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Foreword

The importance for humanity of peppers of the Capsicum genus began in the Americas thousands of years ago. Crops date back to 7000 years BC in Mexico, Peru, and Bolivia. With the discovery of America by Columbus, peppers, originated in Mexico and Central America, were spread throughout Europe via Spain, becoming a lucrative business for the Spanish. Around the same time, vendors in Mexico City traded different ways of preparing peppers, emphasizing fresh fruits and paprika used in many dishes from Aztec cuisine.

Among domesticated species, such as *C. annuum*, *C. pubescens*, *C. baccatum*, *C. frutescens*, and *C. chinense*, Brazil is the center of origin of peppers belonging to the *C. chinense* species. Several Latin American countries, including Brazil, are listed as first priority in the collection of *Capsicum* germplasm. Amazonia and southeastern Brazil are described as key areas when it comes to exploring the species of the genus. In these areas, there is great variability in fruits, for color, shape, size, and pungency, which still remain unexplored.

In the 1960s, the Universidade Federal de Viçosa (UFV) started a *Capsicum* seed collection program in different geographical regions of the country, on small farms and in the native forests of Brazil. From these collections, the Capsicum's Germplasm Bank was established at UFV, containing the cultivated species and many wild ones. Many of the collected accessions were morphologically and chemically characterized in various masters and doctoral theses at UFV. This collection offers unique and diverse material that helps to analyze the genetic diversity of the genus, which will take years of study in order properly to assess the potential of each accession in the improvement of cultivated peppers.

Currently, in addition to being used as a condiment, peppers are marketed as ornamental plants, opening new frontiers of improvement and selection of cultivars adapted to growing in pots. Ornamental peppers are generally of the *C. annuum* species, adapted to growing in pots by the producers themselves. The possibility of crossing with other cultivated species, in particular *C. baccatum*, *C. frutescens*, and *C. chinense*, opens the possibility of obtaining commercial cultivars that are properly suited to growing in pots. This book addresses cultivation, morphological characteristics for growing in pots, as well as care and physiological factors that interfere with the postproduction of these plants.

In addition, it addresses several practical and theoretical aspects of the cultivation and breeding of peppers, with the participation of researchers and teachers who have been working in these areas. The book's chapters cover different subjects, such as importance and growth, cytogenetics, physiology, and postharvest of pepper fruits, genetics and plant breeding, molecular markers in pepper breeding, and tissue culture. The publication of this book adds new knowledge obtained through research conducted in recent decades.

Vicente Wagner Dias Casali

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Chapter 1
Pepper Importance and Growth (*Capsicum* spp.)

Cleide M. Ferreira Pinto, Izabel C. dos Santos, Fernanda Ferreira de Araujo, and Tania Pires da Silva

Abstract The cultivation of pepper has great importance in all regions of Brazil, due to its characteristics of profitability, especially when the producer and processing industry add value to the product, or its social importance because it employs large numbers of skilled labor. Peppers require monthly temperatures ranging between 21 and 30 °C, with an average of 18 °C. At low temperatures, there is a decrease in germination, wilting of young parts, and slow growth. Plants require adequate level of nitrogen, favoring plants and fruit growth. Most the cultivars require large spacing for adequate growth due to the canopy of the plants. Proper insect, disease, and weed control prolong the harvest of fruits for longer periods, reducing losses. The crop cycle and harvest period are directly affected by weather conditions, incidence of pests and diseases, and cultural practices including adequate fertilization, irrigation, and adoption of phytosanitary control measures. In general for most cultivars, the first harvest starts 90 days after sowing, which can be prolonged for a couple of months depending on the plant physiological condition.

Keywords Crop production • Cultivars • Fertilization • Insect control • Fungal and bacterial diseases

1.1 Socioeconomic Importance of Pepper

Approximately 89 % of total areas cultivated with peppers in the world are located on the Asian continent with the main growing areas located in India, China, Korea, Thailand, Vietnam, Sri Lanka, and Indonesia. The second most important region in

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the cultivation of peppers comprises the United States and Mexico with about 7 % of the total planted, and finally, 4 % of the cultivated area is in countries of Europe, Africa, and the Middle East (Rufino and Penteado 2006). The Thai and South Korean people are the biggest consumers of pepper in the world, consuming 5–8 g per person/day (Ribeiro et al. 2012).

In Brazil, the cultivation of peppers has great importance due to their characteristics of profitability, especially when the farmer adds value to the product, or due to social importance because employs large numbers of skilled labor. In addition cultivation of pepper allows the fixation of small farmers and their families in the countryside. The activity also allows seasonal hiring of labor during the harvest and the establishment of new processing industries, which is the key to the generation of new jobs. The major pepper-producing regions in Brazil are the Southeast and Midwest and, the main producing states are Minas Gerais, Goiás, São Paulo, Ceará, and Rio Grande do Sul. In 2012, the cultivated area with pepper in Minas Gerais was 264.7 ha with a production of 2467.3 metric tonnes. This year, the Central Supply Minas Gerais S/A (Ceasa-Minas), in all units, sold around 960 metric tonnes of fresh peppers (31 % total production), in the amount of US$ 450,000.

The Brazilian fresh pepper market presents various types, names, sizes, colors, flavors, and hotness of fruits. The Pimenta Cumari or Pimenta Passarinho (*Capsicum baccatum* var. *praetermissum*) is most common in the southeast. The Pimenta de Cheiro (*Capsicum chinense*) is the most widely cultivated especially in the northern part of the country, distinguished by a great variety of fruit colors ranging from yellow, milky yellow, light yellow, deep yellow, orange, salmon, red, and even black. Peppers with lower production, but very important, *Capsicum chinense*, is the Pimenta Murupi, whose major producers are located at Amazonas and Pará states. Pimenta de Bode is grown mainly in the western region of Brazil. The Pimenta Malagueta (*Capsicum frutescens*) is grown all over the country, but there are major production areas in the states of Minas Gerais, Bahia, and Ceará. In the latter state, there are large areas for production of Tabasco (Pinto et al. 2006a,b).

1.2 Climate Requirements and Growing Season

Climate factors have great influence on seed germination, development, and fruiting of pepper plants. The pepper requires high temperatures throughout the cycle and as a tropical plant it is sensitive to low temperatures and is frost intolerant. The ideal average monthly temperatures range between 21 and 30 °C, with an average of 18 °C. At lower temperatures, there is a decrease in germination, wilting of young parts, and slow growth. At temperatures above 35 °C, the fruit set is adversely affected, especially with low air humidity or dry winds. Temperature affects the fruit quality, especially the sugar content and vitamin C, as well as the intensity of the red and yellow colors, which are in general greater at high temperatures. Low temperatures can also affect the pungency of the fruit. Reseaches show that fruits of pepper grown in spring and summer are more pungent than those plants cultivated in autumn–winter (Estrada et al. 1999; Kirschbaum-Titze et al. 2002).

In Brazil, the peppers are grown both in hot climates and under cold weather. The sowing season is contingent upon the local climatic peculiarities. In the mountain regions with an altitude above 800 m and mild temperature, sowing is done in the months from August to February; however, a more convenient season is from September to November due to the requirement of the species for high temperatures. In regions with mild winters, especially those of lower altitude (below 400 m), sowing can be done all year around (Pinto et al. 2006a, b).

In the pepper-producing regions of the south and southeast Brazil, from August to January are the months indicated for sowing. In the pepper-producing regions of Minas Gerais state with mild temperature, seeding occurs from August to February, although the most suitable period is from September to November. In the western part of the country, the cultivation of peppers can be done all year. Normally, sowing is done in November, but can extend up to the end of January. In the north and northeast of Brazil, one should avoid planting in the rainy season, which makes the tillage, cultivation, and pest control difficult.

1.3 Soil Preparation and Fertilization

Peppers do not grow well in heavy or compacted soils; the most suitable soils are those of medium (clay–sandy) texture, and sandy soil should be avoided.

Peppers are susceptible to attack by pests and disease; it is not advisable to plant peppers in areas that have been grown in the previous year with tomato, potato, eggplant, gilo, or peppers that belong to the same pepper family. Likewise, planting in areas with pumpkin, squash, and zucchini should be avoided, which can also be sources of pests and diseases. The planting of these crops in nearby areas, as well as planting continuously for years on the same site should be avoided. Crop rotation with corn or beans in alternate years is recommended.

Good soil preparation in needed to facilitate setting and rooting of plants. Sloppy areas should be delimited by contour lines spaced within 20–30 m of each other. Plantlets should be spaced from 1.20 to 1.50 m.

In almost all of Brazil, the soils are generally more acidic than ideal for the development of pepper, which requires pH ranging between 5.5 and 6.5. High acidity of the soil can cause a lot of problems for farming, such as high levels of aluminum or manganese, which drastically reduces production; in lower pHs there is a deficiency of calcium, magnesium, phosphorus, and other nutrients needed for proper growth, development, and yield of plants.

It is common for farmers to neglect proper soil pH correction by liming and they also do not do any chemical analysis of the soil. In contrast, it is common to apply heavy mineral fertilizers in acidic areas, jeopardizing the proper use of supplied nutrients, plant development, and increased cost of production.

It is necessary to apply lime to raise the base saturation to 70–80 % and minimum content of magnesium of 0.8–1.0 to $cmol_c/dm^3$ (Casali and Fontes 1999). The limestone should be applied on moist soil, about 15 days before planting, spread evenly over the area to be planted with incorporation at 15–20 cm deep. When doses are greater than 2 t/ha, it is recommended that 50 % of lime be applied before plowing and 50 % after plowing, and in doses less than 2 t/ha, the limestone must be applied before plowing. The finer the particle size and the higher the neutralizing value of the lime, the greater will be the relative power of full neutralization and the faster will be the effects in the correction of acidity.

1.4 Aspects of Mineral Nutrition and Fertilization in Pepper Plants

The visual symptoms of mineral deficiencies presented by pepper plants are important to diagnose nutritional status in field conditions. Some more specific symptoms of nutrient deficiency in pepper (Monnerat 1984; Balakrishnan 1999) are presented below:

(a) *Nitrogen* (*N*): Symptoms of N deficiency are uniform yellowing of leaves, including the veins, being more pronounced in older leaves. When the persistence deficiency occurs, plants show reduced growth and reduced leaf size. In addition, there is reduction of flowering and fruiting. Deficient plants also have poorly developed root systems. High levels of N can cause excessive growth of the plant canopy, inducing the appearance of apical rot in fruits, especially in the warmer periods.

(b) *Phosphorus* (*P*): Leaves with deficiency can be reduced in size and deeper green color (blue-green) with intervein necrosis in the middle part of fully developed leaves. Browning at the lower portion of the plants and reduced root growth can also occur. Due to the advancement deficiency, irregular interruptions appear on the leaf surface, the edges of older leaves become chlorotic, and severe leaf fall occurs. There are few fruits because of the dropping of flowers.

(c) *Potassium* (*K*): The symptoms of K deficiency are smaller plants with fewer leaves. The upper third of leaves becomes compactly arranged. There are also chlorosis and necrotic scores between the leaf veins. Due to the advancement deficiency, necrosis arises at the edges of the youngest leaves, expanding to the petiole, causing leaf drop. The excess of K reduces the absorption of calcium and magnesium, which makes them more susceptible to the apical fruit necrosis.

(d) *Magnesium* (*Mg*): Plants with Mg deficiency have reduced size. The fully developed upper third leaves become chlorotic and the younger with twisted blades. Due to the advancement deficiency, necrosis can be found between the veins. The fruits have reduced number and size. The root system does not develop normally.

(e) *Calcium* (*Ca*): Plants with Ca deficiency are small, compact, and with a reduced number of leaves. The young leaves have reduced development, becoming wrinkled and curled, and chlorotic in the base and between the veins. Due to the advancement deficiency, the leaves become necrotic and fall because of necrosis of the peduncle. Total drop of flowers may occur and, consequently, no fruiting. There is reduced formation of small fruit and brown staining on the bottom of the fruit.

(f) *Sulfur* (*S*): Plants with S deficiency are short and show yellowing of leaves starting at the base, gradually expanding to the tip. Due to the advancement deficiency, all leaves become yellow and there is no formation of fruits. The leaf blade has a wavy appearance, as if there were an uneven growth of veins and leaf blade. The fruits exhibit a pale green color.

(g) *Boron* (*B*): Plants with B deficiency are small and compact, due to the death of the growing apex. Old leaves become curved inwards and the new leaves are reduced in size, wrinkled at the base, translucent, and apparently thicker. The stems and leaves become brittle. Complete drop of flowers can occur and not fruit formation. The root system is severely affected, being undeveloped, with necrosis in the extremities.

(h) *Iron* (*Fe*): Plants with Fe deficiency show yellowing of younger leaves like the deficiency of S and N, however, the veins of the leaf blade are greener and the plants have higher height and number of leaves than plants with a deficiency in those nutrients. Due to the advancement of deficiency of Zn, all leaves become chlorotic. The fruits develop a pale yellow color.

(i) *Zinc* (*Zn*): Plants with Zn deficiency are small with a narrow leaf blade with discoloration between the veins. Extreme deficiency causes rosette-like plants.

The diagnosis of the symptoms of nutritional imbalance in the field, using the visual method is not always easy and accurate. Due to lack of equilibrated fertilization, more than one symptom often occurs. Leaf analysis of the nutrients helps to solve the nutritional problems (Fontes 2001). Some references on the levels of nutrients in pepper are presented in Table 1.1.

It is common to find, especially in Zona da Mata of Minas Gerais state, most of the pepper farms apply certain nutrients in excess or use unbalanced fertilizer, which can cause loss of fertilizer as well as environmental problems. Additionally, several foliar fertilizers containing nitrogen, which has caused great nutritional imbalances, are applied on the crops (Pinto et al. 2006a, b).

Fertilizer requirements for the culture of pepper should be based on the chemical characteristics of the soil, the type of irrigation used, and expected productivity. Regarding the latter, one should take into account the quantities of nutrients extracted by the crop. As such, amounts extracted are most often unknown; recommendations are usually based on various authors used as references for the addition of nutrients. Often, the amount of fertilizer to be applied at planting is determined based on published reports from some Brazilian states or regions (Table 1.2). Most of these reports are used for sweet pepper (*Capsicum annuum*). The total fertilizer indicated should be evenly distributed in the row.