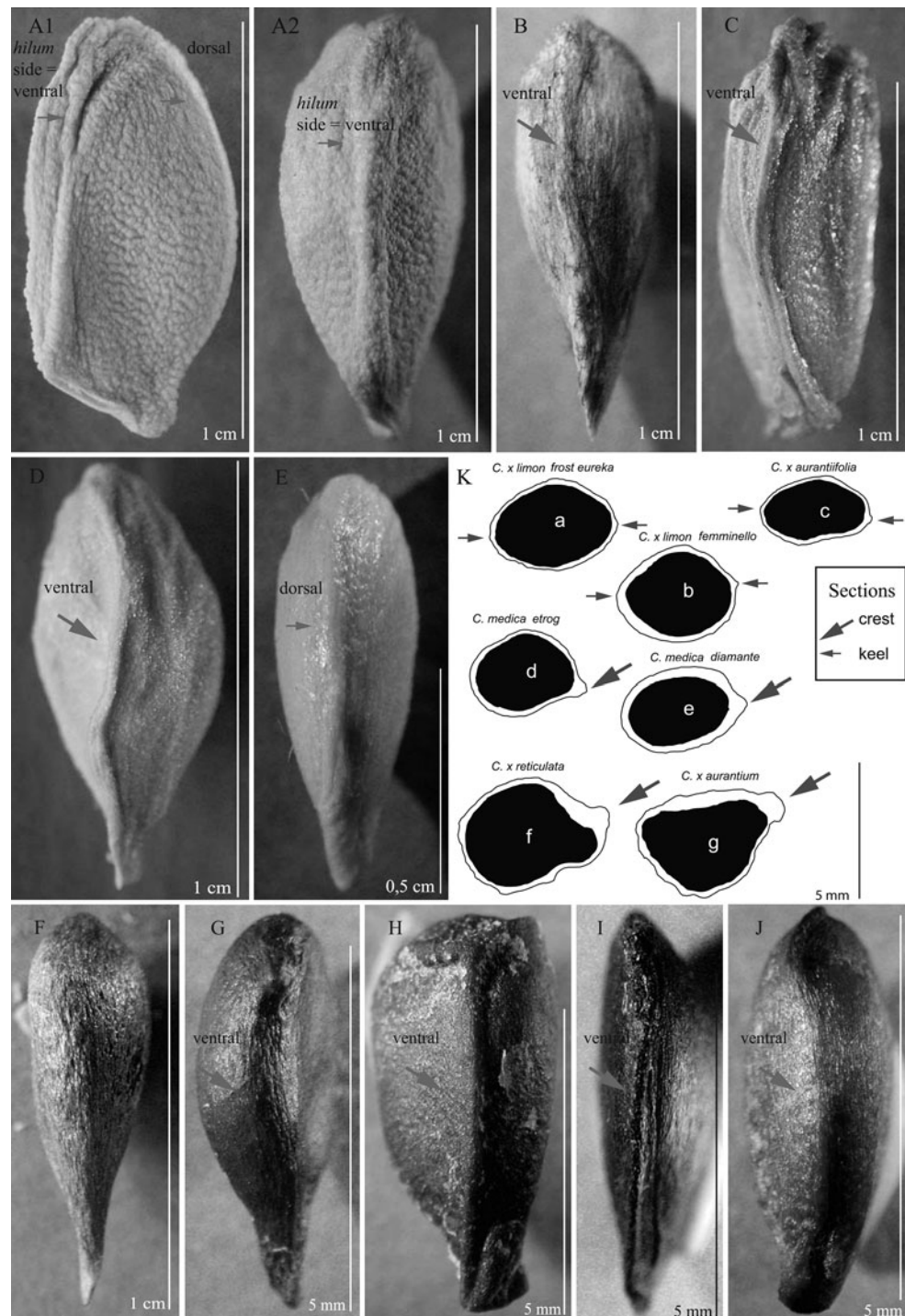
In comparison to *C. medica*, the cells of *Malus* are clearly polygonal, so that the epidermis of *Malus* seeds has a fibrillose appearance, due to the juxtaposition of long ranges of those elongated cells (Fig. 9A1/2). The surface of *Pyrus* seeds has a regular reticulate pattern (Fig. 9 C1/2), punctuated with small dimples (reticulate). *Cydonia* is quite similar, characterised by a reticulate-foveate net-pattern (Fig. 9D1/2). *Sorbus domestica* shows a scalfiform (ladder-like) outer layer structure, also perceptible in *S. aria*, although it covers a sulcate fibre structure (Fig. 9B1/2, E1/2).

The seeds of *Malus domestica*, with their long elongated cells can be confused with those of *C. medica* and their fascicle pattern, when both are mineralised. The seeds of both taxa have a fibrillose surface. Moreover, if a reticulate pattern is characteristic of *Pyrus communis*, the inner layer, under the epidermis, is also composed of longitudinal fibres. The observation of the cells at a magnification of ×180 is therefore a minimum to identify the species, especially when the seeds are preserved by mineralisation.

Concerning the differentiation of the *C. medica* and *C. × limon* types, a comparison between *C. medica* “Diamante” and *C. × limon* “Femminello” was made (Fig. 10). At lower magnification (80×), the testa of *C. medica* looked more fibrous, due to the layout of the cells

(hilum side) (Fig. 7K d–g, B–D). The seeds of the Maloideae do not show any dorsal crest (Fig. 7F–J). Most of them possess a ventral crest on the hilum side, but it is

**Fig. 7** Crests/keels (presence/absence; dorsal/ventral); **A1/2** ventral and dorsal keels of *C. × limon* “Femminello”; ventral crests of **B**, *C. medica* “Etrog”; **C** *C. × aurantium*; **D** *C. reticulata*; **E**, dorsal keel of *C. × aurantiifolia*; **F** absence of crest or keel (ventral view) of *Malus domestica*; ventral keels of **G**, *Pyrus communis*; **H** *Cydonia oblonga*; **I** *Sorbus domestica*; **J** *Sorbus aria*; **K** cross-sections of **a** *C. × limon* “Frost Eureka”; **b** *C. × limon* “Femminello”; **c** *C. × aurantiifolia*; **d** *C. medica* “Etrog”; **e** *C. medica* “Diamante”; **f** *C. reticulata*; **g** *C. aurantium*; photos by V. Zech-Matterne



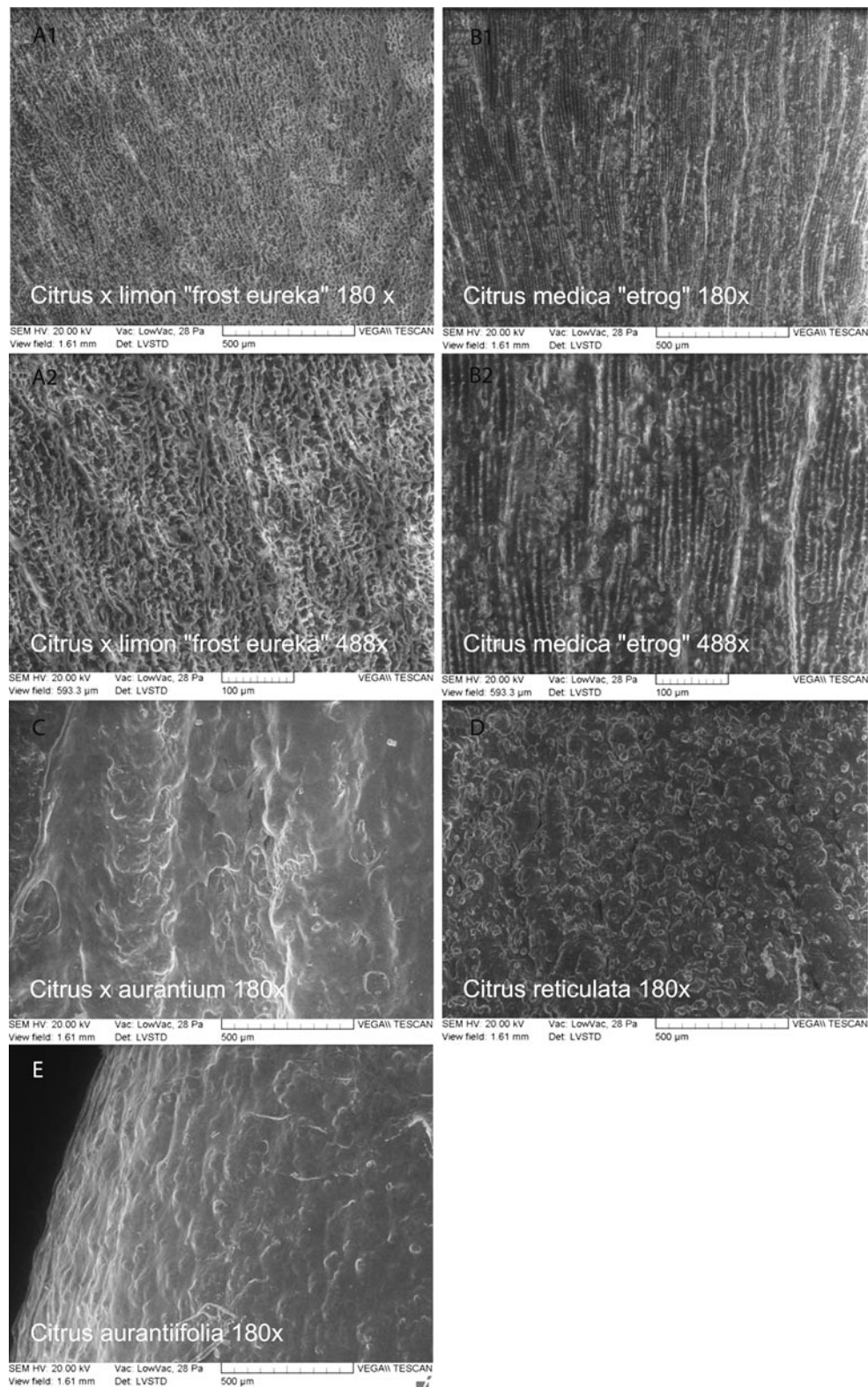
in irregular fascicles (Fig. 10A3). At magnification 10–20 $\times$ , the surface of *C. × limon* is neatly verrucate, in contrast to the seed coat of *C. medica* which is rugose and longitudinally sinuous. On the *Citrus × limon* seed coat, a transverse wrinkling pattern is visible (10 B2), which is not present on *C. medica* (10 A2).

On the basis of all the previous observations, it appears that the best criteria rely on the seed coat topography and cellular organisation, observed at a high magnification of at

least  $\times 180$ . The number of the keels can help but is not constant, as a dorsal keel is more often observed in the types *Citrus × limon* and *C. × aurantiifolia*.

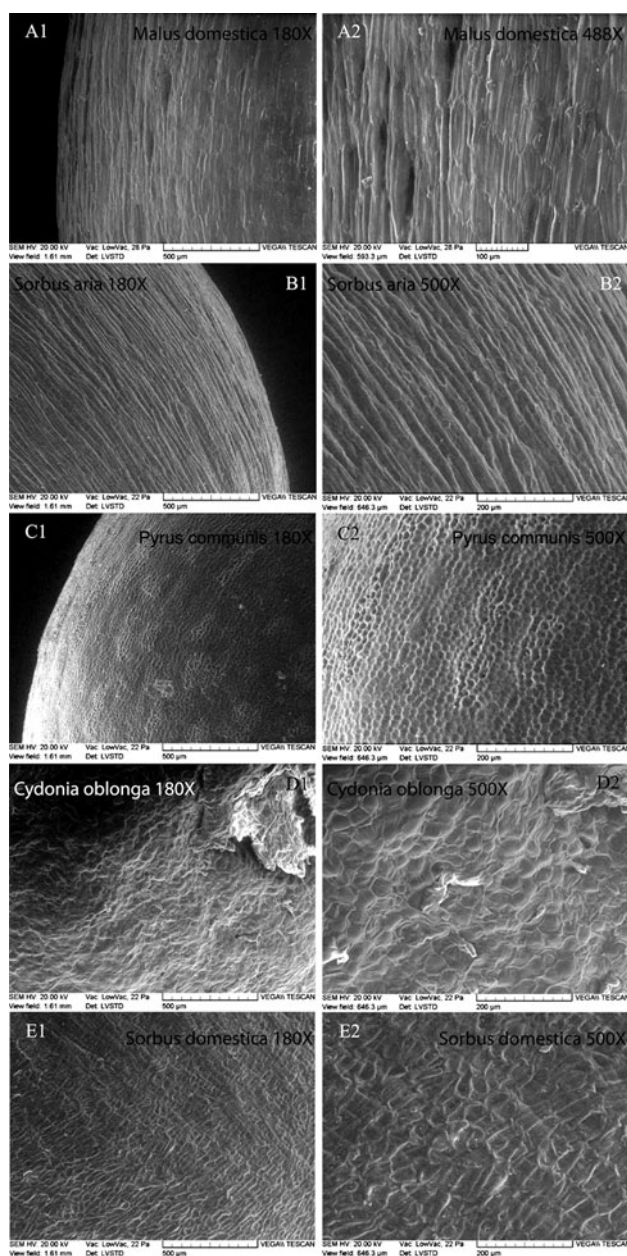
#### Description of the recent finds from Pompeii and Rome

The five mineralised seeds from Pompeii from the Samnites levels under the temple of Venus have ovoid and spheroid shapes, with a ventral crest (Fig. 2).



**Fig. 8** Comparison of the seed surfaces: cell patterns of the *Citrus* species: **A1/2** *C. x limon* "Frost Eureka" (magnifications 180× and 488×); **B1/2** *C. medica* "Étrog" (180× and 488×); **C** *C. x aurantium*

(180×); **D** *C. reticulata* (180×); **E** *C. x aurantiifolia* (180×); photos by S. Pont, MNHN Paris



**Fig. 9** Comparison of the seed surfaces: cell patterns of the Maloideae taxa. **A1/2** *Malus domestica* (180× and 488×); **B1/2** *Sorbus aria* (180× and 500×); **C1/2** *Pyrus communis* (180× and 500×); **D1/2** *Cydonia oblonga* (180× and 500×); **E1/2** *Sorbus domestica* (180× and 500×); photos by S. Pont, MNHN Paris

The cells are arranged in regular fascicles with a ribbed pattern, longitudinally sinuous. This allows us to attribute them most probably to *C. medica*. Their dimensions in mm are as follows (length/breadth/thickness): min—6.3/3.1/2.3, max—7.0/4.2/3.5, average—6.7/3.7/x.

The *Citrus* seeds found in the Forum Romanum are characterized by very distinct dorsal and ventral keels and accompanied by a skin fragment of the hesperidium (the “fruit”), which make the genus determination certain (Fig. 3B). A SEM analysis of the seed surface showed a

very irregular cell pattern, without longitudinal striations (Fig. 3C), indicating that the seeds found in Rome most probably belong to *C. × limon* (lemon). Their dimensions (mm) are as follows (length/breadth/thickness): min—8.82/3.72/3.14, max—11.76/6.17/4.61, average—10.12/4.93/4.10.

## Discussion

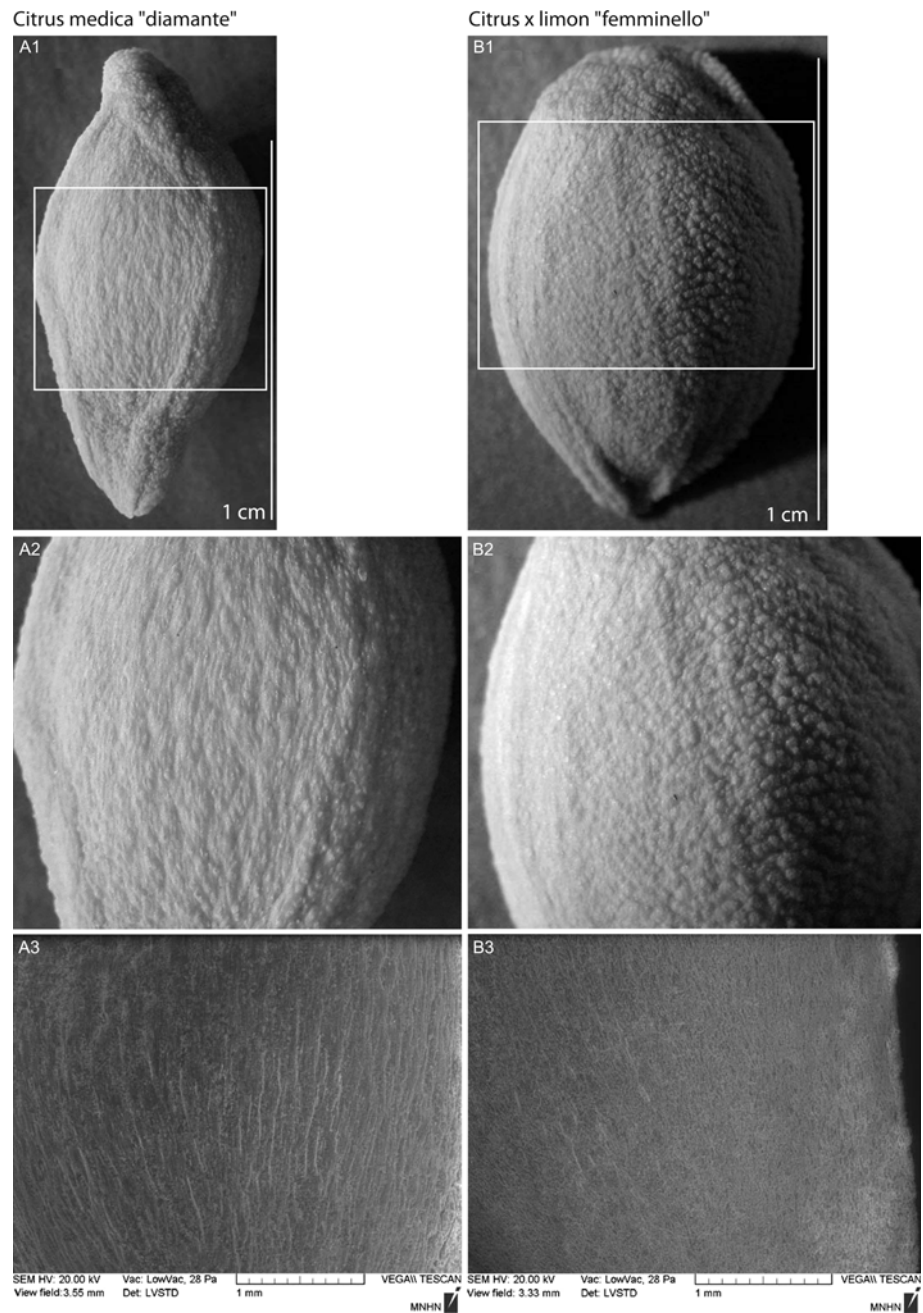
### Identification

The analysis of the testa surface and cell pattern suggests the identification of *C. cf. medica* (citron) in Pompeii contexts and *C. cf. × limon* (lemon) in Rome. These are the first archaeobotanical records of the two taxa in Italy and they shed new light on the spread of *Citrus* fruits in the Mediterranean area. The finds of well-preserved mineralised seeds from the Pompeian temple of Venus represent the most ancient finds so far of *C. cf. medica* in Italy (3rd–2nd century B.C.) and in the Mediterranean zone, together with the pollen grains of *Citrus* sp. from the Cumae core (896–657 cal. B.C.). The *Citrus* remains (seeds and the skin fragment) from the Forum Romanum currently represent the most conspicuous and best preserved record of *C. cf. × limon*, precisely AMS dated to the Augustan age. The votive archaeological contexts of both finds support the hypothesis that *Citrus* was a precious fruit which was used in sacred ceremonies. The properties of the fruit, which was considered a miraculous plant remain, are mentioned by several ancient authors. Vergilius names the fruit *malum felix*, the “salutary apple” (*Georgica* 2, 127) and Plinius writes that *malus Assyria* is “the most salutary tree” (*Nat. Hist.* 12, 14). The properties which ancient writers attribute to the plant may explain this name.

### Diffusion agents and acclimatisation of *Citrus* in the Mediterranean

The origins of *Citrus* domestication lie somewhere in southeastern Asia (see for an overview Miller and Gross 2011, and literature cited there). However, early sources, reaching back to the period before Christ, are not available or difficult to interpret. In China, only during the Tang Dynasty (A.D. 618–907) is it clear that the cultivation of numerous varieties of *Citrus* was already well established. This tends to put the establishment of Chinese *Citrus* cultivation some time between A.D. 200 and 600. In fact the *Plants of the Southern Region* written by Chi Han (A.D. 304) is probably the first reference to *Citrus* fruits from the far south of modern China (Guangdong), while the first monograph on *Citrus* (Han Yen-Chih’s Chü Lu), is dated to 1178 (Hagerty 1923; see Simoons 1991 for further discussion). In eastern India, the domestication of certain

**Fig. 10** Differentiation of the *C. medica* and *C. limon* types. **A1** lateral view of the seed of *C. medica* “Diamante”; **A2** detail of the epidermis; **A3** cell patterns of the seed (80×), the longitudinal fascicled aspect is clearly visible; **B1** lateral view of the seed of *C. × limon* “Femminello”; **B2** detail of the epidermis; **B3** cell patterns of the seed (80×), the transverse wrinkled pattern is obvious; photos by V. Zech-Matterne, S. Pont, MNHN Paris



fruits including citron is supposed to have taken place at the beginning of the first millennium B.C. as a result of the trade in forest products between hill and plain dwellers (Kingwell-Banham and Fuller 2012).

Contact between the Far East and the Mediterranean region probably existed before the Roman period, but the routes and frequency of exchanges are unknown. Furthermore, there is no evidence of *Citrus* fruit trade dating back to prehistoric or Roman times, and similarly, except for the remains from Cyprus, no evidence of *Citrus* fruits being found in areas between the Far East and Italy. However,

archaeobotanical investigations in these regions may also have been rare, and this could explain the lack of remains.

During the first part of the 1st millennium B.C., the role played by Phoenician settlers in the spread of plants from the eastern to the western Mediterranean is supported by the discoveries at Monte Sirai/Sulcis on Sardinia and at Cumae in southern Italy. Recent archaeological finds tend to demonstrate the early date and extensive spread of the Phoenician presence in southern Italy (Botto 2008). The first evidence dates back to the 9th century B.C. and is closely linked to the Cypriot influence in relation to the

iron trade and the export of related technologies. Long distance contacts continued between the 8th century and the first half of the 7th century B.C. They mainly concern the southern coasts of Italy, especially the Campania region. The city of Pithecusae on the island of Ischia, in the Gulf of Naples, in front of the site of Cumae, played a major role in international trade activities from the middle of the 8th century B.C. onwards. Sardinia, acting as a crossroad for long-distance trade and contact between East and West, could have significantly contributed to the spread of *Citrus* taxa towards the western Mediterranean.

It is difficult to assess the exact role played by Egypt in the spread of *Citrus* in the Mediterranean region. The finds from Egypt are more recent or at best, contemporary with the Italian finds. One can even ask if the Romans played a role in the spread of *Citrus* into Egypt.

Despite the fact that the archaeobotanical evidence tends to be more abundant by the beginning of the historical period, even during the 1st century A.D. *Citrus* does not seem to have been widely grown in Italy. Columella in *De re rustica* (Forster and Hefner 1954); Varro in *De agricultura* and Cato in *De re rustica* do not mention it (Hooper and Ash 1967). Plinius mentions *malus Assyria* among the exotic trees (*Nat. Hist.* 12, 14). In the 4th century A.D., citrus fruit still does not seem to have been widely cultivated, although written evidence seems to suggest that it was present. In Palladius's work *Opus agriculturae*, *citrium* is classified among the cultivated trees (*Agr.* 3, 24, 14; 4, 10) (Rodgers 1975). Palladius mentions a *citretum*, a place where *citrea* grow under a "roof" (*tegumentum*) which protects trees from the cold (*Agr.* 3, 24, 14). This *citretum* should be a greenhouse, or an orangery, rather than a *Citrus* orchard, as it is traditionally translated. Thus, in Palladius' time, citrus fruits were probably cultivated by a few people, who could afford to construct and maintain greenhouses.

The acclimatisation process and probably the ongoing diversification into several varieties can be perceived through the evolution of plant uses in the written sources. According to Theophrastus and Plinius, the *citrium* was not eaten (*Hist. Plant.* 4, 4, 2; *Nat. Hist.* 12, 15), and it was first imported as an ornamental tree. Some treatises on horticulture indicate that *Citrus* was very sensitive to cold, and must be planted in a pot in order to be put indoors during winter and covered with grass tops or gourd tops (Palladius, *Agr.* 4, 10, 14; *Geoponica* 10 7). The attitude towards the *Citrus* fruit seems to change between the 4th and the 1st century B.C. Plinius (in the 1st century A.D.) reports that *citrium* was so sour that it was hated (Plinius *Nat. Hist.* 13, 103). But according to Plutarchus, towards the end of the 1st century A.D., *melon medicon* was eaten (Pearson and Sandbach 1997). He writes that some foodstuffs, which were not eaten by the elders, were at his time appreciated, and he uses *melon medicon* as an example (*Symp.* 8, 9, 3).

Athenaeus (2nd/3rd century A.D.) writes about a text from Theophrastus' *History of Plants* (4th century B.C.) that it is not surprising that he says *kitrion* was not eaten, because the "elders" did not eat it (Gulick 1961). However, the guests of the *Deipnosophists* (a treatise by Athenaeus) were probably used to eating it, which is why they may have been surprised by Theophrastus' words [*Deipn.* 3 (83f)].

Various citrus fruit taxa were introduced into the Mediterranean area during antiquity, and it is possible that new taxa appeared spontaneously during the centuries following their introduction, given the reproductive biology of this genus. Grafting may have been practised on trees, since ancient people liked experiments (Theophrastus, *De Causis Plantarum* 1 (Einarson 1976); Plinius *Nat. Hist.* 17, 22–26; *Geop.* 10, 7; 10, 76). Change of attitudes towards *Citrus* fruits may reflect the appearance of new taxa during the first centuries of our era. Moreover, the edict of Diocletian in A.D. 301 mentions a *citrium maximum* among other food items (*Edictum Diocletianum* 6, 75) (Mommsen 1873). It may name a distinct *Citrus* fruit species. "*citrium maximum*" had a maximum price of 24 *denarii*. The highest price for other fruit was about four or eight *denarii*, so the *citrium maximum* seems, in comparison, quite expensive, and this leads us to think that it was not a common food item during the early 4th century A.D.

## Conclusions

The identification criteria based on present day "archaic" varieties of *C. medica*, *C. × limon* and additionally *C. × aurantium*, *C. reticulata* and *C. × aurantiifolia* have allowed the attribution of archaeological specimens from Pompeii and Rome to *C. cf. medica* and *C. cf. × limon*, and established the existence of two *Citrus* taxa in Italy, at least by the end of the 1st century B.C. However, a misidentification problem of confusion with some Maloideae types potentially exists, above all when mineralised or otherwise poorly preserved material is found.

Nevertheless, the introduction of *Citrus* to Italy might be much older, as new evidences from various sources, such as pollen grains and chemical analyses of organic residues, show. They can be dated back to at least the 6th century B.C. in Sardinia and on the Campanian coast. This sets the hypothesis of an early introduction from eastern Mediterranean countries, potentially by Phoenician settlers.

Since it appears that the popular properties of *Citrus* were medicinal, odoriferous or symbolic, and it was not then considered edible, it should be appropriate to look for archaeobotanical remains of *Citrus* in other kinds of structures than cesspits or rubbish deposits. Nevertheless, it remained probably a rare fruit, even when its diversity began to extend from Roman times onwards.



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