The Capsicum Crop: An Introduction

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Abstract

Capsicum (*Capsicum* spp.), also called as pepper, is a main vegetable and spice crop originated in the American tropics and today cultivated all over the world for fresh, dried, and processing products. Around the genus *Capsicum* there is an increasing interest and fascination due to the considerable variation for several traits, which makes this crop extremely versatile and suitable for innumerable uses as food and non-food products. The genus *Capsicum* includes over 30 species, five of which (*C. annuum*, *C. frutescens*, *C. chinense*, *C. baccatum,* and *C. pubescens*) are domesticated and mainly grown for consumption. A large number of accessions of domesticated and wild species are stored in the world seed banks, representing a valuable resource for breeding in order to transfer traits related to resistances to various abiotic and biotic stresses as well for quality improvement. The recent advances in terms of genetic and genomic knowledge will help to unlock the potentiality of these resources. In this chapter, we provide an overview of the origin and history of the pepper, describing its economic importance, properties, and commercial market types.

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1.1 Origin and Diffusion

The genus *Capsicum* is part of the large Solanaceae family, which, among the more than 90 genera and 2500 species of flowering plants, includes commercially important vegetables such as tomato, potato, and eggplant. This genus is native to tropical and subtropical America (Hunziker 2001) in a wide region comprising Mexico and northern Central America, the Caribbean, the lowland Bolivia, the northern lowland Amazonia, and the mid-elevation southern Andes, where archaeological evidence suggests use of this spice crop since 6000 BC (Davenport 1970; Basu and De 2003; Perry et al. 2007). At the beginning, fruits were exchanged for black pepper (*Piper nigrum*), a species similar in taste (though not in appearance) although not phylogenetically related to *Capsicum* (Gordo et al. 2012). For this reason, it was incorrectly named "pepper" (Walsh and Hoot 2001).

It was Fuchs, who proposed for the first time in 1543, the botanical term *Capsicum*, which was adopted later in 1753 by Linneo. The name would be the Neolithic derivation of Greek "Capsa," which refers to the peculiar shape of the

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fruit. The crop was firstly introduced in Europe by Christopher Columbus during his travels after the discovery of America in the fifteenth century and later spread to Africa and Asia. Early imported varieties belong to *C. chinense* (Scotch Bonnet or Habanero) which most probably were the most consumed during that time (Walsh and Hoot 2001). The flourishing commercial exchanges of Spanish and Portuguese facilitated the spread of pepper around the globe, with an immediate success due to a well acclimatization in the regions, where they were used as a spice from that part of the population who could not afford to purchase cinnamon, nutmeg, and other spices that are widely used for seasoning and preserving food. To date, the existence of 35 *Capsicum* species is reported (Carrizo García et al. 2016), five of which, namely, *C. annuum*, *C. baccatum*, *C. chinense*, *C. frutescens*, and *C. pubescens* have been domesticated and widespread with different terms depending on the region of cultivation. In Mexico and Central America, the crop is called "chile" which was the ancient name given by local populations of the new world, in American English it becomes "chilli," in Caribbean and countries Latin American countries it is commonly referred to as "ají" and "rocoto," from which derived names of many cultivars of different species today present on the market (i.e., aji Amarillo, aji limon, aji panca, rocoto manzano, rocoto brown, and rocoto de seda). It is also known as pimiento (Spanish), red pepper and pepper (English), pepper (Italian), piment (French), paprika (German and other northern European languages). Overall, the present term "chili pepper" refers to varieties with small and spicy fruits, on the contrary, the term "sweet pepper" refers to varieties with larger fruits and little or no spicy.

1.2 Economic and Culinary Importance

World pepper production has grown considerably over 20 years (1997–2017, www.fao.org/faostat), from 2 to about 4.5 million tons of dry types and from over 17 to 36 million tons as fresh. The area harvested followed a similar trend, with an increase of the surface cultivated area of about 35% in the last 20 years, being today about 3.8 millions of hectares. Fresh pepper is cultivated in 126 countries of the world in all the continents. The world's largest producer is China with over 18 million tons annually, followed by the Mexico with about 3.5 million tons (FAOSTAT 2017). Dry pepper is cultivated in 70 countries and no relevant production is reported in Oceania. India is the largest producer with about 2.0 million tons, followed by Thailand (349.615 tons). Peppers are grown almost all over the world and are fairly easy to cultivate both in the field and in the greenhouse in a wide range of climatic and environmental conditions. Africa, Europe, and America contribute in the same proportion to the total world production (about 10–12% each) for fresh pepper; while for dry pepper, Asia and Africa are the main producers contributing to the 70.3 and 21.2%, respectively (Fig. 1.1). The economic value of pepper production has increased since 1991 becoming a good source of income for producers in many countries and giving an important role in international trading. The present worth of dry pepper is 3.8 billion dollars, while fresh pepper contributes with 30,208 billion dollars. For both, the increase observed over the past 25 years is four times higher in dry pepper and six times higher in fresh pepper.

Around the genus *Capsicum,* there is an increasing interest and fascination due to the amazing diversity in many characteristics, such as plant architecture, flower morphology, fruit typology, colors, pungency, and qualitative traits which make this crop extremely versatile and suitable for innumerable uses. As food, a variety of recipes are ensured thanks to the presence of sweet and hot types. The former are mainly widespread in temperate regions of Europe and North America where they are used freshly or cooked as vegetables. The latter are instead mainly spread in the tropical regions of America, Africa, and Asia, where they are mostly consumed fresh or dried as condiment as spice in powder or salsa in many

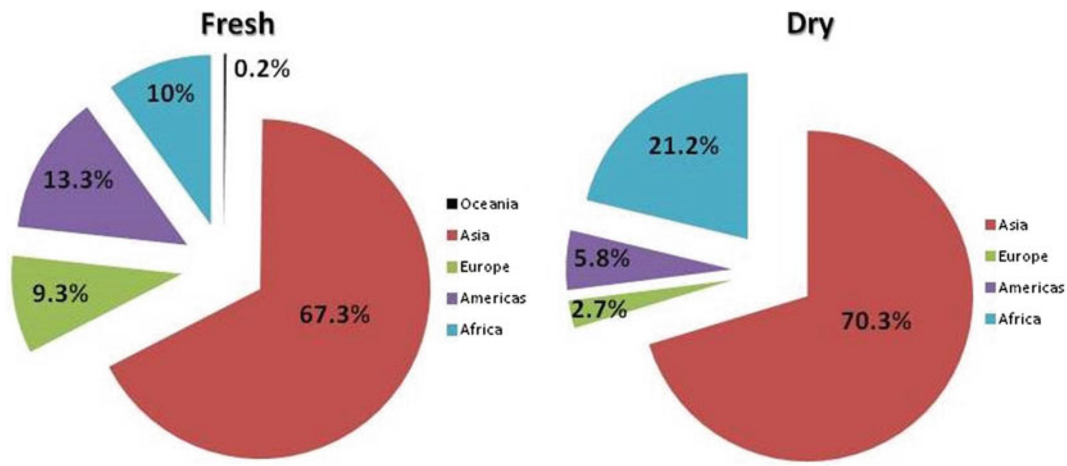

Fig. 1.1 Production share of dry and fresh pepper by region (FAOSTAT 2017)

Fig. 1.2 Examples of popular pod types of hot and sweet peppers. *Photo credit* Susan Lin, World Vegetable Center, Taiwan

dishes. Food uses of peppers could then be summarized in the following classes: (a) fresh use, of immature green fruits, mature red fruits, and leaves; (b) fresh processing, for sauces, pastes, pickles, beer etc.; (c) dried spices, from mature whole fruits and powder (Poulos 1994). Based on pod shape and size, more than 20 market types (e.g. bell, cayenne, ancho, jalapeño, pasilla, Hungarian wax, jwala, and Thai) are commercially cultivated (Fig. 1.2). Furthermore, within each of these market types, there may be several variants; for instance, bell may have blocky, conical, or mini pods and cherry bell may have small or big pods (Fig. 1.2).

1.3 The Properties of Pepper

The uniqueness of pepper is the typical pungency due to the presence of capsaicinoids. Capsaicinoids are secondary metabolites and derivatives of phenylpropanoids produced in placental epidermis cells and accumulated in structures (blisters) located on the placenta surface (Stewart et al. 2007). The hotness sensation when consumed is given by the interaction with vanilloid receptors, supposed to be a mechanism of defense against mammalian herbivory. Capsaicin and dihydrocapsaicin are the two predominant compounds, accounting for almost 90% of total capsaicinoids. Anti-inflammatory, anticancer, and anti-obesity activities have been recognized within capsaicinoids (Luo et al. 2010). These properties are exerted by the release of substance P, a neurotransmitter involved in pain transmission by nerve (Gamse et al. 1981). Peppers are also an extremely good source of compounds exerting antioxidant properties and responsible for fruit pigmentation. Different colors are encountered in mature fruits as a result of accumulation of carotenoids in chromoplasts during ripening such as capsanthin and capsorubin (mainly in red fruits), violaxanthin and neoxanthin (mainly in yellow fruit), and lutein and β-carotene (mainly in orange fruit) (Gómez-García and Ochoa-Alejo 2013). Fruits are further well-known to have played a leading role in the discovery of vitamin C by Albert Szent-Györgyj, who extracted the first pure chemical compound from Hungarian paprika and was awarded Nobel Prize for Medicine and Physiology in 1937 (http://www.nobelprize.org). Indeed, within *Capsicum* species, a high level of ascorbic acid (vitamin C) able to satisfy the recommended daily intake (FDA 2018, attested to 60 mg for 100 g of raw pepper) is commonly found in both sweet and hot types and widely documented in the literature. High contents of other essential vitamins such vitamin A in the form of β-carotene and vitamins of group B (thiamine, riboflavin, and niacin) are recognized. All these compounds, of which content is determined by species, cultivar, environmental conditions, and maturation stage, exert their biological effects protecting cells against oxidative damage through the interaction with oxygen molecules and scavenging peroxyl radicals (Padayatty et al. 2003; Howard and Wildman 2007). Finally, antimicrobial and antivirulence properties, against *Streptococcus pyogenes*, a major human pathogen (Marini et al. 2015) and *Fusarium* infection (Tewksbury et al. 2008) a polyphagous fungus affecting many vegetables, are reported. All these properties make pepper a good candidate against diseases.

Other than food uses are recognized as active ingredient in cosmetics, pharmaceuticals, and pest management (Bosland and Votava 1999). The extractable colors from fruits due to the presence of compounds unique in pepper such as capsanthin, capsorubin, and cryptocapsin are extensively used in the food processing industry as natural colorant for a wide range of products such meats, cheeses, and other foods. Non-food uses include (a) coloring and flavoring agents, from oleoresins (carotenoids) extracts or powder, as example, paprika powder can be used to inhibit lipid oxidation of pork meat while oleoresin is used to enhance physical and sensory properties of food products (Baenas et al. 2019); (b) ethno-botanical/traditional medicine, from fruit extracts and powders (pungent fruits); (c) modern medicine/pharmaceuticals, from extracts of capsaicinoids and carotenoids which can exert analgesic, antimicrobial, antioxidant, and anti-inflammatory effects; (d) insecticides/repellents and antibacterial effect from capsaicinoids extracts and organic acids (i.e., cinnamic, coumaric, ferulic, and caffeic); (e) spiritual, using whole fruits, e.g., "ristras"; (f) ornamental, using whole plants or fruits; (g) defense/punishment, using capsaicin extracts/or powder (Kumar et al. 2006). The use in cosmesis is favored by the presence of natural compounds which allow to avoid allergies and other side effects and are addressed to protect skin oxidative and UVA-mediated damage having thanks to the anti-wrinkle action and fighting against free radicals (Baenas et al. 2019). The industrial preparations are based on oleoresins rich of the above-mentioned bioactive compounds. Finally, among the most curious aspects of the *Capsicum* genus, there is certainly the rampant interest of many, searching and collecting, even in urban contexts, different species, characterized by a wide variety traits, as well as ornamental, aesthetically appreciated or rare varieties. This is evident in the rise of associations and websites dedicated to the subject.

1.4 Genetic Resources and Breeding

The *Capsicum* genome has an estimated size of 3.5 Gb and includes mainly diploid species with 12 chromosome ($2n = 2x = 24$). Within the genus, there are also recognized species with 13 chromosomes ($2n = 2x = 26$) as well as one tetraploid species ($2n = 4x = 48$) which is *C. annuum* var. *glabriusculum*, the wild form of the cultivated pepper. Recent investigations have grouped the *Capsicum* species in 11 clades according to main morphological features, provenance, and phylogenetic relationships (Carrizo García et al. 2016) (Table 1.1). The species of greatest interest for consumption and breeding are in three main clades namely: Annuum which includes three domesticated (*C. annuum*, *C. frutescens,* and *C. chinense*) and two wilds (*C. annuum* var. *glabriusculum* and *C. galapagoense*); Baccatum including three forms of *C. baccatum* (var. *baccatum*, var. *pendulum*, and var. *umbilicatum*) and the wilds *C. chacoense* and *C. praetermisssum*; Pubescens which only includes the homonymous domesticated species.

C. annuum is commercially most popular species worldwide. This species is characterized by pungent and non-pungent accessions with herb or sub-shrub growth and fruits having different size, shape, and colors at maturity. *C. frutescens* and *C. chinense* are mainly cultivated in American, Asian, and African countries. The former includes pungent accessions with fruits predominantly small with less than 2 cm of length, the latter instead comprise accessions highly pungent and irregular shape of fruits. The other two domesticated species (*C. baccatum* and *C. pubescens*) are cultivated in Central and South America and are distinguished by particular phenotypic characteristics such as the yellow or green spots in the corolla (*C. baccatum*) or the dark colored seeds (*C. pubescens*). Several wild species are part of the genus *Capsicum* and are principally distributed in the area of origin (Table 1.1). All of them are characterized by very small oval or spherical fruits (Fig. 1.3) with specific distinctive traits related to flower color (white, yellow, and purple with different type of spots), seed color (brownish or black), and flower shape (stellate, rotate, or campanulate) (Barboza and Bianchetti 2005). Although the uniqueness and beautiness distinguish many species of pepper, most of the breeding activities have been carried out within the Annuum clade due to the lack of interspecific barriers between *C. annuum*, *C. chinense,* and *C. frutescens* (Pickersgill 1997; Perry et al. 2007). However, the incompatibility occurring across clades could be overcome using aids such as embryo rescue. Wild and

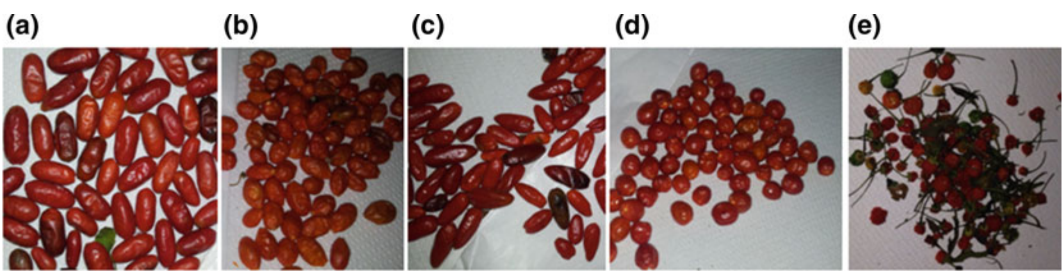

Fig. 1.3 Mature fruits of wild *Capsicum* species: **a** *C. chacoense*, **b** *C. praetermissum*, **c** *C. eximium*, **d** *C. annuum* var. *glabriusculum*, and **e** *C. flexuosum*

Table 1.1 *Capsicum* clades and related species, main features and native area

Clade[a], species name, chromosome number	Pungency	Fruit color[b]	Area of origin[a]
1. Annuum (*x*=12)			
C. annuum	Non-pungent and pungent	Variable	Central and south America regions
C. annuum var. *glabriusculum*	Pungent	Red	Venezuela, central america
C. chinense	Pungent	Variable	Central America, Colombia, Ecuador, south-eastern Brazil, Venezuela
C. frutescens	Pungent	Variable	Central America, central-eastern Brazil, Colombia, Ecuador,Venezuela
C. galapagoense	Pungent	Red	Galapagos Islands
2. Baccatum (x=12)			
C. baccatum var. *baccatum*	Non-pungent and pungent	Variable	Argentina, Bolivia Paraguay, Peru'
C. baccatum var. *pendulum*	Non-pungent and pungent	Variable	Argentina, Bolivia Paraguay, Peru'
C. baccatum var. *umbilicatum*	pungent	Variable	Argentina (north and central), Bolivia (lowlands)
C. chacoense	Pungent	Red	Argentina, Bolivia, paraguay
C. praetermissum	Pungent	Red	South-eastern Brazil
3. Tovarii (x=12)	Pungent		
C. tovarii	Pungent	Red	Perù
4. Pubescens (x=12)	Pungent		
C. pubescens	Pungent	Variable	Argentina, Bolivia, central America, Ecuador, Perù
5. Purple corolla (x=12)	Pungent		
C. cardenasii	Pungent	Red	Bolivia (highlands)
C. eximium	Pungent	Red	Argentina (north and central), Bolivia (lowlands)
C. eshbaughii[*]	Pungent	Red	Bolivia (lowlands)
6. Atlantic forest (x=13)	Pungent		
C. campylopodium	Pungent	Greenish-yellow	South-eastern Brazil
C. cornutum	Pungent	Greenish-yellow	South-eastern Brazil
C. friburgense	Pungent	Greenish-yellow	South-eastern Brazil
C. hunzikerianum	Pungent	Greenish-yellow	South-eastern Brazil
C. mirabile	Pungent	Greenish-yellow	South-eastern Brazil
C. pereirae	Pungent	Greenish-yellow	South-eastern Brazil
C. recurvatum	Pungent	Greenish-yellow	South-eastern Brazil
C. schottianum	Pungent	Greenish-yellow	South-eastern Brazil
C. villosum var. *villosum*	Pungent	Greenish-yellow	South-eastern Brazil

(continued)

Table 1.1 (continued)

Clade[a], species name, chromosome number	Pungency	Fruit color[b]	Area of origin[a]
7. Longidentatum (x=13)			
C. longidentatum	Non-pungent	Greenish-yellow	Central-eastern Brazil
8. Bolivian (x=*)			
C. caballeroi	Pungent	Red	Bolivia (lowlands)
C. minutiflorum	Pungent	Red	Bolivia (lowlands)
C. ceratocalyx	Pungent	Red	Bolivia (highlands)
C. coccineum	Pungent	Red	Bolivia, western Brazil
9. Flexuosum			
C. flexuosum	Non-pungent and pungent	Red	South-eastern Brazil, north-eastern Argentina and eastern Paraguay
10. Caatinga (x=13)			
C. caatingae	Pungent	Greenish-yellow	Central-eastern Brazil
C. parvifolium	Pungent	Greenish-yellow	Central-eastern Brazil, Colombia, Venezuela
11. Andean (x = 12)			
C. rhomboideum	Non-pungent	Red	Central America, Colombia, Ecuador, Perù, Venezuela
C. scolnikianum	Non-pungent	Red	Colombia, Ecuador, Perù
C. geminifolium	Non-pungent	Red	Ecuador, Perù
C. lanceolatum	Non-pungent	Red	Ecuador, Perù, central America
C. dimorphum	Non-pungent	Red	Colombia, Ecuador, Perù

[a]according to Carrizo García et al. (2016)
[b]at maturity stage
*chromosome number not reported

domesticated species have been used particularly for disease resistance and results are widely documented in the literature.

Breeding of pepper, has four main macro-objectives to achieve and related to: (a) main agronomic traits such as yield, fruit features such as color and shape, plant habit, and fruit set; (b) resistances to abiotic stresses such as drought and salinity which limit the cultivation in certain areas; (c) resistances to a plethora of bacterial, fungal, and viral disease causing severe damage to cultivations and loss of quality of the production; (d) quality, for which breeding objectives are mainly related to the improvement of various bioactive compounds such as capsaicinoids, isoprenoids, flavonoids, and vitamin C. The international initiatives aimed to enhance *Capsicum* genetic resources including the progress in breeding and genomics are discussed further in the chapters to be followed.

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