Enrico Biancardi · Leonard W. Panella · J. Mitchell McGrath *Editors*

Beta maritima

The Origin of Beets

Second Edition

Springer

Beta maritima

Enrico Biancardi · Leonard W. Panella ·
J. Mitchell McGrath
Editors

Beta maritima

The Origin of Beets

Second Edition

Springer

Editors
Enrico Biancardi
Formerly Stazione Sperimentale
di Bieticoltura
Rovigo, Italy

J. Mitchell McGrath
USDA-ARS, Sugar Beet and Bean Research
Michigan State University
East Lansing, MI, USA

Leonard W. Panella
Crop Research Laboratory
Department of Soil and Crop Sciences
Colorado State University
(Formerly USDA-ARS)
Fort Collins, CO, USA

ISBN 978-3-030-28747-4 ISBN 978-3-030-28748-1 (eBook)
https://doi.org/10.1007/978-3-030-28748-1

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

The only success achieved, but without doubt petty and insignificant if compared to the juvenile hopes, dates back to the beginning of the Century, when seed of Beta maritima collected along the Adriatic coast was crossed with sugar beet varieties. It was possible to identify some genealogies endowed with an actual resistance to cercospora leaf spot

Ottavio Munerati

Rovigo, 1949

Foreword

It might be tempting to ask "why a book about sea beet?": a wild plant with no immediately obvious attraction or significance, a somewhat limited geographical distribution, and for a scientist an underlying genetics that doesn't lend itself to easy experimentation. This book provides counterarguments to allay such misapprehensions, detailing its journey through pre-history, its contribution to one of the world's most recently evolved crop plants, and its significance in terms of modern biodiversity conservation. To emphasize its significance, aside from a book on teosinte written in the 1960s, there are probably no other books that focus specifically on a single crop wild relative.

While sea beet is commonly thought to be an inhabitant of Europe, North Africa, and the Near East, closely related leaf forms of beet were undoubtedly used as a medicinal plant and as a herb or vegetable in Chinese cuisine as far back as the first millennium BC. In 1976, I received correspondence from William Gardener, who was an obsessive collector of plant data and who lived part of his life in China, fluent in both the spoken and written languages. He had recorded that the leaves of "t'ien ts'ai" or cultivated beet, along with some fish, could be used in the preparation of a preserve called "cha". Cha is a preparation originating from the Yangtze valley and Gardener's research led him to believe that t'ien ts'ai, when brought into culinary use, was a coastal plant from anywhere south of Shantung, and perhaps a riparian plant from along the lower Yangtze. However, there are now no records of wild beets growing anywhere in China, so Gardener's assumption that wild as well as cultivated beets existed in China in these times represents one of the enigmas surrounding this crop wild relative.

Considering geographical range and moving to a different continent, it has long intrigued me as to how wild forms of beet, closely related to *Beta maritima*, come to exist in California. The fact that genetic evidence suggests that there are two distinct forms living in the Imperial Valley, both having European origins, only partly clarifies the situation. One form is likely to be a naturalized or de-domesticated cultivated beet, while the other closely resembles the wild *Beta macrocarpa* (a sister species to *maritima*). So a second enigma exists as to precisely how both forms of wild beets reached California.

What else is intriguing about *Beta maritima*? For me, it is its place in the history of genetic resources conservation. I believe that it could comprise one of the first crop genetic resources to have been actively conserved. As a postgraduate student, I was first introduced to the needs of "genetic conservation" by my mentor Prof. Jack Hawkes in Birmingham who, along with Prof. Trevor Williams, my supervisor, collected beet germplasm with me in Turkey in 1972. Other key figures who passed through Birmingham at the time such as Jack Harlan, Erna Bennett, and Otto Frankel were also key to my education. Jack Hawkes, in particular, had met the great Russian geneticist Nikolai Ivanovič Vavilov in the Soviet Union and acknowledged him to be the "father" of plant genetic resources. Vavilov had proposed in the 1920s that crop improvement should draw from wide genetic variation and on this premise collected cultivated plants and their wild relatives from most parts of the world. The germplasm that he collected was for immediate use for the development of new crop varieties in the Soviet Union, and not specifically for conservation. George H. Coons on the other hand was a US scientist, sugar beet breeder, and germplasm collector, who also influenced my early thoughts and activities ahead of my germplasm collecting missions to Turkey back in the 1970s. Remarkable for me, some of Coons's material was actually conserved, allowing me to use some of it in my research, and indeed still survives within the USDA-ARS system in Salinas, California. In many ways, Coons was no different to Vavilov; expeditions to Europe in 1925 and 1935 allowed him to collect and then evaluate diverse germplasm and put it to good use in sugar beet improvement programs and so Coons should be placed alongside Vavilov in the promotion of germplasm conservation.

Maybe as a plant scientist one could easily be put off working on beet. But really its basic genetics is what makes it fascinating. *Beta maritima* and its relatives range from being short-lived annuals where flowering and seed set can be as short as 6 to 8 weeks, to long-lived perennials that are known to survive for as long as 8 years. They can be strongly inbreeding on the one hand but exhibit genetic incompatibility and obligate out-crossing on the other. In light of the most recent taxonomy where *Beta maritima* is actually a subspecies of *Beta vulgaris*, then this wide range of habits and genetic tendencies is all to be found within a single species and may make it much less vulnerable to climate change, unlike other crop wild relatives. Again, because the wild and cultivated are so close genetically, this is a benefit if genes from wild populations need to be used in crop improvement. In contrast, this represents a serious problem in terms of breeding strategies where hybrids can easily occur and contaminate sugar beet seed crops. This may also leave wild beets vulnerable to contamination from GM sugar beet crops.

These features of beet, particularly related to the life cycle are what has made it worthwhile to sequence its genome along with that of sugar beet, something that has happened between now and the first edition of the book.

With a reference genome in place, and the sequence availability of closely related species such as spinach, we will rapidly be able to answer some of the intriguing questions, particularly regarding genes conferring diverse genetic adaptation exhibited by this enigmatic species, many of which are covered in this valuable book. Finally, I strongly believe the value of the book lies in its contribution to avoiding "reinventing the wheel." Combining historical perspective with sound taxonomy, plant breeding, and molecular genetics, it will provide an important overview of the current state of crop wild relative and sugar beet research. It will also provide access to knowledge for new researchers who may wish to revisit the enigmas that wild beet represents.

Birmingham, UK
2012

Brian Ford-Lloyd

Preface

The publication of a book dealing only with a plant without any direct commercial interest is a task requiring some explanation. Given that *Beta maritima* is believed to be the common ancestor of all cultivated beets, the collection in a single publication of the more relevant references concerning the species is useful for biologists, agronomists, and researchers who have the task of preserving, studying, and utilizing the *Beta* gene pool. Indeed, *Beta maritima* is necessary to ensure a sustainable future for the beet crops. This very important reason is the easiest to present, but not fully satisfactory to explain a book dedicated to a single wild plant.

Among other reasons, increasing attention must be paid to wild germplasm as source of potentially useful traits in cultivated crops. Indeed, genetic resistances are a crucial argument due to the urgent need to minimize both production costs and the use of chemical. The need is especially apparent for sugar beet, which is cultivated on about 5.2 Mha in 38 countries, supplying around 20% of the sugar consumed worldwide.

Editing this book, particular attention was paid to the history of the use, recognition, and knowledge of *Beta maritima*. This was done because little has been collectively recorded, and because science evolves also on the foundations of the past. This interpretation of the flow, distillation, and accumulation of knowledge that points forward is another task of the book. The information was collected from the literature dealing in medicinal and food plants in general, and, to a lesser extent, with cultivated beets. This part required reading reprinted manuscripts written over almost two millennia, but the search gleaned information sometimes unknown even to insiders.

Recently, an increasing number of scientific papers related to *Beta maritima* have been published, based on the developments and applications of molecular biology. Several doctoral theses concerning particular aspects of the species have been authored as well. In fact, sea beet germplasm currently is used as a model for gene flow experiments, owing to the frequent coexistence in the same area of different and interfertile genotypes belonging to the genus *Beta*. Being a littoral species and consequently distributed in populations more extended in length (along the beach) than in width, *Beta maritima* fits very well into research concerning population genetics, natural selection, colonization, speciation, etc. In these fields of research, *Beta maritima* is surely one of the more interesting and studied wild plants.

Part of historical information was collected through digital libraries listed in the Appendices. The traditional system of bibliographic research has retained its importance not only for the large amount of yet to be digitized books (and therefore named "analogic" by some) but also for old collections of journals no longer in print or with limited distribution, such as the "Österreiche-Ungarische Zeitung für Zuckerindustrie und Landwirtschaft", where the first important experiences on *Beta maritima* were published at the end of 1800s.

The large number of researches concerning molecular genetics recently undertaken and the download of more than 4200 single chapters of the first edition have led the publisher to propose the second edition. The request surprised the editors, absolutely unready for this occurrence. It seemed impossible that there was any interest in a book with such a limited and specific target, moreover, concerning mainly a noncommercial plant. In the end, the proposal was accepted, despite the need to rewrite at least half of the first edition. The rapid evolution of the matter required the involvement of other experienced researchers and the remaking *ex novo* of the chapters regarding molecular genetics.

The modern breeding techniques have moved mainly to glasshouses and laboratories. This evolution resulted in researchers having less and less contact with the real crop and its background. A further task of the book is to try to provide them an updated, comprehensive summary on everything that involves the species. The outlook should be appreciated, given the future difficulties to put together the variety of skills that allowed the publication of this book.

Owing to the huge amount of recent papers, the editors apologize for possible omissions.

Rovigo, Italy — Enrico Biancardi
Fort Collins, USA — Leonard W. Panella
East Lansing, USA — J. Mitchell McGrath

Acknowledgements

First of all, the editors would like to thank the friend Bob Lewellen for his fundamental contribution to the first edition of this book. He justified his resignation in this way: "I have been retired for a few years and I am not enough updated on the latest literature, so I do not feel able to participate in the role of editor." Notwithstanding his huge modesty, it can be recalled that he will be considered the most prolific (in terms of released genotypes) and meritorious breeder in the history of sugar beet.

It must be recalled with gratitude the collaboration given by Luciano Soldano, Hsing-Yeh Liu, Gudrun Kadereit, and Nigel Maxted in some basic matter. Thanks are also addressed to Marco Bertaggia, Gianpaolo Fama, and Davide Drago for their contribution in the preliminary bibliographic searches. Special appreciation is given to Donatella Ferraresi for her original watercolor paintings and to Mauro Colombo for his support in the graphics and organization of the second edition of the book.

Thanks must be given to the entire private beet seed, production, and processing companies that have been so generous in their funding of the public research efforts, and in North America to the Beet Sugar Development Foundation, which functions as the beet sugar industry's research support organization.

Finally, for their help in historical researches, the authors wish to express their appreciation to the staff of the public and private libraries listed in Appendix E.

Rovigo, Italy — Enrico Biancardi
Fort Collins, USA — Leonard W. Panella
East Lansing, USA — J. Mitchell McGrath

About This Book

Along the undisturbed shores of the Mediterranean Sea and the European North Atlantic Ocean, the plant called *Beta maritima* or more commonly “sea beet” is quite widespread. The species has had and will continue to have invaluable economic and scientific value. Indeed, according to Linnaeus, it is considered the progenitor of the cultivated beet crops, which has been confirmed by recent molecular research. Something similar to mass selection applied after domestication has created many cultivated types with different uses (fresh vegetable, fodder, sugar, ethanol, etc.). Also, the wild plant has been harvested since antiquity and used both for food and for its medicinal properties. Sea beet hybridizes easily with the cultivated types. This facilitates the transmission of genetic traits partly lost during the domestication processes aimed at increasing the features useful to farmers, consumers, and sugar industry. In the last decades, modern breeding techniques have moved mainly to the laboratory. As for other crops, this evolution has resulted in researchers having less contact with the real crop and its cultivation practice. Also for this reason, one of the objectives of the book is to provide an updated summary of everything that involves sea beet, including history, distribution, physiology, breeding, and taxonomy.

Beta maritima has been successfully used to improve the genetic resistances against diseases and pests of the crop, allowing some of the more important results in plant breeding. In fact, without the recovery of traits of resistance preserved in the wild germplasm, the cultivation of sugar beet would be today impossible in almost all countries.

Enrico Biancardi
Leonard W. Panella
J. Mitchell McGrath

Note to the Reader

To make more comprehensible the rare and fragmentary references, the knowledge regarding *Beta maritima* and synonyms was ordered chronologically and placed in its historical framework. In fact, it has been necessary to briefly review information on the evolution of scientific though. Because of the direct parentage with *Beta maritima*, the similarity of the two taxa and their continuous interrelationships after domestication, some information involving the beet crops has been required. Actually, without molecular analyses, differences in morphology are frequently not sufficient for the correct classification inside the section *Beta*, leading to some uncertainties in current *in situ* and *ex situ* collections.

In this book, *Beta maritima*, now classified *Beta vulgaris* L. subsp. *maritima* (L.) Arcang., is called for the sake of brevity "*Beta maritima*" or "sea beet". To avoid confusion and other complications, these names will be utilized also before the taxonomy of Linnaeus. The term "wild beet" is used to indicate the species (spp.) and subspecies (subsp.) belonging to the genus *Beta* excluding *Beta vulgaris* L. subsp. *vulgaris* (cultivated beets). In order to avoid confusion, *Beta maritima* is considered species (spp.) or subspecies (subsp.) according to the respective reference.

In the references of old books, and manuscripts, after the anglicized name of the author, year of publication and title, the printer or publisher (when available), are listed the anglicized name of the printing location and the country. The printer or publisher is typed in Roman fonts. References of more recent reprintings are indicated as well, where applicable.

For uniformity, the initial of the word *Beta* is always capitalized, even though this was not compulsory before Linnaeus. Latin phrases, words, and botanical names (genus, sections, species, and subspecies) are written in Italic (APG II 2003). According to the same classification, subfamily, family, and superior categories are written in Roman. Latin or Latinized names of the authors are typed in Italic or in Roman if Anglicized. The common or vulgar names of plants are also typed in Roman. The initials of the common names of diseases are written in lowercase, as are the acronyms of viruses. Words and phrases in other languages are written in Italic between brackets, whereas the English translation is written in Roman between parentheses. The captions of figures (Fig.) and tables (Tab.) without indication of the source are intended as supplied by the editors. The references cited in captions, notes, and in Appendix A are included in the first chapter.

Contents

Affiliation of Editors and Collaborators

Detlef Bartsch: University of Aachen, Germany
Enrico Biancardi (ed.): Formerly Stazione Sperimentale di Bieticoltura, Rovigo, Italy
Henry Darmency: Formerly INRA, Dijon, France
Marco de Biaggi: Sugar Beet Breeding Consultant, Massalombarda, Italy
Brian Ford-Lloyd: Formerly University of Birmingham
Lothar Frese: Formerly Julius KuhnInstitute, Kuedlingsburg Germany
Nina Hautekeete: University of Lille, France
Robert T. Lewellen: Formerly USDA-ARS, Salinas CA, USA
J. Mitchell McGrath (ed.): USDA-ARS, East Lansing MI, USA
Leonard W. Panella (ed.): Formerly USDA-ARS, Fort Collins CO, USA
Rania Pavli: Agricultural University of Athens, Greece
George N. Skaracis: Formerly Agricultural University of Athens, Greece
Piergiorgio Stevanato: DAFNAE, University of Padua, Italy
Pascal Touzet: University of Lille, France
Henk van Dijk: University of Lille, France

Abbreviations

ARS	Agricultural Research Service (USA)
ASSBT	American Society Sugar Beet Technologists
BMV	Beet Mosaic Virus
BNYVV	Beet Necrotic Yellow Vein Virus
BYV	Beet Yellowing Virus
CMS	Cytoplasmic Male Sterility
CRA	Consiglio per la Ricerca e Sperimentazione in Agricoltura
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeat
CWR	Crop Wild Relatives
DNA	Deoxyribonucleic Acid
FAO	Food and Agriculture Organization
GABI	German Agricultural Biotechnology Initiative
GP1, GP2, GP3	Gene pool 1, Gene Pool 2, Gene Pool 3
GRIN	Germplasm Resource Information Network (USA)
GWP	Gathered Wild Plant
IBPGRI	International Plant Genetic Resources Institute
IIRB	International Institute of Sugar Beet Research
IPK	Leibniz Institute of Plant Genetics and Crop Plant Research (Germany)
IRBAB	Institut Royal Belge pour l'Amelioration de la Betterave
ISCI	Istituto Sperimentale perle Colture Industriali (Italy)
LDC	Least Developed Countries
mM	milliMolar
NMS	Nuclear (or Mendelian) Male Sterility
OECD	Organisation for Economic Cooperation and Development
OT	O-type
QTL	Quantitative Trait Locus (Loci)
R-gene	Resistance gene
RI	Recombinant Inherited
RNA	Ribonucleic Acid

SNP	Single-Nucleotide Polymorphism
SSR	Simple Sequence Repeat
USDA	United States Department of Agriculture
WBN	World Beta Network

Chapter 1
History and Current Importance

Enrico Biancardi and Robert T. Lewellen

Abstract The ancestors of *Beta maritima were* known from prehistory. After domestication, beet became more important not only for food and drug source, but also as sugar (sucrose) producer. The cultivation for leaves and root to be used as vegetable or cattle feed retains its economic value. *Beta maritima* was described by several authors, becoming in the last century crucial as source of traits disappeared in the beet crops after domestication. The research has led to important results, especially in the field of resistance to severe diseases. An increasing numbers of publications are dedicated to *Beta maritima* because it fits well into studies concerning breeding in general, population genetics, natural selection, colonization, speciation, gene flow, transgenes pollution, and so on. The discovery of new useful qualities in the wild germplasm is expected by the application of molecular biology.

Keywords *Beta maritima* · Origin · Domestication · History · Crop evolution · Breeding

Beta maritima,[1] commonly named "sea beet", is a very hardy plant that tolerates both high concentrations of salt in the soil and severe drought conditions (Shaw et al. 2002). Thus, it can also grow in extreme situations such as along the seashores almost in contact with saltwater "frequently between the high tide zone and the start of the vegetation, or where the wastage of the sea is deposited" (Figs. 1.1 and 1.2). On the contrary, sea beet is sensitive to competition with weeds especially under water and nutritional deficiency (Fig. 1.3) (Coons 1954; de Bock 1986). Sea beet seems to take advantage of its salt and drought tolerance to reduce the presence of competitor plants in the neighborhood (Coons 1954; Biancardi and de Biaggi

[1] *Beta maritima*, now classified *Beta vulgaris* L. subsp. *maritima* (L.) Arcang, is called for the sake of brevity "*Beta maritima*" or "sea beet".

E. Biancardi (✉)
Stazione Sperimentale di Bieticoltura, viale Amendola 82, 45100 Rovigo, Italy
e-mail: enrico.biancardi@alice.it

R. T. Lewellen
USDA-ARS, Salinas, CA, USA

E. Biancardi et al. (eds.), *Beta maritima*,
https://doi.org/10.1007/978-3-030-28748-1_1

Fig. 1.1 Sea beet on a stone bank at the mouth of Po di Levante River, Italy. The plant grew on a few grams of sea debris and was able to flower and set seeds notwithstanding being surrounded by salty water. Any other superior plant can survive in these conditions, thus demonstrating the very high environmental adaptability and stress tolerance of the species. Due to the uneven distribution of rains and the limited water supply, *Beta maritima* can be observed in this site only after rainy season, that is, once in about a decade. Therefore, the survival of the populations, at least in the mentioned location, implies also a longlasting germination ability under high salt concentration and unknown interactions with the seed dormancy (Biancardi, unpublished)

Fig. 1.2 Site with optimal growing conditions for *Beta maritima*: vicinity to the seawater; sandy/stony soil; low presence of competing weeds; tourism connected activities; grazing cattle; etc. Baja California USA (Courtesy, Bartsch)

Fig. 1.3 *Beta maritima* competing against weeds (Torcello, Italy)

1979). Salty soils, frequently caused by seawater spray, tidal flows, storms, and so on, also induce relatively low pathogen pressure, thus may be helpful for the survival of the species. von Proskowetz (1910) referred to having never seen cysts of nematodes on sea beet roots, likely due to their very high woodiness. Conversely, Munerati et al. (1913) observed severe attacks of *Cercospora beticola*; *Uromyces betae*; *Peronospora schachtii*; and *Lixus junci* along the Italian-Adriatic seashores. Bartsch and Brand (1998) referred to the absence of beet necrotic yellow vein virus (BNYVV), the causal agent of rhizomania, as likely related to the high salt content in soils.

Saltwater plays an important role in the dispersal of the species. Less frequently, also for this reason, sea beet populations are localized in interior areas, in the presence or absence of beet crops in the vicinity. In the first case, the wild populations are likely to be feral or ruderal beets[2] that are more or less aged offspring of beet cultivation (Ford-Lloyd and Hawkes 1986; Bartsch et al. 2003).

1.1 Predomestication

The first use of sea beet (or one of its earlier relatives) goes back to prehistory, when the leaves were gathered and used as raw vegetable or pot herb (von Boguslawski 1984). The leaves, shiny and emerald green even in winter (Fuchs 1551), were unlikely confused with those of other plants, a feature that was very important for the first harvesters. The separation of the sub-family Betoideae (to which the genus *Beta* belongs) from the ancestral family Chenopodiaceae is estimated to have occurred between 38 and 27 million years ago (Hohmann et al. 2006). Therefore, it is possible that sea beet already was known to our ancestors in their remote African dawn.

Further confirmation of sea beet's ancient and widespread use are the remains of desiccated seed stalks, carbonized seeds, and fragments of root parenchyma found in the sites of Tybrind Vig and Hallskow, Denmark, dated from the late Mesolithic (5600–4000 BC) (Kubiak-Martens 1999, 2002; Robinson and Harild 2002). Pals (1984) reported on the discovery of similar remains in the Neolithic site (around 3000 BC) at Aartswoud, Holland. In agreement with Kubiak-Martens (1999), evidence of harvest and use of sea beet also are present at the Neolithic site at Dabki, Poland. Pollen of *Beta* wild plants was recognized in sediments sampled at Lake Urmia (Iran), Lake Jues (Germany), and Adabag (Turkey) dated around 10,000 years BC (Voigt et al. 2008; Bottema 2010).

The presence of fragments of root in the sites suggests that this part was used as frequently as the leaves. It is important to remember that in northern regions, the roots of sea beet are much more regular and developed than in southern environments. Therefore, the root better lends itself to harvest (Fig. 1.4) most likely beginning in

[2]Feral beets originate by a "dedomestication" of the crop. The process starts with the early flowering (bolting) of some cultivated beets before harvest.

Fig. 1.4 Atlantic *Beta maritima* with regular and swollen root (Smith 1803)

August, whereas the leaves were collected mainly in winter through spring (Kubiak-Martens 1999). After the discovery of fire, leaves and roots were eaten after cooking (Turner 1995). The frequent presence of remains of other wild plant species in these sites suggests the key role that vegetables played in the hunter–gatherer's diet even in pre-agrarian times (Kubiak-Martens 2002).

Charred remains of sea beet seeds were identified in late Mesolithic sites located in the northern region of the Netherlands, demonstrating the ancient presence of the species along the North-Atlantic seashores (Perry 1999), as it was further confirmed by the remains of sea beet found at the site of Peins, the Netherlands, dated to the first century BC (Nieuwhof 2006). Collecting data from 61 archeological sites in different parts of Egypt dated from predynastic to Greco-Roman times, Fahmy (1997) recognized 112 weed species including sea beet. Macro remains of the plant (seeds, leaves, stalks, etc.) were preserved by desiccation in sites dated from 3100 BC until the middle of the Pharaonic period (2400 BC).

As to the area of origin of the species, de Candolle (1885) wrote: "beets originated from Central Europe or from nearby regions, due to the large amount of wild species of the genus *Beta* present throughout the area". Some years later, de Candolle (1884) asserted that the beet crop, "which is the more easily [plant] to be improved by selection", was derived from the species now classified *Beta cicla* (or *Beta vulgaris* L. subsp. *vulgaris* Leaf Beet Group), very similar to sea beet. He also affirmed that *Beta cicla* expanded from the Canary Islands along the North-Atlantic coasts to the Mediterranean areas, up to the countries around the Caspian Sea, Persia, and Mesopotamia. The hypothesis of de Candolle, perhaps reasonable because of the numerous *Beta* species present today on Canary Islands, has not been confirmed by later authors (Meyer 1849; Pitard and Proust 1909; Francisco-Ortega et al. 2000). According to Coons (1954), the origin of sea beet could be located to the areas delimited by Ulbrich (1934) some decades before (Fig. 1.5).

Southwest Asia could be the area of origin, not only of sea beet and many other important crops (wheat, barley, etc.), but also of the family Chenopodiaceae (now Amaranthaceae), in which the genus *Beta* is included. Avagyan (2008) suggested that the species could have originated in Armenia. A number of authors: Honaker, Koch, Boissier, Bunge, Radde, and others reviewed by von Lippmann (1925), agree in locating the origin of the genus *Beta* in the area comprising the shores of the Caspian Sea, Transcaucasia, the East and South coasts of the Black Sea, Armenia, Asia Minor, the shores of the Red Sea, Persia, and India. Analyses of cytoplasmic diversity confirmed that the area of origin of sea beet should be the Mediterranean countries, where it is widely diffused even today (de Bock 1986; Cheng et al. 2011).

Fig. 1.5 Distribution of the species and sub-species of genus *Beta* according to Ulbrich (1934)

1.2 Domestication

Domestication can be described as the changes necessary to adapt plants to habitats especially prepared by man (van Raamsdonk 1993). Based on the rudimentary tools found in settlements of Neolithic age, the first farming of wheat (*Triticum* spp.) and barley (*Hordeum* spp.) is thought to have arisen in the Near East, perhaps earlier than 8500 BC (Zohary and Hopf 2000). The agricultural practices then would have spread into the Mediterranean areas through the ship routes of that time, and more slowly toward Central Europe. At least three millennia were necessary for agriculture to arrive in the British Islands, Scandinavia, and Portugal (Zohary and Hopf 1973, 2000): that is spreading at a rate of about 1 km per year (Cavalli-Sforza and Edwards 1967).

Beet cultivation may have begun, perhaps more than once, in Mesopotamia around 8000 BC (Simmonds 1976; McGrath et al. 2011). According to Krasochkin (1959), the first beet cultivation occurred in Asia Minor, mostly in localities at relatively high altitude with a cool growing season. Subsequently, the practice spread to Mediterranean areas, developing a great diversity of primitive forms of beet still existing today. The wild ancestor may have resembled types currently present in western Anatolia and Afghanistan, characterized by short life span, large seed-balls, elongated and fangy roots, tendency to flower very early, and so on (Krasochkin 1959, 1960). Using analyses of mitochondrial DNA, Santoni and Bervillè (1992) confirmed the hypothesis that cultivated beets likely originated from a unique ancestor quite different from the one currently known. After domestication, sea beet has continued to be harvested in wild sites and to be used as a vegetable, a custom still widespread in many coastal areas (Thornton 1812). According to Magnol (1636) "*Nihil in culinis Beta frequentius est*" (nothing is more used in the kitchen than beet). Rivera et al. (2006) consider the sea beet among the most gathered wild plants for food (GWP) in the Mediterranean and Caucasian regions. In the mentioned paper, the local names of sea beet are listed in 25 languages.

van Zeist and de Roller (1993) argued that beet farming had spread throughout much of Egypt by the time of construction of the pyramids of Giza (around 2700 BC). This hypothesis is supported by Herodotus (von Lippmann 1925). Because of the large quantity of beet that would have been required, the vegetable must have been domesticated. According to Buschan (1895), some wall paintings (Fig. 1.6) inside the tombs of Beni Hassan near Thebes, and dating to the 12th Dynasty (2000–1788 BC), represent beet and not horseradish (*Cochlearia armoracia*), as speculated by others. In a second painting inside the same tomb (Fig. 1.7) the farmer seems to have a beet in his hand, while the plants on the ground most likely are garlic (*Allium sativum*) (Woenig 1866). In both paintings, the regular shape of the root suggested that should be a cultivated variety of beet. Given the extensive spread of sea beet along the northern Egyptian coasts, Buschan (1895) speculated that its cultivation in the region had begun much earlier. In Fig. 1.8, the word meaning "beet" is written in ancient Egyptian (Kircher 1643; Veyssiere de la Croze 1755). Other findings dating from the third Dynasty (2700–2680 BC) have been made at Memphis, Egypt (Zohary

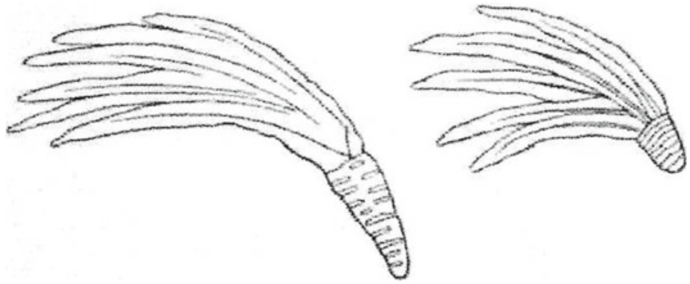

Fig. 1.6 Sea beet (or something similar) drawing at Beni Hassan, Egypt (Buschan 1895)

Fig. 1.7 Sea beet (likely) in the hands of the farmer. Painting at Beni Hassan, Egypt (Woenig 1866)

Fig. 1.8 The word meaning "beet" written in old Egyptian alphabet (Veyssiere de la Croze 1755)

and Hopf 2000). The lack of morphological differentiation often does not allow the establishment of whether remains are from wild or cultivated beets. In general, if the beet plant remains are found far from the sea and after the spread of agriculture in the area, it may be assumed that they are derived from cultivated beets. This is the case of beet seeds found in central Germany in sites dating to the Roman Empire (Zohary and Hopf 2000). A very original hypothesis was proposed by Stokes (1812).

He restored the old name *Beta sylvestris* and the likewise old name *Pyrola major,* establishing that it is "native of North America and Europe".

The cultivated beets have been adapted in response to selective pressures imposed by growers, who instinctively selected for reproduction the plants with the best expression of the traits of interest. The domestication process was hastened by utilizing plants showing mutations as well, but only if the new trait enhanced the qualities required by the farmers (Fehr 1987). This early selection, according to Ford-Lloyd et al. (1975), gave rise to a taxon classified as *Beta vulgaris* subsp. *provulgaris*, an ancestral form selected both for root and leaf production. The inherited offspring of this plant is believed still existent in Turkey (Ford-Lloyd et al. 1975).

Some traits necessary for survival in the wild became superfluous in cultivated field (Zohary 2004). For example, cultivation by the farmer reduced the beet's already poor competitive ability against weeds, a trait which is not necessary or of reduced in artificial monoculture. The annual cycle, necessary for increasing seed production and thus essential for the survival in the wild (Biancardi et al. 2005, 2010), slowly became biennial. In this way, as with other vegetables, was increased the duration over which leaves and roots remained edible (Harlan 1992). As a consequence of the selection process, genetic diversity decreased rapidly (Bartsch et al. 1999). Santoni and Bervillè (1995) observed in cultivated beets the lack of the rDNA unit V-10.4-3.3, common vice versa in wild beets. Because *Beta maritima* has been used in the last century as a source of resistances, the authors suspected the elimination of this DNA unit occurred through the selection processes. Recently, Li et al. (2010) confirmed the key role of genetic variation for the traits of interest in the first phase of sugar beet breeding (Ober and Luterbacher 2002).

The first written mention of beet farming goes back to an Assyrian text of the eighth century BC, which described the hanging gardens of Babylon (Meissner 1926; Ulbrich 1934; Körber-Grohne 1987; Mabberley 1997; Zohary and Hopf 2000). As has happened with the most important crops, the cultivated beet left its first domestication sites (Kleiner and Hacker 2010). Whereas Cheng et al. (2011) speculated that *Beta* has been domesticated in the Mediterranean area. Some centuries BC, the leaf beet was called "selga" or "silga", words that, according to Winner (1993), would have the same origin as the Latin adjective "*sicula*" (Sicilian). Around 400 BC, the cultivated leaf beet returned to Asia Minor (whence the sea beet had spread some millennia earlier) from Sicily, whose population of Greek origin had extensive trade relations with Mycenae and the eastern Mediterranean harbors (Becker-Dillingen 1928; Ulbrich 1934). Older European peoples, such as the Arians, did not cultivate beet (de Candolle 1885; Geschwind and Sellier 1902).

1.3 Athens and Rome

The first unambiguous written reference to beet cultivation dates back to Aristophanes, who mentions beet, at the time called τευτλον (*seutlon* or *teutlon*), in the plays "The Acharners", "The Frogs", and "Friends" (Winner 1993). According to