VEGETABLES I

HANDBOOK OF PLANT BREEDING

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Volume 1
Vegetables I: Asteraceae, Brassicaceae, Chenopodicaceae, and Cucurbitaceae
Edited by Jaime Prohens and Fernando Nuez

Volume 2
Vegetables II: Fabaceae, Liliaceae, Solanaceae and Umbelliferae
Edited by Jaime Prohens and Fernando Nuez

VEGETABLES I

Asteraceae, Brassicaceae, Chenopodicaceae, and Cucurbitaceae

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Cover illustration: A lettuce seed production field near Fresno, California, U.S.A. (courtesy of Y. Peng)

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Preface

The production and consumption of vegetables has expanded dramatically in the last years, with a global growth in the production of more than 50% in the last decade, a rate of increase that is much higher than for other plant commodities. Vegetables constitute an important part of a varied and healthy diet and provide significant amounts of vitamins, antioxidants and other substances that prevent diseases and contribute to an improvement in the quality of life. In consequence, it is expected that in the coming years, vegetable crops production will continue its expansion.

Improved varieties have had a main role in the increases in yield and quality of vegetable crops. In this respect, the vegetables seed market is very dynamic and competitive, and predominant varieties are quickly replaced by new varieties. Therefore, updated information on the state of the art of the genetic improvement of specific crops is of interest to vegetable crops breeders, researchers and scholars. During the last years an immense quantity of new knowledge on the genetic diversity of vegetables and the utilization of genetic resources, breeding methods and techniques, and on the development and utilization of modern biotechnologies in vegetables crop breeding has accumulated, and there is a need of a major reference work that synthesizes this information. This is our objective.

The diversity of vegetable crops is appalling, with hundreds of species being (or having been) grown. However, among this plethora of crops, there are some which are prominent, and for which there has been a greater development in the breeding science and development of varieties. In consequence, we have produced two volumes devoted to 20 of these most important vegetable crops. These crops belong to eight different botanical families. Because in many cases crops from the same botanical family share many reproductive, physiological, and agronomic features, as well as similar breeding techniques, we have decide to group them by this taxonomic category. In this respect, this first volume includes 12 chapters that deal with vegetables that belong to four families: Asteraceae or Compositae (chicory and endive,

globe artichoke and cardoon, and lettuce), Brassicaceae or Cruciferae (cabbage, and cauliflower and broccoli), Chenopodiaceae (spinach and sugar beet) and Cucurbitaceae (cucumber, melon, pumpkin and winter squash, summer squash, and watermelon).

Chapters have been written by outstanding breeders with wide experience in the crop treated. Each chapter includes information on the origin and domestication, varietal groups, genetic resources, major breeding achievements and current goals of breeding, breeding methods and techniques, integration of the new biotechnologies in the breeding programmes, and the production of seed of specific crops.

The completion of this book would not have been possible without the contributions of the many authors, who have devoted much time to the task of writing the chapters. We also want to thank the staff of Springer, in particular Jinnie Kim and Shoshana Sternlicht, who have made possible to produce a high quality book in a very short time span. We are also indebted to many colleagues for useful suggestions that have contributed to improve this book.

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Family Asteraceae (=Compositae)

Chicory and Endive

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1 Introduction

Chicory and Endive are common names that correctly indicate two different species. Their conversational use may nevertheless bring about some misunderstanding as they do not only refer to a series of different leafy vegetables but, more extensively, to substantially different crops from which many different products are obtained.

As leafy vegetables, chicory and endive are much less used than lettuce or cabbages, but they are anyway among the most known and popular horticultural products in the world and, although with great differences in cultural practices and type of utilization, they are diffused in almost every country and are included in the diet of most western as well as eastern populations. Mainly known as important components for fresh salads, they are also often cooked and differently prepared according to traditions and alimentary habits.

Chicory and endive are two traditional European horticultural crops and, although they cannot be considered as autochthonous, their evolution as vegetable crops has taken place in continental Europe where they have gradually differentiated in a variety of cultivated types.

Actually, the name “Endive” only indicates a leafy vegetable crop whose cultivated material usually refers to two groups of cultivars: the “Escarole Group” and the “Curled Endive Group”. On the other side, the term “Chicory” indicates at least two kinds of crops: a leafy vegetable, very differentiated according to several cultural types, and a root crop whose industrial utilization seems at present mainly addressed to inulin extraction or, on a more limited scale, to the production of a coffee substitute. Both these types of “root chicory”, have the same origin as they have been derived from the so called “Magdeburg chicory”, the ancient root chicory

known and traditionally used in some European countries as a coffee substitute since the end of 16th century and that gained outstanding importance with the continental block at the time of Napoleon. Also a very important leafy vegetable, the so called "Witloof chicory" or "Belgian endive", perhaps the most known among the leafy chicories, has to be considered a derivative of the Magdeburg chicory as it seems commonly accepted that its first well known pale yellowish sprouts have casually been obtained by a Belgian farmer who, around 1870, had observed and harvested them from a stock of roots piled up in autumn and left apart during the cold season, waiting to be dried, grounded, and toasted.

Lacking comprehensive, homogeneous, sufficiently detailed, and univocal data on horticultural productions and trade, it is impossible to give reliable figures on the diffusion and economic importance of the two cultures in Europe, where chicory and endive are mostly grown.

In the most recent statistics concerning the European market (EU Market Survey 2004 for fresh fruit and vegetables) too, chicory and endive are often confused under the general voice "salads", or considered together with lettuce which is by far the most important leafy vegetable at both European and world-wide scale. The situation is not very different if one considers, as a source of reliable information, the statistics of each single country. On the basis of accessible data it is however possible to figure out that Belgium, France, Italy, and Netherlands are the almost exclusive producers of chicory and endive. These two crops do not give a great contribution to each country's total agricultural income, but they are very important at local level, as they characterize the agriculture of limited areas where from 80 to 90% of the country's production is concentrated. This is the case of France, where 86% of the more than 15.000 ha of Witloof chicory grown in the country are localized in four northern departments, or of Italy, where the north eastern region accounts for 87% of the national acreage and 84% of the national production of that particular type of red or variegated chicory known as "Radicchio". The Escarole and Curly endive types, in both France and Italy, are much less concentrated and may extend far south where they are usually grown. The same occurs with other chicory types like the "Chicory of Catalogne". By the way, regarding the possible confusion between the two terms, it may be interesting to note that the Witloof chicory is officially registered by French statistics as "Endive", while the Escarole and the Curly endive are identified as "Chicorèe".

Furthermore, it is perhaps worth noting that chicory and endive are not only important for the local economies, but they may have significance at an international trade scale too. Altogether, the US imports of chicory in 2002 have been equal to 5996 Mt for a value of $ 8.193.000. About a half of these amounts, both in quantity and value, are represented by Witloof chicory, whose imports from Belgium and Netherlands sum up to more than 90% of the whole figure. Thus, although still on a regional scale, chicory and endive have their own place among more known and used vegetables and may represent a significant source of income for farmers in areas where they have been traditionally present.

Within this frame, two observations may be added. The first concerns the marked decrease of US not qualified chicory imports from Europe, in particular from Belgium, Netherlands, and Italy (2622 Mt in1996, 536 Mt in 2002), and the increase

of imports from Central and Southern America (1046 Mt in 1996, 2522 Mt in 2002). Compared to the stable or lightly increasing figures recorded during the same period for Witloof chicory (between 2000 and 2400 Mt) this trend seems to indicate that Witloof has taken an advantage thanks to the quality and standardization of the marketable product. The second observation regards the "Radicchio" which is now considered with more and more attention both in Europe and in the US, as well as in other overseas countries, where its cultivation has started some years ago and seems to have an increasing evaluation as its red or variegated leaves are particularly appreciated as a component of prepared salads.

Finally, the recognised value of some compounds present in chicory's roots and leaves may enhance its appreciation beyond the horticultural use and has to be underlined to completely figure out the potentiality of the plant and the possible breeding goals. From this point of view, the industrial use of chicory for inulin production deserves particular attention. In Belgium, the acreage dedicated to this utilization has been constantly increasing during the last ten years and has passed from 11.700 ha in 1997 to 15.700 ha in 2005.

2 Taxonomy and Origin

Both Chicory (*Cichorium intybus* L.) and Endive (*Cichorium endivia* L.) belong to the family *Asteraceae*, a very large family with about 23.000 species subdivided in 1535 genera grouped in three subfamilies: *Barnadesioideae*, *Cichorioideae*, and *Asteroideae* (Bremer et al., 1994). The tribe *Lactuceae*, in the subfamily *Cichorioideae*, includes the genus *Cichorium* within which different species are recognized according to the source. Tutin et al. (1976), referring to the European flora, describe the three species *C. spinosum*, *C. intybus*, and *C. endivia* and subdivide this last one in subsp. *endivia* (cultivated), and subsp. *divaricatum* (wild). Pignatti (1982), taking into account the Italian flora, refers to the three wild species *C. spinosum*, *C. intybus*, with the var. *glabratum* (Presl) Fiori, and *C. pumilum*, maintaining *C. endivia* as a cultivated species only. In a revision of the genus made by Bedarff in 1985 (cited by Kiers, 2000) and partially published by Wagenitz and Bedarff (1989), seven species were described on the basis of morphological characters, and C. *endivia* and C. *intybus* were further divided in two subspecies (*C. endivia* subsp. *endivia* and C. *endivia* subsp. *divaricatum*; *C. intybus* subsp. *intybus* and *C. intybus* subsp. *glabratum*). This classification does not agree with the one given by the Royal Botanical Garden which, in the Flora Europea section, only referring to *C. intybus*, indicates three subspecies: subsp. *foliosum* (Hegi) Janch., subsp. *glabratum* (C. Presl) Arcang., and subsp. *sativum* (Bisch.) Janch.

Kiers et al. (2000), integrating morphological characters with molecular observations, describe the two cultivated and most known species *C. intybus* and *C. endivia* and the two wild species *C. spinosum* and *C. pumilum*. Moreover, two additional species, never observed in Europe, are added, *C. calvum* and *C. bottae*, the former endemic to the dry and hot environments of Middle East and South Western Asia and the latter from Yemen and Saudi Arabia. More recently, Conti et al. (2005), in their study of the Italian flora, recognized three species in the genus: *C. endivia*,

with the two subspecies *endivia* Hegi and *pumilum* (Jacq) Cout., *C. intybus*, with the two subspecies *glabratum* (C. Presl) Arcang. and *intybus*, and C. *spinosum*.

Since the early nineties, when the analysis of DNA fragments became more and more familiar to taxonomists, several studies have allowed the task to explore, and possibly clarify, the relationships among the two cultivated species - *C. intybus* and *C. endivia* - and their wild relatives. Vermeulen et al. (1994), using mitochondrial RFLPs, suggest that *C. spinosum* may be considered an ecotype of *C. intybus* rather than a separate species. Gemeinholzer and Bachmann (2005), with other and more sensible molecular methods (ITS, AFLP, SSR), were unable to discriminate between these two species which, on the contrary, could be clearly delimited with two diagnostic and one overlapping morphological character. On the basis of chloroplast DNA RFLPs and chloroplast DNA and nuclear rDNA sequence analysis (Kiers et al.,1999) or using AFLP markers (Kiers et al., 2000) it has been confirmed that *C. intybus* is closely related to *C. spinosum*, while *C. endivia*, *C. pumilum*, and *C. calvum* show a close molecular resemblance among each other and are fairly well separated from the first two. The sixth species, *C. bottae*, has to be considered a sister species.

Besides morphological and molecular resemblances or diversities, a distinction among these six species can be made on the basis of their life cycle and reproductive system. Thus, two groups may be established: on one side *C. intybus*, *C. spinosum*, and *C. bottae*, perennials that are characterized by a strong self-incompatibility system, on the other *C. endivia*, *C. pumilum*, and *C. calvum*, annual and self-compatible species. Within this frame, the names of the recognized botanical varieties do not appear, although it is from them that the various cultivated types have originated.

The origin and differentiation of the genus is concordantly located in South-Eastern Europe, the Eastern Mediterranean basin and the South Western Asia. Within this large centre, *C. intybus* and *C. endivia* partially share their area of origin which, for *C. intybus*, tends to be located in the southern Balkan peninsula and northern Middle East and, for C. *endivia*, is claimed to be the whole Middle East with an extension to the northern Arabic peninsula. From there, they firstly migrated in the whole Mediterranean basin and, on the other side, toward Southern and Eastern Asia where they seem to have found different areas of diffusion and adoption as horticultural crops.

At present, *C. intybus* is mainly grown all over continental Europe, in South Western Asia, and on limited areas in Northern America, South Africa, and Australia. *C. endivia*, other than in continental Europe, perhaps in accordance with its more southern origin, is grown in Central and Southern America and all along the Mediterranean coast of the African continent. In Asia, it seems to have found particularly favourable conditions in the eastern part of the continent, on an area which includes South Eastern China, Korea, and the eastern part of Inner Mongolia.

Probably known by the Egyptians and used as food and/or medicinal plants by ancient Greeks and the Romans, in Europe both species gradually underwent a process of naturalization and, as said before, although they cannot be considered as autochthonous species, they became part of the natural and agricultural European flora. Thus, *C. endivia*, traditionally indicated only as a cultivated species, may be

found in the spontaneous flora of at least some Italian regions (Conti et al., 2005). *Cichorium intybus* covers, as wild, a great portion of the whole European continent and traditionally enters into the diet of local populations as an important ingredient of typical local dishes. This might be the consequence and, at the same time, the cause of the great differentiation among a number of types which, mostly within *C. intybus*, have originated an always increasing number of cultivar groups, types, populations which, altogether, make the horticultural landscape of the genus *Cichorium* particularly rich and interesting from a historic, cultural, agronomic, commercial, and scientific point of view.

Several extensive lists of *Cichorium* species, subspecies, botanical varieties, and cultivar groups, have been published and are present in accessible internet sites, where scientific and technical news often mix up with commercial promotion, forming a mass of information not always easy to be interpreted.

The most exhaustive seems to be the list given by Mansfeld's World Database of Agricultural and Horticultural Crops (IPK Gatersleben 2002) which includes 49 entries. Many of them are synonyms and often refer to differences among commercial types rather than to taxonomic distinctiveness. Almost as large is the list at the web site of Melbourne University (2003) - M. H. Porcher mantainer – where 29 entries of species and synonyms are given together with a large, although not always accurate, picture of the cultivated types. More restricted, although still large, is the list given by GRIN (Germplasm Resources Information Network - USDA) where cultivar groups do not appear, but synonym subspecies and botanical varieties are nevertheless taken into consideration.

Altogether, at least six cultivar groups, mainly differentiated on the basis of their use, are recognizable (Kiers et al., 1999, 2000; Kiers, 2000; Van Stallen et al., 2001).

Aiming to schematise in a readable manner the whole of these information, a synopsis is proposed in table 1 where a correspondence between taxonomy, cultivar group and most frequent and known utilization has been attempted.

3 Biological Features

Although they strongly resemble each other on the basis of morphological characters, *C. intybus* and *C. endivia* have always been considered as two different species. For an accurate morphological description see Kiers et al. (1999). Here a very synthetic picture is proposed where attention is mainly brought on the life cycle and the breeding system, i.e. on characters and features particularly concerned with breeding and, as such, proper of the cultivated types rather than of wild or naturalized species. From this point of view it has to be stressed that a description of the behaviour of the two species is strictly dependent on the environmental and cultural conditions and, in particular, on the latitude which one refers to. Since both species are grown under very different situations, it is worth to underline that we will consider what occurs with direct sowing or transplanting in open field at a latitude of about 45° N, as this is the average latitude of North Eastern Italy where both species are usually grown using different cultural techniques: in greenhouse, under temporary covers, or in the open field.

Table 1. Chicory and Endive: European species of *Cichorium*, cultivar groups and use.

Taxonomic position	Cultivar group	Use
C. endivia		
subsp. *endivia*	wild [a]	
var. *latifolium*	Endive	salads
var. *crispum*	Crispum	salads
subsp. *pumilum*	wild [a]	
C. intybus		
subsp. *intybus*	wild [b]	
var. *foliosum*	Witloof chicory	cooked/salads
	Pain de sucre	cooked/salads
	Radicchio	salads
	Catalogne	cooked
var. *sativum*	Root chicory (roasted)	coffee substitute
	Root chicory (industrial)	inulin extraction
	Root chicory	cooked
subsp. *glabratum*	wild [b]	
C. spinosum	wild [b]	

[a]Exotic, naturalized in Europe, and [b]autochthonous (Conti et al. 2005).

Both species have a tap root which in *C. endivia* is subdivided in parallel branches and may deepen in the soil down to over 1 m (Tesi, 1965), while in *C. intybus* is larger and unique. Particularly large is in the industrial types, whose commercial product is the root, or in the horticultural types whose commercial product is the bunch of leaves obtained through "forcing", as it happens with the "Witloof chicory" or with the late type of "Radicchio di Treviso".

C. *endivia* has to be considered an annual, in as much as, independently of the moment of sowing or transplanting, between May and August, if temperature is sufficiently high, the plant forms an enlarged rosette of leaves which are characterized by a wide midrib and an extended flat (var. *latifolium*) or crisp (var *crispum*) lamina and, immediately thereafter, develops a flowering stalk.

C. intybus is a biennial or, in the wild, a perennial species. An early sowing or transplanting in spring, under long days, although with differences according to the cultivar group, brings about an almost generalized flowering. If sowing or

transplanting are delayed to the month of July, the plant forms a rather loosen rosette, or a fairly compact "head", which remains in the field until the following spring when, between May and June, the central bud develops in a stem bearing, as in *C. endivia*, blue "flowers" (rarely white or mauve).

On the flowering stalk many clusters of 4-6 sessile "flowers" (2-4, rarely 8, in *C. intybus*) are inserted in axillary position, or single "flowers" are brought at the end of peduncles 10-20 cm long (4-7, rarely up to 13, in *C. intybus*). The "flower" is actually an inflorescence (*capitulum*) which is typical of the whole family and is a cluster of 15-25 single hermaphrodite flowers, borne on a receptacle and protected by an involucre. Each single flower has a gamopetalous and ligulate corolla, and bears five filamentous stamens fused by their anthers to form a column surrounding a pistil with a bifid stigma.

At flowering, the style elongates, the stigma is pushed up through the small channel made by the anthers, the two halves of the stigma separate and assume a rather pronounced spiral form that may bring the inner receptive surface, completely free from pollen, to touch the outer surface of the pistil which, extruding from the staminal column, has remained densely covered with pollen grains. Thus, in both species, independently of the intervention of external agents, self-pollination is possible. This does not mean that both species are self-fertile. As we will see later, while *C. endivia* is self-fertile, *C. intybus* is characterized by a strong sporophytic incompatibility system which inhibits self-fertilization.

4 Cultivar Groups

In table 1 nine cultivar groups are listed, mainly according to the product they give and its use. Two of these refer to root crops for industrial utilization, coffee substitute or inulin extraction, and thus they are outside the strict horticultural field. All the others, although after different culinary transformations, are directly used, as leaves or roots, as fresh or cooked foods.

Although, as it has been said, chicory and endive are cultivated all over Europe and tend to expand towards always new horticultural areas, most of these groups are well known and extensively adopted, as horticultural crops, at a local scale only and, as such, their description in the scientific and technical literature is often incomplete or inaccurate. This is particularly true when the crop is largely differentiated and has generated subgroups among which it may be really difficult to find differences and affinities. We are aware that, particularly for this kind of horticultural crops, diversity is often the most efficient tool for commercial success, both for the seed-man and the farmer; thus, it may be unwise, in a continuously moving breeding world, to establish a rigid frame within which everything has to find its place. Nevertheless, it seems advisable to have an account, as complete as possible, of the material we are talking about. This is the reason why, giving attention to the most distinctive traits and with the help of some pictures, we feel stimulated to attempt a short description of the most frequently cultivated plant material. Doing this, we do not intend, in any way, to cover the whole landscape of the chicory and endive types, cultivars, local populations, and farmer's selections grown in Europe and outside: we

only want to propose a tool, although far from being exhaustive and of general satisfaction, usable for classifying at least the major part of the cultivated material according to objective criteria rather than to commercial perceptions.

C. endivia subsp. *endivia* var. *latifolium* (2n = 18) (Fig 1A)
English: Escarole, Batavian endive, Broad leaved endive;
French: Scarole, Chicorée blanche;
Italian: Scarola;
German: Endivie-Eskariol;
Spanish: Escarola.

C. endivia subsp. *endivia* var. *crispum* (2n = 18) (Fig.1B)
English: Curled endive;
French: Chicorée frisée;
Italian: Indivia riccia;
German: Krause endivie;
Spanish : Escarola crespa.

The name "endive" correctly pertains to the cultivated material belonging to the two botanical varieties mentioned above. Their main use, alone or in mixtures, is in fresh salads for which their yellowish or pale green leaves are particularly appreciated. Cultivation techniques are much the same for the two types: they are typical spring-summer crops and are scarcely tolerant to low temperatures. Any out of season cultivation, both delayed or anticipated, although possible, needs artificial protection. The commercial value of the final product mainly depends on the ratio between the bunch of etiolated leaves which form the "heart" and the whole of the plant. In ancient times this ratio was traditionally increased by closing the rosette with a rubber band during the last period of permanence in the field. Recently bred cultivars, tendentiously self blanching, form a more or less closed rosette of leaves, so that the etiolated "heart" is naturally obtained directly in the field.

C. intybus subsp. *intybus* (2n = 18)

Two main groups can be recognized within this subspecies to which all the cultivated types of chicory belong: the first, which refers to the var. *foliosum*, traditionally includes all the cultivar groups whose commercial products are the leaves, while the second regards the var. *sativum* and comprises all the types whose commercial product, either destined to industrial transformation or direct human consumption, is the root.

It might be argued that if it is true, as commonly accepted, that Witloof chicory has been firstly obtained from roots of Magdeburg, then, strictly speaking, it should be grouped under the var. *sativum*, together with all the other root chicories. Nevertheless, the most recent scientific literature refers to Witloof chicory as a type belonging to the var. *foliosum* (Koch et al., 1997; Van Stallen et al., 2001; Van Stallen et al., 2003; Van Stallen, 2003; de Proft et al., 2003; Van Stallen et al., 2005)

and as such it is considered here together with the cultivar groups Pain de sucre, Radicchio, and Chicory of Catalogne.

Witloof chicory (Fig. 1C)

English: Witloof;
French: Chicorée de Bruxelles, Chicorée witloof;
Italian: Cicoria witloof, Cicoria di Bruxelles, Cicoria belga;
German: Zichorienzalat;
Spanish: Endibia, Achicoria de Bruselas.

The productive cycle of Witloof chicory may be divided in two distinct phases. The first is aimed to obtain well developed and uniform roots which, in the second one, were traditionally forced under a soil coverage, ending up with the production of the well known firm etiolated heads (*chicons*) formed by leaves tightly grown. At present, due to the adoption of hydroponic culture techniques, a year round production is possible. In this evolution a role has been played by the development of specific hybrids which, thanks to both their targeted selection and uniformity, gradually replaced the original populations and the old farmer's selections, further reducing the narrow genetic basis of the crop (de Proft, l.c.). In spite of this, genetically differentiated populations might still be sporadically traceable and used. Besides to physiological or parasitic disturbances which may alter the overall productivity and the product's marketability, breeders pay attention to quality traits which may increase its commercial attractiveness. Among these, the pale yellowish colour of the leaf blade and an absolutely colourless midrib are most important, although much attention is also paid to the head's closeness and firmness. Intrinsic quality has been considered as well and the almost complete disappearance of the bitter taste from the commercial product has to be retained as one of the reasons for its generalized acceptance outside the area of origin.

More recently, attempts of innovation in the appearance of the commercial product have been made and, taking advantage from the within species variability and the interfertility among all the cultivar groups, new looking red or reddish leafed cultivars have been put on the market.

Pain de sucre (Fig. 1D)

English: Sugarloaf chicory, Tall heading chicory;
French: Chicorée pain de sucre ;
Italian: Pan di zucchero ;
German: Zichorien;
Spanish: Achicoria.

It is perhaps one of the most ancient results of selection from wild populations. The plant's appearance at maturity is more like Romaine lettuce or Chinese cabbage as it has very large leaves enveloping one over the other to form a large, firm, tightly closed head, yellowish green in colour, weighing up to 1.5-2.0 Kg. Its cultivation is not very widespread but, as it happens with other types of chicory, it may give a connotation to the horticulture of some restricted areas like, for instance, Southern France, North Western Italy and Southern Switzerland. Despite the name, it has

maintained quite an accentuated bitter flavour which renders this vegetable perhaps more adapted to be cooked rather than to enter as a component in crude salads. Open pollinated populations as well as some hybrid varieties are available on the seed market.

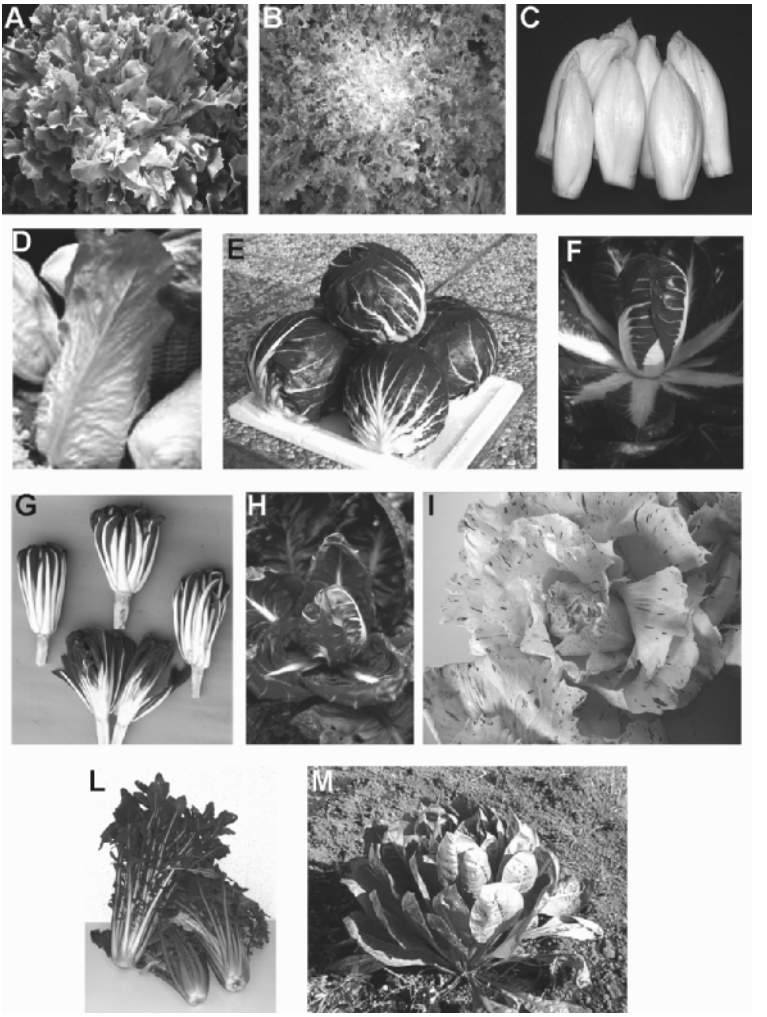

Fig. 1. Varietal groups of endive and chicory: A escarole (photo ISI Sementi), B curled endive (photo ISI Sementi), C Witloof chicory, D pain de sucre, E radicchio Red of Chioggia (photo Veneto Agricoltura), F radicchio Early Red of Treviso (photo Veneto Agricoltura), G radicchio Late Red of Treviso (photo Veneto Agricoltura) , H radicchio Red of Verona (photo Veneto Agricoltura), I radicchio Variegated of Castelfranco (photo Veneto Agricoltura), L asparagus chicory (Catalogna) , M root chicory.

Radicchio

This Italian common name has been adopted by all the most internationally used languages and indicates a very differentiated group of chicories, with red or variegated leaves, traditionally cultivated in North Eastern Italy.

There is no documented history about the origin of coloured chicory in Italy. All the red types of Radicchio now being cultivated seem to derive from red-leaved individuals firstly introduced in XV century. According to Bianchedi (1961) the cultivation of red chicory goes back to the first half of XVI century. For sure, the original type has to be identified with the "Rosso di Treviso" which has been for long the only cultivated radicchio in the Venetian territories. Later on, possibly from spontaneous or controlled crosses between red leaved individuals and plants of *C. endivia*, the types with red spotted or variegated leaves have been originated. After spreading out to the nearest territories, the original type underwent an accentuated selection according to very different criteria suggested by each farmer's personal preference, but at least partially due, or depending on, the various environmental situations met by the crop. Thus, in the area of Verona, from the original "Rosso di Treviso" a small winter hardy type forming a rosette of deep-red coloured leaves has been initially selected; from this, the most recent populations of "Rosso di Verona" have been obtained around 1960. During the second half of the last century a further selection from the original Treviso type has been made, thus originating a long leaved and early maturing population with self closing plants. Differently, in the area of Chioggia, a traditional horticultural area established since ever on the sandy soils extending southward of this small sea sided town just south of Venice, a variegated type, able to form rather conic, firm, and tightly closed heads while in the field, had been originally selected around 1930. From this, a large leaved red type with an accentuated and white midrib and characteristic ball-shaped heads has been initially selected about twenty years later and an almost completely light-yellowish type of very limited cultivation has been obtained toward the end of the last century.

As a result, at least five grown types, named according to their province or town of origin, may be distinguished, at present, within this cultivar group:

Rosso di Chioggia = Red of Chioggia (Fig. 1E)
Rosso di Treviso Precoce = Early Red of Treviso (Fig. 1F)
Rosso di Treviso Tardivo = Late Red of Treviso (Fig. 1G)
Rosso di Verona = Red of Verona (Fig. 1H)
Variegato di Castelfranco = Variegated of Castelfranco (Fig. 1I)

Rosso di Chioggia (Fig. 1E). This is by far the most widely grown among the various types of Radicchio and the one which presents the highest within-type differentiation as far as the availability of cultivars able to guarantee an almost complete year round production. As a matter of fact, it has shown a great adaptability to very different environmental situations all around the world, becoming the most grown type of Radicchio outside Italy and, thanks to this fact, the most known at international level. Independently of the sowing time, it grows in the open field and only early cultivations, able to give a product in the months of May and June, need

protection during the first part of the cycle. Its massive production is concentrated between September and the end of February of the following year. Its main features are, first of all, the ball shaped and very firm heads which, at harvest, may reach a weight of 500 g once the outside green leaves have been eliminated. Other distinctive traits are the deep red colour of the leaf lamina and the extension of the midrib which must be associated with its absolute whiteness. Although the seed industry has since long become interested to this crop and named commercial varieties have been adopted, the great majority of the farmers in the typical area of production still use seed of their own populations which they maintain through a yearly conservative selection and an on-farm seed production. Quite often this seed is sold and bought through private transactions, outside the official seed market, both inside and outside the typical area, while commercial seed is mainly used outside Italy. The majority of the commercial varieties are open pollinated populations derived through selection from the original genetic pool. In recent years so called hybrid varieties have been put on the market and are favourably adopted mainly for out of season productions.

Rosso di Treviso Precoce (Fig. 1F). It is characterized by having upright long leaves with a large and thick midrib sustaining a rather expanded deep-red coloured lamina. During the vegetative period, as the plant grows, the newly developed leaves do not expand in an open rosette, but tighten more and more to form closed and firm heads. It is sown or transplanted in the field from July to mid August and harvested in September through December. At harvest, the outer green leaves and the major part of the tap root are taken away in order to leave the inside red heart ready for the market. Although it is one of the most recent selections, it is becoming more and more known outside its initially limited area of production and, thanks to a cultivation technique very similar to the one of “Rosso di Chioggia”, it is on the way to follow the same trend of expansion. As a consequence, the seed industry has been looking with increasing attention to this type of radicchio and, at present, besides some open pollinated commercial populations, one hybrid variety has been put on the market. Since an out of season cultivation has started to be adopted, an increasing need of genetically improved material is foreseeable. Anyway, at present, most farmers are using their own populations derived from the original genetic pool and maintained through yearly mass selection.

Rosso di Treviso Tardivo (Fig. 1G). It is the most ancient type of Radicchio grown in Italy and can be considered the legitimate ancestor of all the others. It is a typical winter crop in as much as it is sown or transplanted in the field from July to mid August and may be harvested in October through February. The plant grows with long, deep-green, basically upright leaves which form a loose rosette and whose both midrib and lamina assume an always more accentuated reddish colour as temperature lowers. At harvesting, the entire plants are dig out, stocked with all their leaves and roots, and maintained at low temperature (around 0°C) as long as possible. According to the market’s request, plants are forced placing them under a black cover, with their roots in running water at 10-12°C.

After 10-18 days, according to the air temperature, the forcing period is concluded: plants are cleaned off, the outer leaves and a great portion of the tap root are eliminated leaving a bunch of bright-red coloured leaves with a white large midrib and a rather reduced lamina. As it seems clear enough, this crop has at least some features in common with Witloof chicory with which it shares the shape of the leaves, the growth habit, the large tap root, and the forcing process in order to obtain the commercial product. It is grown in a very restricted area and, together with the "Variegato di Castelfranco" and the "Rosso di Treviso Precoce" is one of the three radicchios recognized since the late '90s with the PGI (Protected Geographical Indication) mark. Its peculiar aspect and really superior culinary quality make this Italian Radicchio the most appreciated one. Its market price, particularly at Christmas, may reach as much as twice or three times the price of any other Radicchio. In spite of this, no named commercial variety is on the seed market except for selected open pollinated populations. As a matter of fact, its cultivation is very limited and the whole productive procedure is rather complicated and much less standardized than the one adopted for Witloof chicory. So, unless it reaches a comparable degree of popularity, it seems difficult that the seed industry would invest on this very peculiar crop. Almost the total present production relies on farmers' populations whose history may go back for generations and which are maintained through yearly mass selection.

Rosso di Verona (Fig. 1H). The first populations of this type of Radicchio, as we know it now, were obtained about fifty years ago. With respect to previous populations, the present ones have plants with much larger heads which may resemble those of "Rosso di Chioggia". In comparison to these, besides being smaller on the average, they are more egg-shaped and formed by less expanded leaves with a brighter red lamina and a large and thick midrib from which less evident and intersecting veins depart. Its cultivation is much like that of "Rosso di Chioggia" and "Rosso di Treviso Precoce". Sowing dates are from July to mid August, while harvesting starts at mid October and goes on until the end of February. During the vegetative period the plant develops a rosette of pale-green leaves which gradually close and tighten up to form a very firm head. It is a typical winter crop whose popularity and area of cultivation is increasing both in Italy, where it is expanding to more southern regions, and outside the country. The reason of this is much the same as for the early Rosso di Treviso: its cultivation can be standardized quite easily, there is no need for forcing, thanks to its attractiveness the product is well accepted by the market, and the consumer recognizes to it a better culinary quality in comparison to other Radicchio types. In spite of this increasing popularity, the seed market is rather poor and the available commercial varieties are selected open pollinated populations. The development of the first hybrid variety seems not too far anyway. The most frequently used seed is thus from the farmer's populations selected during the last decades and maintained through mass selection. It seems worth noting that in developing these populations, a procedure implying crosses of the initial small leaved "Rosso di Verona" with the larger headed type "Rosso di Chioggia" may have been adopted.

Variegato di Castelfranco (Fig. 1I). Together with the "Rosso di Treviso Tardivo", is the second most traditional type of Radicchio grown in North Eastern Italy. Its morphological traits make it easily distinguishable from any other type. Directly sown or transplanted between July and mid August, plants form a large rosette of more or less indented brilliant green leaves with a very extended red spotted or variegated lamina sustained by a not too evident white midrib. When developing, the inside leaves wrap up and tighten to form a closed but not too firm cone-shaped self blanching head. At harvest, the external green leaves are removed and the internal ones are open to form a bunch of pale yellowish red spotted leaves which looks very much like a flower. As a matter of fact, this Radicchio is also known as the "Rose of Castelfranco" and is one of the most appreciated components of fresh salads during the cold season The selected populations grown at present are all self blanching thus making the cultivation of the "Variegato di Castelfranco" comparable to the one described for the other types of Radicchio with the exception of the "Rosso di Treviso Tardivo" with which has for long been sharing the final forcing process. As far as the availability of commercial seed, the situation is much the same as for the majority of the other radicchios. Selected populations are available on the market, but the great part of the crop is planted with seed of farmers populations selected and maintained through mass selection by each farmer.

Catalogna (Fig. 1L)

English: Asparagus chicory; Large leafed chicory;
French: Chicorée asperge d'Italie;
Italian : Cicoria Catalogna;
German: Katalanische endivie.

Has a recognised Italian origin but, other than in Italy, it is grown in Southern France, Spain, and, generally speaking, in all the Mediterranean countries, as well as outside Europe where the environmental conditions are sufficiently mild and favourable. The plant has tall deep green coloured upright leaves, with indented or continuous lamina and a marked midrib, growing in a tuft without forming a head. Its rather bitter taste is particularly appreciated. It is usually cooked, but young sprouts which origin from inside the plant may be used as fresh salad (*puntarelle*). Many cultivars are known whose names often refer to the place they come from or to the culinary utilization, thus generating synonyms used at commercial level to indicate the same product. It is rather frequent to find these names included in lists or catalogues, as if they were belonging to different cultivar groups, together with other types of different chicories, thus generating a little bit of confusion.

Root chicory (Fig. 1M). This cultivar group has to be referred to *C. intybus* subsp. *intybus* var *sativum* and includes both horticultural crops, grown for direct consumption as cooked food, and industrial crops whose destination is the preparation of a coffee substitute or inulin extraction. As far as the first utilization is concerned, the crop has no great diffusion and may have significance at local level only. All the grown types, differing in name according to the place of origin, have been derived from the ancient Magdeburg chicory. In selected varieties, roots tend to

be cylindrical, with smooth surface, few hairy roots, and the central part reduced at a minimum. Their bitter taste, which renders them particularly appreciated by the connoisseurs, has been strongly reduced in comparison to that of the original types. Selected open pollinated varieties are available on the seed market, but local populations maintained by farmers through mass selection are adopted in most cases.

5 Genetics and Breeding

5.1 Reproductive Systems and Population Genetics

In any breeding program, the breeding schemes that can be adopted as well as the variety types that can be constituted depend on the reproductive barriers and mating systems of plants, and hence on the genetic structure of populations.

The genetic structure of natural populations of cultivated *Cichorium* species cannot be referred to a unique model as there are basic differences between *C. endivia* and *C. intybus* in their reproductive system.

C. endivia (2n = 18) is a self-pollinated species with less than 1% of spontaneous crosses (Rick, 1953), whose populations are composed of a mixture of pure lines, genetically related but reproductively independent from each other. Thus, genetic as well as phenotypic variation are principally detectable among lines, due to the presence, within natural populations, of fixed genotypes, mainly homozygous for different alleles. Spontaneous hybridization is however possible to some extent, depending on environmental factors and germplasm sources. Commercial endive varieties are usually represented by pure lines obtained through repeated selfing of a number of plants selected from original genetically variable populations or of hybrid individuals stemmed from crosses between superior parental lines chosen for complementary morphological and commercial traits. The close autogamy of endive limits the choice among breeding strategies to mass selection, individual selection, pedigree breeding and back-crossing (Ryder, 1998). The first strategy enables to constitute multiple line varieties, whereas the other ones lead to single pure lines: from here comes the uniformity of the commercial product. Production of F_1 hybrids, which is usually more appropriate for cross-pollinated species, has been developed in other related self-pollinated leafy vegetables, such as lettuce, but it has yet to be exploited in endive. Although many commercial cultivars are on the seed market and represent the great majority of the cultivated material, local populations are still grown and, according to the area of cultivation, may give rise to different and very specific local productions.

C. intybus (2n = 18) is a strictly allogamous species for which selfing is strongly hampered by an efficient incompatibility system that prevents inbreeding and promots out-breeding.

The original populations of C. *intybus*, as far as their genetic structure is concerned, could be considered as natural since, independently of their historic background, the production of both Witloof and Radicchio has for long relied on

populations, maintained by farmers for their own use, on which very little selection, if any, might have been applied according to personal criteria. All these populations, obtained by mass selection and maintained through the intercrossing of selected parents, have to be considered highly heterozygous and genetically heterogeneous whose behaviour and level of adaptation to different environments and/or cultural conditions depend on the frequency of favourable genes or gene combinations. As the interest for the edible product grew, farmers' selection criteria became more and more attentive to the consumer's request and most of them elaborated their own ideotype. This brought about a great deal of genetic and morphological differentiation which has been entirely preserved until organized breeding programs have been established, firstly by public institution and, in more recent times, by private firms. As it happens for most cross breeding species, in *C. intybus* detectable heterosis effects are present and hybridisation between selected genotypes give uniform and heterotic progenies; the constitution of F_1 hybrid varieties is thus feasible. Nowadays the situation is quite different between Witloof and Radicchio. Since some years, F_1 Witloof hybrids, released by private seed companies, are on the seed market and the crop is at present mainly based on them, thus determining the complete disappearance of most farmer's populations. In Radicchio, although with some differences among the various types, the major part of the crop is still based on farmer's populations which are yearly selected and maintained and whose seed is usually reutilized on farm but may also be sold through private and not officially registered transactions. These populations are very well distinguishable among types, but they are often recognizable within type as well, on the basis of morphological and physiological characters and agronomic performances, although, at the same time, they present an acceptable phenotypic uniformity among individuals. Regarding their genetic variation, as estimated by genetic analysis performed through the application of appropriately chosen molecular markers, it is a common observation, also applicable to Witloof chicory too (Kiers et al., 2000; Van Stallen et al., 2001), that the major part of the genetic variation takes place within populations, while a minor portion is attributable to among population differences (Barcaccia et al., 2003).

Since this is the plant material which, in recent years, has been representing, and still represents, the starting point for the constitution of new commercial varieties, it seems reasonable to state that, if preserved from extinction, it is an invaluable source of genetic diversity on which chicory breeding may rely for long in the future. It is however expected that F_1 hybrid varieties will be bred and adopted with increasing frequency for Radicchio too. This is particularly true for the types which take an advantage from the uniformity of the marketed product as this is often the key for the customers appreciation.

5.2 Breeding Achievements, Methods and Goals

Productive as well as qualitative traits are main objectives in chicory and endive breeding programs. General and common goals in breeding new varieties mainly concern i) single plant size, weight and yield; ii) resistance to biotic (fungal diseases and insects) and abiotic stresses; iii) adaptation to a specific climatic or agronomic

environment; iv) uniformity of crop maturity; v) good market acceptance regarding extrinsic (color, shape, uniformity) and intrinsic (taste and texture) traits.

C. endivia is a minor crop compared to chicory. Most of the breeding work on this species has been done by private seed companies and, as a consequence, there is not much literature on it. The breeding approach adopted with endive is much the same as with any other autogamous species: selection of superior genotypes a) from genetically variable farmer's populations according to a pure line selection scheme and/or b) from segregating populations derived from crosses between previously selected superior parents, following a pedigree procedure. The first approach resulted in a series of varieties on which the crop almost completely relied at least during the whole first half of the last century. These varieties were often heterogeneous at morphological level and had to be considered as mixtures of more or less homozygous genotypes. Thus, although far from being genetically homogeneous, these varieties could be well differentiated from each other for leaf and head size and shape (Tesi, 1974) and for long represented the basis for the successive selection work which led to improved pure line varieties. Because of the almost complete disappearance of the original farmers' populations and the presence of good commercial varieties, at present breeders largely prefer the second strategy, based on selection within segregating populations, with which a number of favorable traits already present in the parents can be combined in superior genotypes. When selection for the favorable parental traits is made after each selfing, four to six generations might be enough to have genotypes with a sufficient level of fixation to be transferred in field trials and tested in comparison to the existing commercial varieties. It seems obvious that the first generations might be grown in dense stands and are mainly aimed to test the segregating material for traits usually under simple genetic control, like the resistance ones, which allow the elimination of large numbers of individuals. Selection for morphological traits, more strictly linked to productivity and marketable quality, should be made in later generations grown in the field. This last part of the work might cover a variable number of generations according to the urgency to release new varieties. When one or more pure lines are considered superior to the existing varieties, the field testing may be extended to different climatic and agronomic situations in order to define the limits or the general adaptability of the selected material. Thereafter, the initial quantities of commercial seed might be produced and, after inscription in the Register of Commercial Varieties, put on the seed market. Sometimes, although morphologically uniform, a new variety is released while still containing some genetic variation which might let further divergent selection, thus originating a number of rather similar sister varieties. Analogously, a variety might have had a long commercial life and thus, through mutation and repeated multiplication, might have been accumulating genetic changes which, by mean of selection, may produce variants of the original variety. This is a practice much used by seed companies to develop new varieties from publicly developed landmark varieties.

When a variety is outstanding in most respects but lacks a specific trait, particularly when this is under the control of one gene as often occurs with resistance traits, the backcrossing approach can be successfully used for transferring that gene from another variety, a landrace or a wild type, where it might be present, to the

otherwise superior line or variety. Once known as a "surgical" method of breeding in as much as, if correctly applied, it preserves the genetic structure and the agronomic performance of the variety to be improved while introducing into it the desired trait, the backcross method has nowadays been efficiently integrated with more sophisticated procedures which make use of the molecular tools in Marker Assisted Selection (MAS) programs. Although very efficient and largely adopted in many important field crops, this approach needs however a molecular knowledge of the species which is not too difficult to reach but which is still lacking as far as *C. endivia* is concerned.

C. intybus is by far more important than *C. endivia* and has a much more ancient breeding history which goes back to at least eighty years ago, when the first varieties have been bred and sold on the seed market.

As far as Witloof is concerned, the main traits evaluated during selection programs are related to morpho-phenological, agronomic, and organoleptic characteristics. Important features are the time of cultivation, class of earliness, thickness and length of the main root, leaf shape and color, adaptation to local environments, disease resistances, taste and bitterness of edible parts.

As already stated, roots are harvested at the end of the growing season and stored under low temperature until they are forced to produce the leafy vegetable.

The production and quality of heads in Witloof chicory changes during the same season, and between production seasons, depending upon climatic factors, cultural practices, time of harvest, storage and forcing conditions, all of which influence the final yield and quality. However, there is no need to underline that the performance of a cultivar is strictly dependent upon its genetic value which, in turn, may be tightly linked to its genetic structure and thus to the strategy adopted for its constitution.

Traditionally, varieties of chicory were developed by mass selection in order to obtain uniform populations characterized by valuable production and acceptable commercial head size and shape. Newly released varieties are mainly synthetics produced by intercrossing a number of phenotypically superior plants, selected on the basis of morpho-phenological and commercial traits. More rarely, plants are also evaluated genotypically by means of progeny tests. Synthetics have a rather large genetic base and are represented by a heterogeneous mixture of highly heterozygous genotypes sharing a common gene pool.

In recent years, methods for the constitution of F_1 hybrids have been developed by private breeders and seed companies. Details on the procedure for the constitution of such hybrids are not available in the current literature and it may be presumed that each company has developed its own protocol, mainly in accordance to the genetic material it has at disposal and to the possibility of applying a more or less efficient control on the F_1 hybrid seed production phase. As a matter of fact, the strong self-incompatibility system, which hinders obtaining highly homozygous parents, and the absence of a male sterility factor within the species or in sexually compatible species, make it difficult to propose a F_1 seed production scheme and, most of all, to consider these newly commercial varieties as true F_1 hybrids.

Many so called Witloof hybrids are now in production and are highly appreciated by growers for their performances and especially for their uniformity. Some