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Three decades of cassava cultivation in Brazil: Potentialities and perspectives

Tres décadas de cultivo de yuca en Brasil: Potencialidades y perspectivas

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Cassava roots and leaves.

Photo: A.U. Bester

ABSTRACT

Cassava (*Manihot esculenta*) has high phenotypic plasticity, acclimatization, broad adaptability, and resilience under adverse edaphoclimatic conditions. This systematic review aimed to identify factors that determined cassava production in Brazil during the last three decades and direct perspectives for this crop in Colombia. The methodology was based on studies that integrated academic information from different situations (1990-2020), environments, states, groups of researchers and existing scientific evidence. Based on the information, a binary matrix of information was assembled based on the following characteristics: plant density per hectare, soil type, city, state, average air temperature, planting line spacing, plant spacing on the planting line, implantation date, implantation station, harvesting station, productivity per hectare, days for harvest, liming, fertilization, precipitation and climate. During the last 30 years, the productivity of cassava in Brazil has increased, mainly in low-income populations and rural populations. There are prospects for increasing cassava production for fresh sale and industries. This crop is characterized as rustic, highly adaptive, tolerant of water stress and acidic soils, and highly influenced by climate, rainfall, air temperature, and incident solar radiation. Productivity is determined by implantation time, liming, fertilization, density, and plant arrangement.

Additional keywords: *Manihot esculenta*; research; sustainability; human food.

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RESUMEN

La yuca (*Manihot esculenta*) muestra alta plasticidad fenotípica, climática, amplia adaptabilidad y resistencia a condiciones edafoclimáticas adversas. En este contexto, esta revisión sistemática tiene como objetivo identificar cuáles fueron los factores que determinaron la producción de yuca en Brasil en las últimas tres décadas, y orientar cuáles son las posibles perspectivas del cultivo en el país. La metodología para producir esta revisión se basó en estudios que integran la información académica producida en diferentes situaciones (1990-2020), entornos, estados, grupos de investigadores y evidencia científica existente para esta temática. Con base en la información, se ensambló una matriz binaria de información basada en los siguientes caracteres: densidad de plantación por hectárea, tipo de suelo, ciudad, estado, temperatura promedio del aire, espaciado entre línea de siembra, espaciado entre plantas en la línea de siembra, fecha de siembra, estación de siembra, estación de cosecha, productividad por hectárea, días de cosecha, encalado, fertilización, precipitación y clima. Es evidente que en los últimos 30 años se a incrementado la productividad de la yuca en Brasil, principalmente en poblaciones de bajos ingresos y ubicadas en áreas rurales. Hay perspectivas de aumentar la producción de yuca para la venta fresca y la industria. El cultivo se caracteriza por ser rústico, altamente adaptativo, tolerante al estrés hídrico y suelos ácidos, siendo altamente influenciado por el clima, las precipitaciones, la temperatura del aire y la radiación solar incidente. La productividad está determinada por el momento de la siembra, encalado, fertilización, densidad y disposición de la planta.

Palabras clave adicionales: *Manihot esculenta*; investigación; sostenibilidad; alimentación humana.

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INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is one of the older species grown in Brazil and is mainly used for human and animal consumption. Its domestication occurred about 9,000 thousand years ago in the Amazon region, and South America is considered the center of origin and genetic diversity (Alves-Pereira *et al*., 2018). Because it is a source of carbohydrates, it can be consumed fresh or cooked, such as flour, tapioca, starch, and a base for industrialized products (Couto, 2013). This crop is of great importance for food in various segments of the Brazilian population, especially in rural areas with low per capita income (Rizzi, 2011), it is a multipurpose crop that responds to the priorities of developing countries, trends in the world economy and the challenge of climate change (FAO, 2013).

This species has high phenotypic plasticity, acclimatization, broad adaptability, and resilience under adverse edaphoclimatic conditions. It has low production costs and high productivity (Tironi *et al*., 2019). In 2019, Brazil stood out with the production of 18.9 million tons of roots, with an increase of 1.93% over previous years. In contrast, there was a 2.50% reduction in area, with productivity exceeding 15 t ha^{-1} (Conab, 2020). The State of São Paulo is superior to others, with 23 t ha^{-1}; however, some places in Rondônia have yields above 50 t ha^{-1} (EMBRAPA, 2020; Silva, 2008; Luna-Castellanos *et al*., 2018; Pérez-Pazos *et al*., 2018).

The increase in cassava productivity has increased for decades; however, the growth and expansion of the crop is due, both in qualitative and quantitative terms, by factors that can be enhanced through new genetic conformations, cultivar positioning, and crop maximization and management practices. This systematic review aimed to identify factors that determined cassava production in Brazil for the last three decades and direct perspectives of this crop.

MATERIALS AND METHODS

A survey of articles published in the academic literature was carried out for factors that influence cassava productivity in Brazil. The methodology of systematic literature review (SLR) was used as a basis, which integrates academic information produced in different situations (publications from 1990 to 2020), environments, states, groups of researchers and existing scientific evidence. It was based on the initial inclusion criteria: experiments carried out in Brazil published in any language on the main factors that interfere with productivity in cassava crops, using

repositories of public articles for magazines in the databases (websites) SciELO, Science Direct, Scopus, NCBI, Capes Journals and Google Scholar.

To carry out the research, a series of questions was used as the inclusion or exclusion criterion, namely: year of publication; what was the objective of the study?; what was the focus of the study?; where the work was implemented, city, state, and region of the country?; What was the month of implementation?; What season of the year?; What density, and spacing between plants and between lines were used?; What was the average productivity achieved?; What management practices were used, especially if fertilization and liming were carried out?; What are the soil, climate, precipitation, and average annual temperatures of the place? Where was the experiment implantedIjui (Brazil). ORCID; How many days after planting was the harvest carried out and in which season?

Based on the information, a binary matrix of information was assembled based on the following characteristics: plant density per hectare (DEN), soil type (SOIL), city (CIT), state (STA), average air temperature (AAT), planting line spacing (PLS), plant spacing on the planting line (SPL), implantation date (IMP), implantation station (IMS), harvesting station (HST), productivity per hectare (PRO), days for harvest (DHA), liming (LIM), fertilization (FER), precipitation (PRC) and climate (CLI).

The data were submitted to descriptive and frequency analyses to obtain the parameters, mean and or expected value. Afterwards, the characteristics were submitted to Spearman's linear correlation to identify the association between the characteristics of importance, validated by the t test at 5% probability. Then, the binary matrix was submitted to the decision tree machine learning algorithm to define the determinant (independent) aspects for cassava productivity in Brazil in the 30 years of the study (dependent). Statistical analyses were performed using software R.

RESULTS AND DISCUSSION

Cassava is perennial, dicotyledonous, and shrubby, with an indeterminate growth habit (Tironi *et al*., 2019). It is the oldest plant grown in Brazil, sharing the common characteristic of its family: the production of a milky secretion, latex, when the plant is injured (Silva, 2010). It is widely grown in tropical and subtropical regions (Ramos *et al*., 2012). It presents more than 100 species from the southern Neotropics of the United States of America - USA, Central America, Mexico, the Antilles and southern Brazil (Mendoza Flores, 2013), of these, 80 species are concentrated in South America (Gusmão and Neto, 2008), with a large number of species concentrated in Brazil, about 78 species, of which 67 are native (Orlandini *et al*., 2014).

Cassava can have indefinite growth, alternating periods of vegetative growth, storage of carbohydrates in the roots and periods of dormancy, caused by severe weather conditions such as low air temperatures and/or a prolonged water deficiency (Thomas, 2016). It has great adaptive capacity to different edaphoclimatic conditions, such as solar radiation, temperature, photoperiod, relative humidity, rainfall and soil characteristics, where the main drivers of growth are development and productivity (Tironi *et al*., 2019). Domestication is an evolutionary process driven by man to adapt plants and animals to human needs. From this process, two main groups arise within cassava that differ in their toxicity: sweet cassava, which presents low amounts of cyanogenic glycosides, and bitter cassava, which requires processing for detoxification because of the large amounts of cyanogenic glycosides (Valle *et al*., 2004). Domesticated species have a series of morphological changes from their wild ancestors (Fedoroff, and Brown, 2004). These modifications include loss of seed dormancy; increase in the size of fruits and seeds; inefficient dispersion mechanisms (indehiscent pods, for example); more compact growth habit; greater uniformity; reduction of toxic substances; and increase in the number of seeds with inflorescence; etc.

The plant consists of five main parts: the stem, petioles, leaves, roots and fruit. Its stem is an erect subshrub that can be predominantly unique in the vegetative cycle and branched in the reproductive cycle, depending on the cultivar (Moreira and Bragança, 2010). When fully developed, it is woody, brittle, with protruding knots, low or high branching (erect stem), and well-defined internodes. The axilla of the nodes have a bud, which is responsible for the vegetative propagation of the species (Mattos *et al*., 2006). Its color may change depending on the cultivar and age of the plant. The younger parts have green tones, while the older parts may have different colors, with gray being the most common (Tironi *et al*., 2019).

The cassava leaf system is composed of simple leaves, inserted in the stem in alternating-spirals, lobed and long petiolate disposition (Mattos *et al*., 2006). The lobes vary in color, shape, number and size, ranging from light green to dark green and purple. The leaves are incomplete (Mattos *et al*., 2006). The inflorescences are located at the top of the stems, panicles that are 5 to 15 cm in length, with short and acute basal bracts. Their color depends on the cultivar and may be white or yellowish. Its fruit is schizocarpaceous, with three seeds that are globular or ellipsoidal, more or less 1.5 cm wide, with maturation in about 5 months (Tironi *et al*., 2019).

The plant has a pivoting root system with two types of roots: fibrous , which plays a role in fixing and absorbing water and nutrients, and tubers, which store photoassimilates in the form of starch (Figueiredo, 2012). The roots have different shapes, such as cylindrical, cylinder-conical, conical, spindle-shaped or globose. Its size and number depend on the cultivar and the growing conditions. In addition to the tuberous part, cassava has a peduncle that can be sessile, small and large (Cury, 2008). *M. esculenta* cultivation has suffered human interference throughout its evolutionary history in the domestication process of this species, with clonal propagation used for commercial purposes (Martins, 2005). However, cassava continues to reproduce sexually with allogamy, and seeds generated from these crosses are responsible for promoting genetic variability, enabling the selection of genotypes of greater agronomic importance by breeders (Ebertz and Palomino, 2017). Vegetative propagation occurs by planting cut stems from mature plants, vertically, inclined or horizontal. This method is the most used because seed propagation is not very productive, with a precarious germination power (Cury, 2008).

Within the characterization of the evaluated parameters (Fig. 1), the average productivity for the last thirty years (Fig. 1C), pointing the highest with approximately 61 t ha^{-1}, four times higher than the national average, which is 15 t ha^{-1} (Conab, 2020), however the lowest was 6 t ha^{-1}, a condition found in many Brazilian cities. 71% of the surveys had productivity above the national average.

Planting density is one of the most studied variables because of its influence on cassava productivity (Aguiar *et al*., 2011b). However, there is variation between the densities used throughout Brazil, depending on the purpose of the plant's final use, whether for human, animal or industrial consumption. The densities for the last 30 years have varied from 1,000 to 28,000 plants/ha (Fig. 1A).

The production of tuberous roots is directly influenced by the photosynthetic capacity and, consequently, by the leaf area index. Thus, the interception of solar radiation is the main determining factor for optimal density (Figueiredo, 2014). Therefore, the spacing between plants and between rows is adjusted so that the plant density is between 10,000 and 15,625 plants/ha (Tironi *et al*., 2019). However, the growth habit, the size of the grown plants, and the edaphoclimatic factors need to be taken into account when choosing the number of plants most suited to local conditions (Lopes *et al*., 2010).

In the survey carried out between the years 1970 and 2020 (Fig. 1A), 44% of the works were within this optimum density, demonstrating the maximum use of solar radiation with maximum productivity. However, there was cultivation with 16,667 and 15,625 plants/ha, representing 22 and 6% of the samples, respectively. Effects from density vary according to the cultivar and the distance between plants and between rows. These factors act directly on plant height, stem diameter, top, number of leaves and root yield (Silva *et al*., 2013). It should be noted that, the lower the fertility of the soil is, the greater the density of plants is, and, the greater the fertility is, the lower the density is because plant growth capacity and management maximize productivity.

The use of higher densities allows for faster closing of the canopy, controlling weeds and providing higher productivity because of a greater number of plants per unit area (Silva *et al*., 2012). However, the LAI and leaf duration are shorter, the roots are reduced in size, and the stems are thinner (Streck *et al*., 2014; Tironi *et al*., 2019). Smaller densities provide lower productivity; however, larger roots are preferable by the market and industry. According to Aguiar *et al*. (2011b), the percentage of commercial roots increased with a reduced planting density, from 33 to 43% of commercial roots in relation to total production, with a reduction in the population from 20,000 to 5,000 plants/ha.

An essential factor for the yield of cultivars is the harvesting season: an early harvest means lost productivity because maximum accumulation of dry matter is not reached (Mendonça *et al*., 2003), and a late harvest reduces sensorial and culinary qualities,

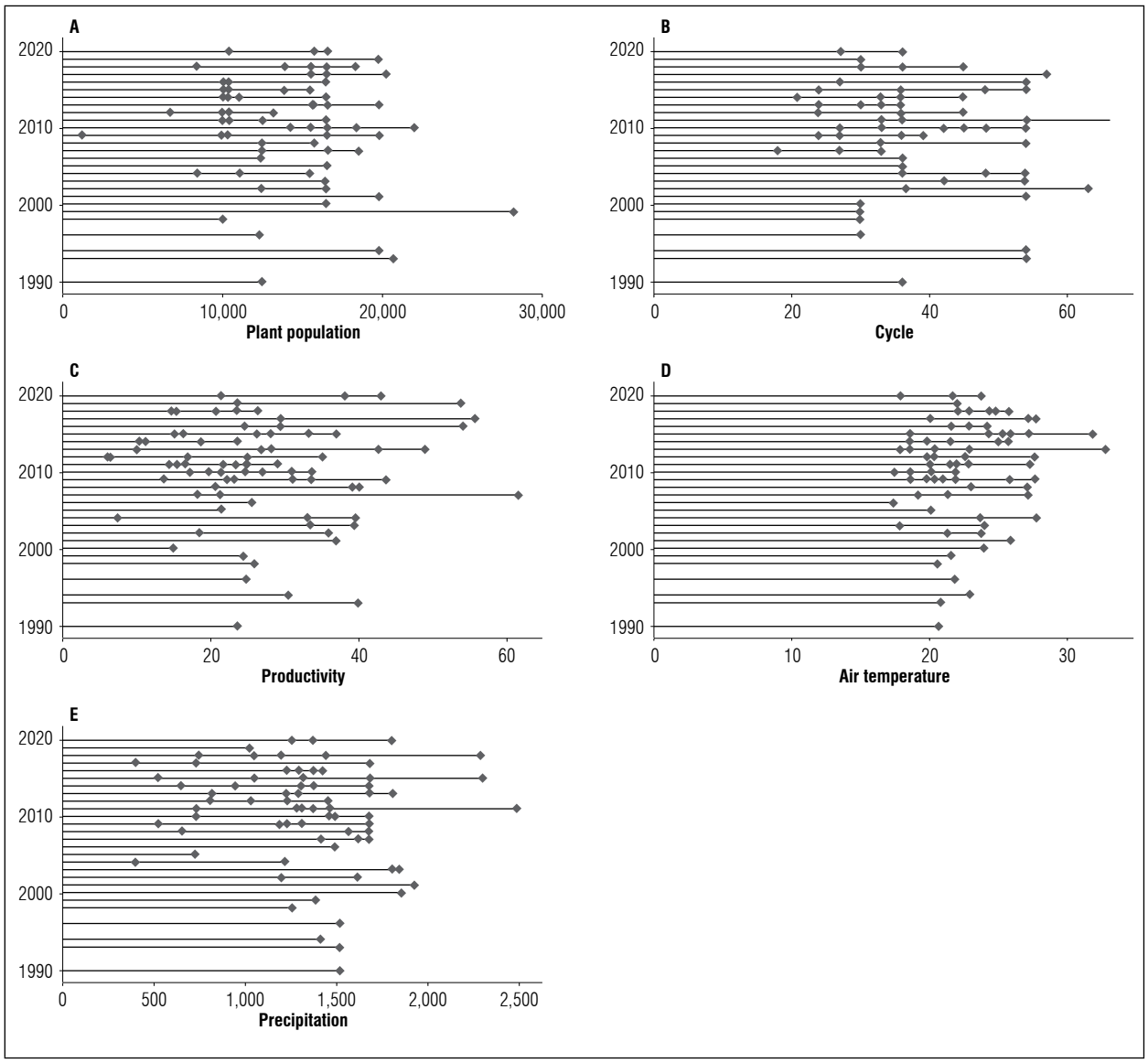

Figure 1. Effect of the year on plant population (A), cycle (B), productivity (C), average air temperature (D), precipitation (E).

i.e. increase in stiffness of the root, greater difficulty peeling the film and the cortex, and formation of small white spots inside the pieces, preventing water from penetrating, resulting in total starch gelation (Oliveira and Moraes, 2009), along with longer cooking times and a higher percentage of fibers (Petri *et al*., 2018).

Cassava is preferably harvested after completing a vegetative cycle of from eight to fourteen months after planting (Aguiar *et al*., 2011a), that is, 240 to 420 d. When evaluating the cycle of cultivars (Fig. 1B), most of the experiments were carried out within this standard, about 55%. The other 45% used more than 420 d or less than 240, 42 and 3%, respectively. Approximately half of the studies showed losses in productivity because the harvest advanced or reduced sensory and culinary qualities because the harvest was too late. However, if the objective is shoot production, Sagrilo *et al*. (2002) reported that, until 14 months after planting, the production averages of the total shoot remained constant, increasing until 17 months, with values approximately 50% higher than at the beginning of the harvest.

Productivity is influenced by several factors, such as management, climate or soil but especially cultivars (Vieira *et al*., 2015), soil management (Filho *et al*., 2000), nutritional management (Alves Filho *et al*., 2015), cover plants (Otsubo *et al*., 2008), planting density (Tironi *et al*., 2019), harvest time (Mendonça *et al*., 2003), implantation time (Fagundes *et al*., 2010) pruning time (Aguiar *et al*., 2011a), weed control (Biffe *et al*., 2010), rainfall (Matos *et al*., 2016), temperature, photoperiod, and air humidity (Cury, 2008). One of the main factors influencing growth and productivity in cassava is temperature. This plant does not grow in places with temperatures below 15°C. This crop has a preference for higher temperatures; however, it does not support temperatures higher than 35°C (Cury, 2008). The optimum temperature is around 30°C, and sprouting stems benefit from soil temperatures around 28 to 30°C (Tironi *et al*., 2019). The studied regions (Fig. 1D) had base temperatures between 15 and 35°C; however, only 11% approached the optimum temperature of this crop.

Cassava plants have an inherent tolerance to prolonged water stress because of various physiological mechanisms that allow them to withstand months without rain (Carvalho *et al*., 2016). This species compensates for the lack of water with a reduction in the leaf surface and a fibrous root system, providing a greater absorption area (Cury, 2008). The crop is capable of presenting good yield, up to 400 mm year^{-1}; however, higher yields need 1,000 to 1,500 mm year^{-1} (Tironi *et al*., 2019). Because no studies have been carried out in regions where rainfall is less than 400 mm year^{-1} (Fig. 1E), 44% of the research carried out is within the range of precipitation for high productivity, 17% had rainfall below 1,000 mm year^{-1} , and 39% had rainfall greater than 1500 mm year^{-1}. Excess water in the soil may delay the development phase and increase the risk of root rot, especially in the accumulating starch phase (Tironi *et al*., 2019).

The Pearson's correlation coefficients (Fig. 2) showed that, when changes in plant density (DEN) occurred, there was a positive association with crop productivity (PRO), line spacing (PLS) and spacing between plants (SPL). Results for this influence on productivity were reported in studies found by Cury (2008), Aguiar *et al*. (2011b) and Tironi *et al*. (2019). Density modifications and changes in the spacing between plants or between rows can also adjust the density according to planting conditions under adverse climatic conditions: where the planting will be late, a higher density is used to prevent productivity losses. For line spacing (PLS), a significant effect was observed for the SPL and DHA variables, with a relationship between spacing between plants and between lines. Therefore, the spacing was directly linked to the purpose of the product: feeding human, animals, industry, or starch production. For days to harvest, the greater the spacing was, the greater the interval between planting and harvest because of the increase in spacing, providing a greater area for the development of the root system, so that the crop can remain longer in the field, also providing greater production and accumulation of starch.

The soil (SOL) had a significant correlation with the variables LIM, FER, and PRC, mainly because of the chemical characteristics of the different soils, i.e. a high concentration of micro and macronutrients and a balanced pH. The production system used by most growers does not use liming and fertilization. If the nutrient and pH contents are not adequate, soil management is carried out. Being a low pH tolerant crop and having good productivity without using fertilizer. Responding well to fertilization and liming, with great return on productivity, since the crop has a high rate of nutrient extraction. Alves *et al*. (2012) stated that the use of fertilization can provide excellent gains in cassava productivity.

For precipitation (PRC), the chemical characteristics of the soil and the physical characteristics must be considered since precipitation is one of the factors of soil formation. Regions with a high annual rainfall index tend to have poorer soils chemically, mainly because of leaching of nutrients to the lower layers, others, more compacted by the impact of raindrop and with erosion problems; however, these problems can be solved by correct management of the soil: correction, fertilization and soil cover. Precipitation is a major factor in changing soils chemically or physically, improving or worsening characteristics. For harvest season, the soil influences physical characteristics, such as porosity, since well-drained soils do not cause problems, maintaining crops longer in the field. If the soil is poorly drained and shows compaction, the harvest must be carried out before the rainy season so that root rot does not occur. In a study by Lopes *et al*. (1978), high soil moisture, linked to high temperatures, was the main factor for the appearance of root rot.

When the variable city was evaluated, it was associated with IMS, IMP and STA, as expected since the time of implantation (IMP) is directly related to the

region. The conditions of the regions (climatic, latitude, longitude and altitude) will determine the ideal implantation time, taking into account that in the south Brazil, cassava is implanted in the spring, from August to December, because of the risk of frost; in the north, it is implanted in the summer until the end of autumn, from the months of December to May, according to the Climatic Risk Agricultural Zoning (ZARC), which considers cycle and phenological class, thermal cut-off limit, available water capacity, index of satisfaction of water and soil needs.

The variables AAT, CLI and PRC showed a positive relationship with each other throughout Brazil in a wide variety of climates with different regional characteristics. The north of the country has an equatorial rainy climate. In the northeast, there is low rainfall, with a hot climate. The south region presents rains all year round, with low temperatures.

In order to maximize cassava productivity in Brazil, figure 3 shows the decision-making tree, which has the average productivity in t ha^{-1}, together with the number (n) of articles with these averages (within the squares). For decision making, the following criteria were included: density (DEN), average air temperature (AAT), productivity (PROD), harvest days (DHA), and precipitation (PRC). To interpret the implantation months (IMP), it was necessary to establish that they range from January (1), February (2) to December (12), that the harvest seasons (HST) are in winter (1) summer (2), autumn (3) and spring (4), and that the regions of the country (REG) are north (1), northeast (2) south (3), southeast (4) and midwest (5), which are represented by numbers in the decision-making tree.

When the density was below 9,167 plants/ha (Fig. 3), there was lower productivity. At lower densities, the definition of production levels is given by the harvest season. When the implantation occurred in season <3, including summer and winter, production was low (8.7 t ha^{-1}); for season >3, autumn and spring, the level of production was medium, with productivity at 24 t ha^{-1}. According to Aguiar *et al*. (2011b), high yields can be obtained by combining high population densities and long growing periods; low densities obtain higher commercial yields.

At densities greater than 9,167 plants/ha, medium and high values were observed for productivity. The average air temperature was a decisive factor. Temperatures below 22°C and time of implantation ≥4 (April to December) showed lower production than

DEN	SOIL	CIT	STA	AAT	PLS	SPL	IMP	IMS	HST	PRO	DHA	LIM	FER	PRC	CLI	
	0.0054	0.046	-0.18*	0.048	0.44***	0.35***	-0.24*	-0.14	0.034	0.23*	0.19*	-0.0039	0.12	0.031	-0.033	DEN
		0.1	*0039	-0.0056	-0.078	-0.16	-0.061	0.035	-0.21*	-0.094	-0.18*	0.23*	0.2*	0.23*	0.075	SOIL
			0.35***	-0.076	0.17*	0.15	0.2*	0.23*	-0.091	-0.11	0.094	-0.13	0.11	-0.16	0.13	CIT
				-0.068	-0.088	-0.064	0.071	-0.062	-0.089	0.051	-0.083	-0.099	-0.024	0.03	0.021	STA
					-0.024	0.07	0.087	0.053	0.074	0.025	-0.037	0.019	0.011	0.61***	0.2*	AAT
						0.79***	-0.059	-0.041	0.052	-0.0054	0.24*	0.038	0.13	-0.11	-0.1	PLS
							-0.015	0.009	0.0073	0.024	0.12	-0.13	-0.042	-0.1	-0.067	SPL
								0.6***	0.21*	-0.024	0.14	-0.029	0.024	-0.13	0.12	IMP
									0.086	0.044	0.06	0.036	0.083	0.056	0.1	IMS
										0.11	0.56***	-0.058	-0.057	-0.038	-0.14	HST
											0.17*	-0.16	-0.17*	0.031	-0.12	PRO
												0.06	0.11	-0.033	-0.11	DHA
													0.75***	0.076	0.063	LIM
														0.037	-00089	FER
															-0.11	PRC
																CLI

Figure 2. Pearson's correlation coefficients, obtained in the correlations between the variables studied in *M. esculenta*. Density (DEN), soil (SOIL), city (CIT), state (STA), average air temperature (AAT), line spacing (PLS), line spacing (SPL), month of implantation (IMP), station of implantation (IMS), harvest season (HST), productivity (PROD), days to harvest (DHA), liming (LIM), fertilization (FER) precipitation (PRC) and climate (CLI). * significant at $P \leq 0.05$ by the t test; * significant at $P \leq 0.01$ by t test.**

the high densities (13 t ha^{-1}). Implantation times less than 4 (January to April) -take into account the implantation region when it is ≥4, southeast and central west- average production of 18 t ha^{-1}. However, if the region is less than 4, days for harvesting (DHA) less than 435 d average production of 22 t ha^{-1}, were considered. If DHA is >435 d, production of 32 t ha^{-1} is considered. Studies by Sagrilo *et al*. (2002) demonstrated that cultivars with more than one cycle (>435 d) have higher yields of tuberous roots, up to 80% higher than crops with only one vegetative cycle. Temperatures above 22°C and precipitation less than 996 mm have productivity that tends to be medium (19 t ha^{-1}). However, if rainfall greater than 996 mm occurs, there are high yields, related to the harvest season, greater than 1 (summer, autumn and spring) present productivity of 34 t ha^{-1}. Harvest stations less than 1 (without definition of harvest season) have a yield of 25 t ha^{-1}. According to Tironi *et al*. (2019), even though it is tolerant to water stress, cassava requires 1,000 to 1,500 mm year^{-1} and a temperature close to 30°C for high productivity.

The cassava crop has been gaining prominence over the years. According to the United Nations survey, world production corresponded to 280 million tons in 2012, an increase of 60% in relation to 2000. For global average yields, there was an increase of almost 1.8% per year in the last decade (FAO, 2013).

Production in the last 47 years in the main producing countries has increased 195%, reaching 291 million tons in 2017. The African continent represented more than half of the global production, 177 million tons. Brazil had a 40% drop in production, from 30 million tons in 1970 to 18.8 million tons in 2017; however, it presented the highest production in South America.

Brazil led the world in root production until 1991, when it was surpassed by Nigeria; in 2014, Brazil was ranked fourth, with a production of 23 million tons. Nigeria remained the world's largest producer with a total of 56 million tons, followed by Thailand, Indonesia, Brazil, Democratic Republic of Congo and Ghana (Conab, 2017).

The Brazilian production of cassava root reached 26 million tons in 2006, 2007, and 2009; however, in the last four harvests, there has been a high reduction in the production of this root in Brazil, around 13%. In the 2016 harvest, production was 23 million tons, with a harvested area of 1.55 million hectares; in 2017, the harvest was 20% lower, with a production of 18 million tons, where the main cause was a reduction of the planted area in most Brazilian states. In the 2020 harvest, production reached 18.9 million tons, with an average productivity of 15.24 t ha^{-1}. Para was the state with the highest production, 3 million tons, followed by Parana and Bahia, with 3 and 1.17

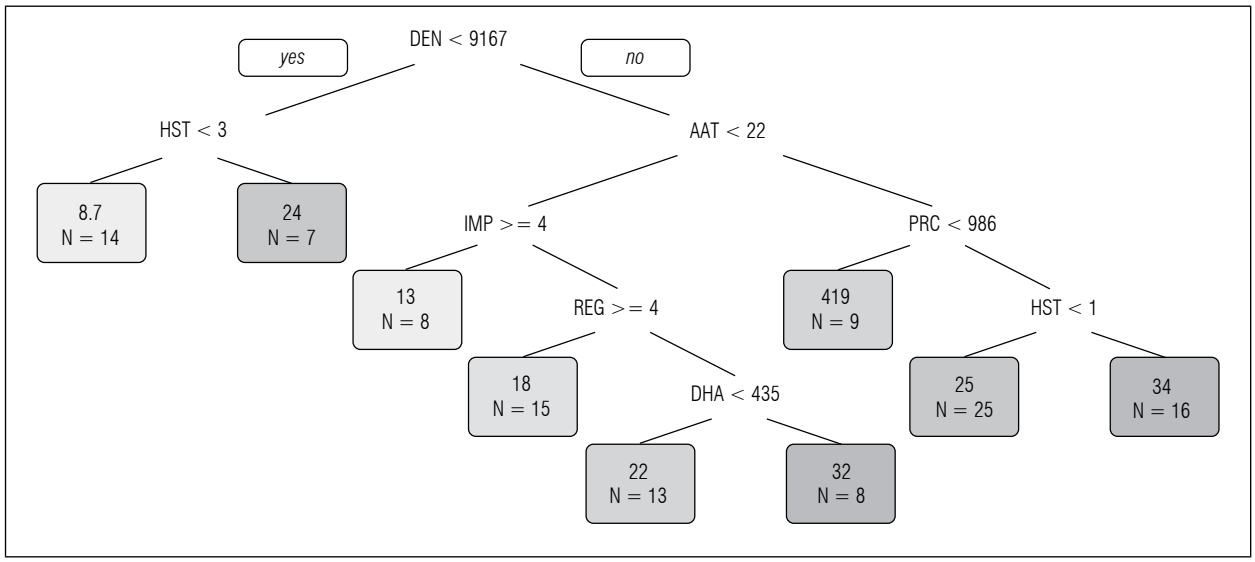

Figure 3. Decision tree that helps to understand the variability of productivity, according to density, harvest season, average temperature, precipitation, implantation, region and days to harvest in cassava crop. Density (DEN), average air temperature (AAT), month of implantation (IMP) is from January (1); February (2) ... December (12), harvest season (HST) (winter (1); summer (2); autumn (3); spring (4)), productivity (PROD), days to harvest (DHA), precipitation (PRC) and region of the country (REG) (north (1); northeast (2); south (3); southeast (4); central west (5)).

million tons, respectively; together, these three states represent almost half of the domestic production.

Productivity in Brazil has had a significant increase in the last 18 years, going from 13 to 15 t ha^{-1}. The north region had an increase of 11%, the northeast had a decrease of 17%, the southeast had an increase of 2.4%, and the south region had a significant increase, from 18 to 21 t ha^{-1} (Embrapa, 2020). According to data from IBGE (2018), the northeast had the largest harvested area, approximately 422,000 ha, and the highest production, 6 million tons; however, the south had the highest productivity, with an average yield of 21 t ha^{-1}. Brazil saw a drop of 6 million tons in production, from 1970 to 2015, a reduction of 500,000 ha; however, the yield per area increased by 0.6 t, with an improvement in cultivation practices (Embrapa, 2020).

Cassava is one of the main crops that will guarantee human food in the future because of its rusticity, high productivity and high adaptive capacity. In the coming years, profound changes can occur in world agriculture if humanity continues to follow the current path (Coimbra, 2013).

In the last 200 years, the concentration of carbon dioxide (CO_2) has increased by 27% in the atmosphere (Pacheco and Helene, 1990). The relative contribution of CO_2 to the greenhouse effect is 60%, resulting in one of the main causes of an increased average temperature on Earth (Júnior *et al*., 2004). CO_2 is the primary substrate for photosynthesis, so, an increase in the concentration of this gas means an increase in crop productivity. However, the increase in temperature will bring serious losses to food production, canceling out all the benefits of the high concentration of CO_2 because of the shortening of the crop cycle and the energy expenditure for maintaining respiration (Gabriel *et al*., 2014). A study by Vale (2017) claimed that the cassava area will increase in the coming years because crops such as soy, rice and coffee are affected by the increase in temperatures, and their areas are being reduced. They also indicated that cassava adapts better than other crops to increases in temperature, which is why it is grown practically throughout Brazil, with numerous climatic variations.

Even though it is a crop of great economic and cultural value that is responsible for feeding millions of people, there is little research on cassava, this is reflected in the low productivity in Brazil, about 15 t ha^{-1}, even though this crop can produce up to 60 t ha^{-1}. Cassava is the third most consumed starch source in the world, behind rice and corn, with the potential of becoming a very important crop that can result in rural development, food security with lower prices in the market, and substitutions for wheat in the production of flour and ethanol.

CONCLUSION

In the last 30 years, cassava productivity in Brazil has increased in most regions of the country.

Even though this crop is characterized as rustic, highly adaptive, and tolerant to water stress and acidic soils, its productivity is highly influenced by climatic conditions (precipitation and air temperature), time of implantation, liming, fertilization, density and disposition of plants, and days per harvest.

Conflict of interests: The manuscript was prepared and reviewed with the participation of the authors, who declare that there exists no conflict of interest that puts at risk the validity of the presented results.

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