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‘Cassava, manioc or yuca’ (*Manihot esculenta*): Agronomic aspects

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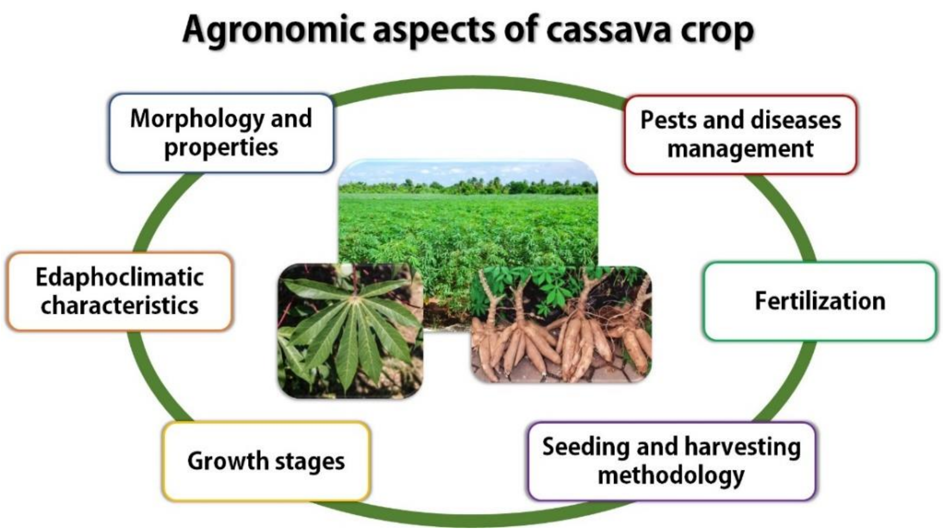
Graphical Abstract



Abstract. *Manihot esculenta*, commonly known as cassava, manioc, or yuca, is one of the largest crops around the world, mainly in tropical and subtropical areas. Its important adaptive characteristics and low requirements for its growth, in addition to its nutritional value, have allowed the growth of its productive and economic development since the middle of the last century. Over time, key agronomic aspects have been established for adequate cultivation of cassava that allows for obtaining high yields and good productivity. Thus, in this review, it was sought to expose and discuss concisely the most relevant agronomic aspects concerning cassava cultivation. Initially, the morphological properties, growth stages, edaphoclimatic conditions, and varieties of cassava were exposed. Subsequently, the seeding process was described, including the selection of the seeds and the preparation of the soil. Also, aspects related to the care and nutrition of crops and soil conservation using fertilizers and the methodologies for pest and pest management were presented. Finally, manual and mechanized cassava harvesting methodologies were discussed, including their differences, advantages, and disadvantages.

Keywords: Agronomic aspects, Cassava cultivation, *Manihot esculenta*, Fertilization, Cassava seeding.

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Content

1. Introduction

Since its domestication several centuries ago, cassava has been one of the crops with the greatest productive development in tropical and subtropical regions around the world. This type of perennial shrub belonging to the *Euphorbiaceae* family has a broad productive and economic development due to the nutritional value of its roots and leaves within human food, animal nutrition, and the production of food derivatives. The high amount of starch in its roots and the load of minerals and vitamins in its leaves have allowed its exploitation as a source of starch, a nutritional resource, and input in different developing countries, mainly in Africa, Asia, and Latin America (Otekunrin and Sawicka, 2019). For this reason, cassava is currently the fifth-largest food staple crop in the world, after corn, wheat, rice, and potatoes (Vilpoux et al., 2017).

In 2018, world cassava production was approximately 278 million tons, with continuous growth in recent years. The largest participation in this production was from Africa, followed by Asia and Latin America, being this way since the beginning of this century. Among the 5 most-producing countries in the world are Nigeria, Thailand, the Democratic Republic of the Congo, Ghana, and Brazil, which have more than 50 % of world production (FAOSTAT, 2020). Despite its growth as a crop, the potential production of cassava has been delayed due to high production costs on an industrial scale, low productivity and yields due to climatic conditions, and inadequate transformation techniques, in addition to low technological development for the improvement of seeding and harvesting techniques (Aristizábal et al., 2007). This, in addition to the short lifetime of cassava, mainly its roots, as food suitable for consumption, has limited its current commercialization. Therefore, the market is mainly focused on neighboring countries and is concentrated in Asia, where Thailand and China have the highest participation in exportations and importations, respectively (Parmar et al., 2017).

Despite the aforementioned limitations, cassava continues to be a crop that has contributed to the economic development of more than 100 countries, in addition to participating in the feeding of its populations. The important properties of this plant, such as its high adaptability to different edaphoclimatic conditions and low requirements for its growth, have allowed its cultivation mainly by small farmers (Brenes et al., 2017). Through its development, different agronomic aspects have been established that are important to consider for optimal cultivation, yield, and productivity of cassava. In this review, the most relevant agronomic aspects of cassava cultivation are briefly presented, beginning with its morphological properties, soil and climatic conditions, and growth, until its seeding and harvesting process, fertilizer employment, and pest and disease treatments.

2. *Manihot esculenta*: morphological, adaptive and growth properties

Manihot esculenta Crantz, or more commonly known as cassava, manioc, or yuca, is a type of perennial shrub that is highly consumed and commercialized in South America, Africa, and Asia. This shrub belongs to the *Euphorbiaceae* family, in which there are approximately 7200 species with a similar characteristic: the development of laticiferous vessels made up of secretory cells of milky substance. More specifically, within the *Manihot* genus there are around 100 species, being *Manihot esculenta* the only one cultivated for several centuries due to its important adaptive properties, its easy cultivation, its nutritional relevance, and its economic value (Aristizábal et al., 2007; FAO, 2013).

2.1. General description and morphology

Morphologically, this plant has a cylindrical stem formed by nodes (union between stem and leaves) and internodes (stem between nodes), as illustrated in **Figure 1**. The stem allows the transport of nutrients to all parts of the plant and serves as seeding material for new crops. The plant can acquire a height between 1 and 3 meters with a stem diameter between 2 and 6 centimeters. Its leaves are long, thick, stiff, and shaped, which are responsible for producing carbohydrates and proteins for the growth and metabolic development of the plant. On the other hand, its flowers are small, simple, and unisexual, through which insect-mediated cross-pollination occurs (Titus et al., 2011).

Importantly, *Manihot esculenta* has two types of roots: one fibrous and the other tuberous. The first type allows the absorption of water and nutrients, while the second type allows the storage of carbohydrates in the form of starch, taking the form of an elongated, cylindrical, conical, fusiform, and irregular tubercle, with a brown

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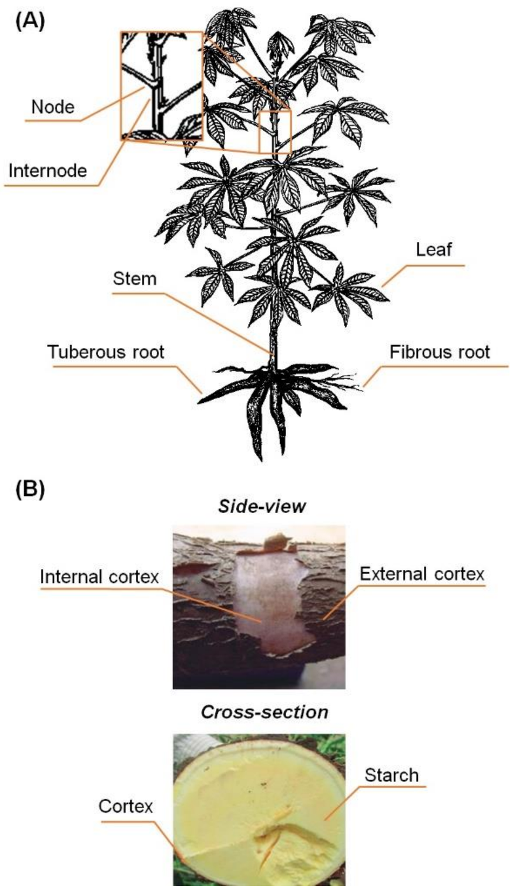

Figure 1. (A) Schematic representation of a cassava plant (Taken and edited from Elfick, 2020) and (B) side-view and cross-section of a tuberous root (Taken and edited from Brenes et al., 2017).

woody outer cortex and a white or pink inner cortex. The tuberous roots can have weights of 1 to 8 kg each one, representing approximately 80 % of the fresh weight of the entire root. Likewise, the tuberous root is the most exploitable part of the plant in economic terms (Brenes et al., 2017).

2.2. Conditions of cassava growth

Cassava presents a wide range of tolerable conditions for its growth. This is why it is cultivated by more than 100 countries around the world, both domestically and on a larger scale of production (de Souza Fernandes, et al., 2019; Lentini et al., 2020).

This type of plant can grow in an optimal temperature range of 25 - 29 °C. Although, any temperature variation can affect the size and number of leaves, in addition to the quantity of carbohydrates in the roots. In this sense, the plant can tolerate even from 16 °C to 38 °C. Temperatures below this range affect the growth of the plant, causing less leaf production, little formation of tuberous roots, and less thickening of these (Anikwe and Ikenganyia, 2018). Additionally, the cassava plant requires 10 to 12 hours of light and is considered a short photoperiod crop. However, this plant can adapt to longer light exposures, since it can carry out photosynthesis as a C_3 plant or C_4 (Brenes et al., 2017).

On the other hand, cassava presents the adaptation to dry and humid zones, although it grows optimally in abundant and well-distributed rain conditions. More specifically, the optimal rainfall is 750 mm to 2000 mm. Even so, the plant can survive in dry periods, but with affected development and yield (Morgante et al., 2020). In long dry periods, foliage shrinkage can occur, woody rings can be formed on the tuberous roots, and yield declines. While, in excess of rain, root rot can occur (Anikwe and Ikenganyia, 2018).

Cassava can grow from sea level up to 1000 meters above. Also, it can grow in diverse tropical conditions, from humid and warm lowland tropics to tropics with cold winters and summer rains. Likewise, although cassava thrives in fertile soil, it can grow in acid soils of low fertility, with sporadic rainfall or long periods of drought (Kristensen et al., 2014). This is a competitive advantage over other types of crops. Additionally, it tends to be recommended not to cultivate cassava for commercial purposes in clayey soils or soils with many stones or other types of obstacles because they do not allow adequate development of tuberous roots (Brenes et al., 2017; Kouakou et al., 2016).

In terms of growth, the development of *Manihot esculenta* can be divided into several stages: (i) slow-growth stage, which includes the lap time from seeding to approximately 60 days after seeding, and it is characterized by the growth of roots, stems, and leaves. The growth of these structures tends to be slow and all the nutrients acquired by the plant are used for its development. Subsequently, (ii) the stage of maximum growth occurs, which is up to 150 days after seeding and includes leaf growth and stem branching. In this stage, the largest amount of biomass is produced in the plant. Also, the process of storage-root formation begins, and then the roots are filling or thickening. Finally, in (iii) the senescence stage, which covers from 150 days to harvesting, results in less growth of stems and leaves, in addition to a reduction in biomass of the superior part of the plant. At this stage, the translocation of photoassimilates to the storage roots is increased (Brenes et al., 2017). **Figure 2** schematically and summarily illustrates the growth stages mentioned, considering an average cultivation time of 12 months. It is important to clarify that the development of cassava can vary depending on the conditions. A short development is achieved in warmer conditions, from 7 to 12 months. While, a longer development is reached in regions of 1300 to 1800 m.a.s.l., with a growth time greater than 12 months (Aristizábal et al., 2007).

2.3. Cassava varieties

Currently, there is a large collection of cassava clones in the in vitro genebank of the International Center for Tropical Agriculture (CIAT). This collection comprises around 6,000 clones of *Manihot*

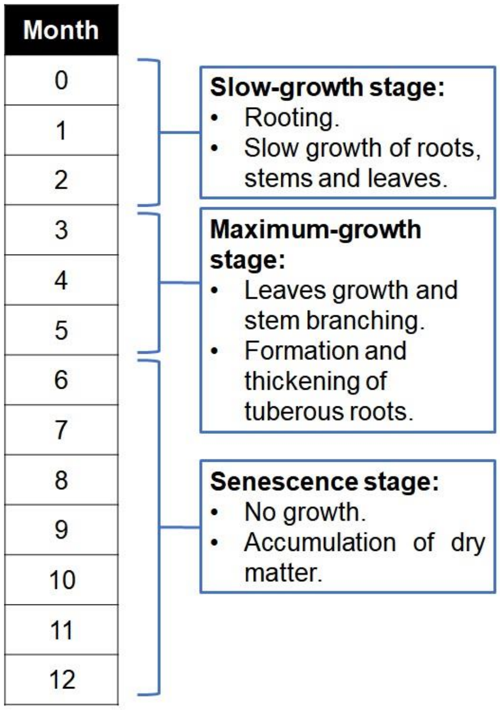

Figure 2. General growth stages of *Manihot esculenta* (Aristizábal et al., 2007; Brenes et al., 2017).

esculenta, which include primitive, improved cultivars, wild species, and genetic material. The collection is the product of the contribution of various countries involved in the production of this plant, such as Colombia, Brazil, El Salvador, Honduras, Nicaragua, the Dominican Republic, Haiti, China, the Philippines, Thailand, Vietnam, among others. Scientifically, these variations are named with a code assigned by the official institution in charge of the germplasm. However, the differentiation of cultivated varieties has commonly been assigned by farmers who cultivate them concerning some special characteristics of the plant or its provenance. For example, in South America you can find cassava "algodonas", varieties that are easy to cook; "llaneras", varieties from the Llanos, "negritas", varieties of stem or dark bud. It is also common to find names assigned by plant breeding institutions corresponding to the release site of the clone or some special characteristics, such as Venezuelan, Panamanian, Brazilian, American, among others (Aristizábal et al., 2007).

Likewise, it is common to distinguish cassava about the presence of cyanogenic glycosides (CNGs), a type of glycoside that, when metabolized by different enzymes in the human body, releases the toxic hydrocyanic acid (Gleadow and Møller, 2014; Vetter, 2000). Depending on the levels of CNGs in cassava, a distinction can be made between bitter cassava and sweet cassava, called *Manihot utilissima* and *Manihot aipi*, respectively. Sweet cassava has low CNGs and is generally consumed after cooking. While bitter cassava has high CNGs content and is considered toxic for consumption without prior treatment, therefore it is used for industrial processes (Oluwole et al., 2007). Although this distinction is very common, it continues to be relative to the content of CNGs and the edaphoclimatic conditions of the crop. For example, fertile soils tend to increase the bitter taste and concentration of CNGs. Bitter cassava is more common in the Amazon and Caribbean areas, while sweet cassava is more frequently found in northern South America (Aristizábal et al., 2007).

3. Seeding process of cassava

In methodological terms, cassava cultivation requires different general stages, which include the initial preparation of the soil, the selection of the seeds, the seeding, some considerations during their development, and finally the harvesting.

3. Soil preparation

Proper soil preparation is essential for optimal plant development and, therefore, good production. This process depends on various factors: climate, soil type, vegetation, topography, degree of mechanization, and cultivation system.

Generally, the soil is prepared in dry seasons to take advantage of the subsequent rains. On the contrary, in areas with a very humid climate, the soil is prepared at the end of the rainy season to take advantage of less intense rains in the development of the roots (Díaz, 2012).

Land preparation begins with the removal of grasses, shrubs, and trees through logging, stump, and sometimes burning. Subsequently, the soil is tilled manually or mechanized. Conventional tillage, with disc plows and heavy harrows, or vertical tillage, using the rigid or vibratory chisel plow, can be used. At this point, it becomes important to prepare the land from 25 to 40 cm deep to obtain disaggregated and clod-free soil, thus facilitating horizontal and vertical root growth (Aristizábal et al., 2007).

Depending on the type of soil and drainage, the soil can be prepared as mounds, ridges, flat, or zero tillage. Drainage determines the size of the mounds and ridges, in addition to the position of the crops. Like corn and legumes, cassava requires good drainage and tends to be planted next to or on top of mounds and ridges, as illustrated in **Figure 3**. These mounds or ridges can have heights of 30-60 cm with a separation of 1 to 2 meters (Anikwe and Ikenganyia, 2018).

3.2. Seeding material

Subsequently, the seeding process of *Manihot esculenta* is carried out using plant stakes, which are simply called "seeds". Stakes are obtained from cuts or pieces of cassava stem and their selection is very important since the health and nutrition of the obtained cassava depend on the selected seeding material. Selection depends on diffe-

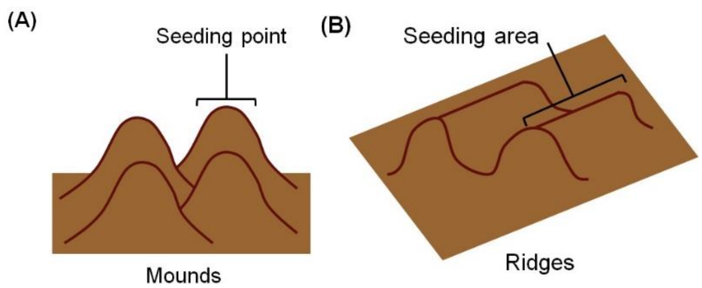

Figure 3. Preparation of the soil for cassava crop in (A) mounds and (B) ridges.

rent aspects, such as stem maturity and thickness, number of nodes, stake size, variety, and health. Likewise, it is important to consider the potential yield, stability, variety, number of ramifications, resistance to pests and diseases, and physiological quality (Aristizábal et al., 2007).

Physiological quality is an aspect of high importance since good cassava genotypes could not express their full potential if the seed is deteriorated and does not germinate properly. Within this, seeds with high nutrient content are needed, since their growth in the first days after seeding will depend exclusively on the nutrients accumulated in the stems, even 40 days after seeding. The age of the seed and its viability are other aspects considered within its physiological quality. It has been determined that cuttings taken from the primary stems or basal part, which is the oldest part of the plant, allow obtaining plants with higher yields than those obtained with cuttings from the apical part, which is the youngest part of the plant. This is related to the higher development and lignification state of the xylem in areas of the plant with older age since this provides a greater amount of nutrients and resistance to dehydration (CLAYUCA, 2015).

Furthermore, viability is related to the amount of moisture within the seed. Once the stake is cut, its dehydration process begins, so if it has low moisture content it will have a faster dehydration process, which is detrimental to its development. For example, a 20 % decrease in moisture content can cause a 50 % reduction in seed sprouting. This aspect has served as a visual indication for an appropriate selection of seeds. With greater viability, there is a faster release of latex from the seed when it is cut. If the latex flows immediately after cutting it means that the stake has enough moisture and therefore it can have good germination. Thus, the stem of a plant aged 10 to 12 months can have a humidity of 70 % and the cuttings produced from it will have a viability of close to 100 % (Aristizábal et al., 2017; CLAYUCA, 2015).

Likewise, the genetic quality of the seed notably influences the crop and yield, being different according to the edaphoclimatic conditions of the seeding sites. Among the genetic factors that affect the production of quality seeds are general vigor and the branching habit. The first is related to the growth of the upper part of the plant and influences the number of branches from which stakes can be obtained. The second is related to the availability of primary and secondary stems. These are used to obtain good-quality stakes. In this sense, different works of crossing and selection of genetic material have been developed to obtain varieties with good adaptation to the conditions of a specific agro-ecological area (Adenle et al., 2012; CLAYUCA, 2015; Ihemere et al., 2006).

Figure 4. (A) Cutting process and (B) obtained stakes from the cassava stem. Taken and edited from Brenes et al. (2017) and Sayre et al. (2011), respectively.

According to the above, stakes are selected from the basal and middle part of the branches, because there is a greater accumulation of reserve substances and have a greater physiological maturity. The optimal size of each stake or seed is 15 to 30 centimeters, having 5 to 6 nodes, in which shoots and roots are generated (Bayiste et al., 2017), as illustrated in **Figure 4**. Stakes with smaller sizes present a low possibility of sprouting due to a smaller number of nodes and nutrients available for seed development. Whereas, stakes with larger sizes present better yields, but greater difficulty for their management (Abass et al., 2014).

3.3. Cassava seeding

Cassava seeding can be done manually or mechanized and it is different in different countries and regions (Anikwe and Ikenganyia, 2018). However, this process contemplates 4 aspects of importance: (i) the depth of seeding, (ii) the length of the stake or seed, (iii) the position of the stake, and (iv) the distance between the seeding points (Aristizábal et al., 2007).

Generally, the seeding depth is 5 to 15 cm for stakes with an average length of 20 cm and 5 to 6 nodes, as mentioned above. Stakes can be seeded vertically, horizontally, or with an inclined position, as shown in **Figure 5**. Stake position has been shown not to significantly affect yield, however, there are some differences from plant development. Thus, vertical seeding sprouts and produces healthy foliage a little faster than horizontal or inclined seeding, and

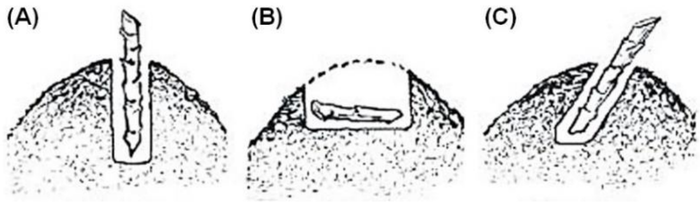

Figure 5. Possible seeding positions of cassava cuttings. (A) Vertical position, (B) horizontal position, and (C) inclined position. Taken and edited from Amposah et al. (2017).

it also reduces plant tipping. While horizontal seeding is recommended in mechanized operations since the roots are separated and this facilitates the harvesting. Besides, the seeding position also depends on the environmental conditions of the growth site. Vertical or inclined seeding is recommended in areas of high precipitation, and horizontal seeding is in dry areas to make the most of the water and avoid root rot in high rainfall seasons (Anikwe and Ikenganyia, 2018). On the other hand, the seeding distance depends on the soil fertility, the seeding season, the variety, the topography of the land, and the climate. Generally, it is carried out at common distances of 80 by 80 cm or 100 by 100 cm, representing seeding densities of 15,000 and 10,000 plants per hectare, respectively (Aristizábal et al., 2007).

In manual seeding, stakes are planted in the direction of the growth of the buds, ensuring that most of them remain under the ground. For this type of seeding, between 6 and 8 days per hectare per day are required. On the other hand, in mechanized seeding, two-line seeding machines are used to place the seed at a standardized depth, in addition to allowing modulation of the distance between the seeding points. This type of seeding can be used on flat land or with ridges. Through machinery, two feeding operators and the tractor driver are required, and up to 5 and 7 hectares are planted per day (Aristizábal et al., 2007; Brenes et al., 2017).

4. Fertilization of cassava crop

One of the most important aspects to consider during the development of the cassava crop is to provide adequate amounts of nutrients to the plant to ensure its optimal growth and enhance its yield (Luar et al., 2018). Cassava is a crop with high nutrient requirements, mainly nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg), in the order K> N> Ca> Mg> P. The cultivation of cassava in soils with a deficiency of this type of nutrients would considerably decrease the yields and quality of the product, so it is recommended to carry out a fertilization process (Temegne and Ngome, 2017). It is estimated that 50 to 100 kg of N, 65 to 80 kg of K, and 10 to 20 kg of P are required annually per hectare to maintain adequate yield and preserve soil fertility (FAO, 2013). Likewise, this process sought to recover, sustain, and increase the productivity of the soils after several cultivation cycles (Biratu, et al., 2019).

Before carrying out this process, it is necessary to carry out a physical and chemical analysis of the plant tissue, the critical level of nutrients in the soil, the identification of nutritional disorders, and the response of the crop to fertilization. This is because the amount and type of fertilizer to be used depend on its efficiency, the balance of nutrients available in the soil, and the requirements of the crop. Thus, the aim is to apply optimal and appropriate fertilizer (Aristizábal et al., 2007; Molina and El-Sharkawy, 1995).

Fertilization can be chemical or organic, depending on the nature of the used fertilizer. Chemical or mineral fertilizers are generally applied one month after seeding and then 60 days after seeding. Examples of chemical or mineral fertilizers used in the cultivation of cassava are urea, single- and triple-superphosphate, di-ammonium phosphate, potassium chloride, potassium sulfate, rock phosphate, lime, gypsum, etc. Among these, there are some more soluble in water than others, which is why it is recommended to apply them when there is good water availability, mainly in sandy soils (Aristizábal et al., 2007; Wilson and Ovid, 1994). These types of fertilizers are applied in bands of 20 to 30 cm with a depth of 4 to 5 cm and at a distance of 5 to 10 cm from the cassava stake. After the application of the fertilizer, it is covered with part of the soil to avoid volatilization of N and loss of nutrients. In this way, the roots grow through the fertilizer band and achieve better absorption of nutrients (FAO, 2013).

According to FAO (2013), the cassava crop should be fertilized with equal amounts of N, phosphorous pentoxide (P_2O_5), and potassium oxide (K_2O), at a rate of 500 kg to 800 kg per hectare and using fertilizer type 15-15-15 or 16-16-16. The continuous cultivation of cassava requires modifications of the balance between the quantities to compensate for the removal of nutrients by the roots, which can be done using mineral fertilizers of type 15-7-20 with N, P_2O_5, and K_2O, or any other with a high content of K and N, and low content of P (Anikwe and Ikenganyia, 2018). Also, it is recommended to apply P at the time of seeding or a little after. Whereas N and K are recommended to be applied in doses, the first one a little after seeding and then 20 or 30 days later, when the cassava plant has reached its maximum growth rate (FAO, 2013).

On the other hand, less soluble mineral fertilizers, such as rock phosphate, lime, gypsum, sulfur, and organic fertilizers, such as organic compost and manure, are applied to the entire growing area before seeding, approximately 20 to 30 days before. This is to achieve optimal contact with the soil and allow adequate inclusion of nutrients in it, either by solubilization or decomposition of the fertilizer. In the case of reduced or zero tillage systems, this type of fertilizer is applied to the bottom of the seeding holes at the time of planting (FAO, 2013). At this point, it is important to highlight that through mineral fertilizers, it is possible to have greater availability of N, K, and P. Organic fertilizers have fewer amounts of these

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nutrients and are less available for use in large crops. However, it has been determined that mineral and organic fertilizers can be used together to enhance the effect on crop development.

Other methodologies that allow for maintaining and improving soil quality have been recommended since fertilization alone would not allow it in the long term for intensive crops. For this, intercropping, mixed crops, the use of crop residues as fertilizer, and alley crops, in addition to the application of organic compost and compost, have been proposed. These types of good agricultural practices in combination with the use of mineral and organic fertilizers have had successful results in the sustainable production of the cassava crop. For example, intercropping has allowed obtaining a substantial improvement in yield, using grain legumes, such as soybean. The fixation of N by this type of crop allows for providing an additional source of nutrients to the cassava (Jongruaysup et al., 2003). On the other hand, the cultivation in alleys with the presence of fast-growing and deep-rooting legume trees, such as *Leucaena leucocephala*, has allowed for significantly improve soil fertility and the obtained yields even without the use of mineral fertilizers (FAO, 2013). Additionally, it has been determined that the association of the cassava plant with soil fungi is possible for greater absorption of nutrients, especially phosphorus, which is used in photosynthesis. This fact has allowed cassava roots and leaves to be obtained with a high nutritional value, due to the storage of nutrients in these parts of the plant (Anikwe and Ikenganyia, 2018).

5. Pest and disease management

On the other hand, different types of pests and diseases for cassava cultivation have been identified, which notably affect yield. For this, it has been necessary to propose different methodologies for their management (Graziosi et al., 2016).

Among the identified pests are cassava green mites (*Mononychellus tanajoa*), red mites (*Tetranychus cinnabarinus*), scale insects (*Coccoidea*), whiteflies (*Aleurotrachelus socialis*), termites (*Coptotermes formosanus*), mealybugs (*Maconellicoccus hirsutus*), long-horned flat-faced beetles (*Lagocheirus obsoletus*), ello sphinx larva (*Erinnyis ello*), among others. **Figure 6** shows some photographs of the effect of some of these pests on different parts of the cassava plant. To solve this, it is sought to maintain a level of low importance for this type of organism, since their presence and high-quality and healthy seeding material can also be cultivated. Also, biological control allows pest control through the deliberate and systematic use of its natural enemies. This is relatively permanent, maintains a good quality of the environment, and avoids the use of pesticides. Control of this type of pest is related to the use of agronomic Among agronomic practices are mixed or intercropping, mixtures of cassava varieties, the destruction of crop residues, and the use of practices, biological control, the resistance of the plant to the host, and the use of pesticides damage will not

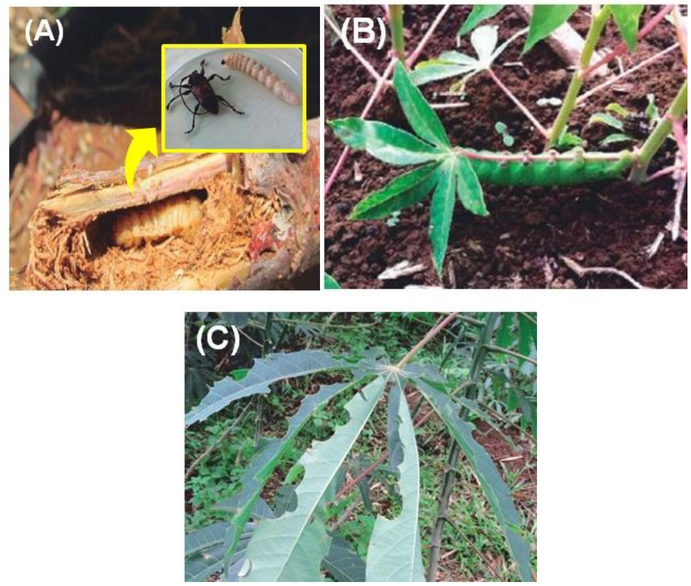

Figure 6. Presence of some pests on the cassava plant. (A) Long-horned flat-faced beetle larva within cassava plant stem, (B) ello sphinx larva on cassava leaf, and (C) defoliation caused by ants. Taken and edited from Brenes et al. (2017).

always affect the production yield of the crop, and the plant can withstand and recover from insect damage. The latter can be effective, but not profitable due to its cost if the loss of performance is not high, in addition to the environmental and possible health impact (Aristizábal et al., 2007). Furthermore, various diseases caused by viruses, fungi, and bacteria have been identified. For example, super elongation (*Sphaceloma manihoticola*), angular leaf spot (*Xanthomonas campestre pv. Cassavae*), white leaf spot (*Phaeoramularia manihotis*), anthracosis of cassava (*Glomerella manihotis*), black root and stem rot (*Scytalidium* sp.), brown leaf spot (*Cercosporidium henningsii*), the common mosaic of cassava (*Potexvirus*), among others. Generally, these diseases are prevented using healthy and resistant planting material, intercrop with corn or sorghum, seed in loose soils, control weeds, fertilize properly, improve soil drainage and plant at the end of rainy periods. While to control these diseases, excess humidity must be reduced in the plantation, eradicate diseased plants, use specific fungicides, eliminate the affected material after harvesting by burning (Aristizábal et al., 2007; Anikwe and Ikenganyia, 2018).

6. Cassava harvesting

Finally, within the cultivation process, the harvest is carried out usually 7 to 15 months after seeding. This depends on the productivity, the dry matter content, the climate, and the state of maturity of the crop. Through this process, the aim is to extract, collect, clean, and pack the tuberous roots. Also, the cutting and selection of foliage and seeds for subsequent crops are carried out.

It is important to note that, in terms of time, sweet varieties are obtained around 7 months, while bitter varieties are obtained at later times, around 12 to 15 months. Harvesting can be done manually or mechanically, depending on the size of the plantation, and it is easier on loose, sandy soils than on heavy, clay soils. For this reason, it is recommended to harvest the cassava before the dry season begins (Aristizábal et al., 2007; Anikwe and Ikenganyia, 2018).

Two stages are included within the manual harvesting: (i) cutting and selection of foliage and seed, in this stage a part of the stem is left attached to the roots for its subsequent extraction; (ii) extraction of roots, in which the cassava roots are extracted and is followed by the collection, cleaning, and packing of these. Likewise, manual harvesting can be carried out in two ways: employing only hand or hand tools. Harvesting by hand is most commonly used on loose or sandy soils, from which the roots can be easily removed. Whereas, hand tools are recommended in soils with a loamy texture that presents compaction problems. In general, these tools allow a better grip and greater force on the stem for its subsequent extraction (Aristizábal et al., 2007).

On the other hand, mechanized harvesting considerably reduces harvesting time, from approximately 8 to 10 days per hectare to 6 hours, and the workers used for this, from 25 to 15 workers. There are two types of cassava harvesting machines on the market: rigid type and flexible type. Both require human action to carry out the harvesting process. Its function is based on breaking the soil at depths of 40 to 50 cm and bringing out the roots. The difference lies in the way of breaking the ground, the rigid type machine uses a V-shaped blade and the flexible type machine uses a fork-shaped tool. However, both types of machines have the same working efficiency (Aristizábal et al., 2007; Anikwe and Ikenganyia, 2018).

Importantly, there is a distinction between manual and mechanized harvesting. The latter entails time savings in the process but it has disadvantages due to some damage to the roots and the subsequent difficulty in separating waste from the soil. For this, the design of effective machinery for the harvesting process is still a challenge for all countries producing *Manihot esculenta*. The delay in development has been highlighted for countries with greater dependence on the production of this crop, for example, African countries such as Nigeria, Ghana, Tanzania, Mozambique, among others (Anikwe and Ikenganyia, 2018).

7. Conclusions

Through this review, it was possible to appreciate the most relevant agronomic aspects of cassava cultivation and its productive development. Due to its adaptive properties, resistance to wide ranges of climatic conditions, and minimum requirements for its growth, cassava is widely cultivated throughout the world, in times of 7 to 15 months. The relative ease of multiplication by vegetative propagation and planting possibilities in different soil types was appreciated. Its domestication for several centuries and the development of genetic engineering have made it possible to obtain different varieties of cassava with better properties and economic value. Likewise, the nutritional care of the crop through the use of chemical or mineral fertilizers together with organic fertilizers has allowed to conserve and improve the quality of the soil, in addition to increasing the yield of cassava production. On the other hand, the recommendation and use of good agronomic practices, such as intercropping, mixed crops, and planting quality seeds, among others, guarantees control and prevention of different pests and diseases of the cassava caused by bacteria, fungi, and viruses. Finally, cassava harvesting was exposed through manual and mechanized methodologies. Emphasizing that the mechanized cassava harvesting methodology continues to be a challenge and, at the same time, an obstacle to further agricultural and productive development of the crop.

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