CAROLINA SANTOS BENJAMIN

PHYSIOLOGY, BIOMETRY AND MINERAL NUTRITION OF COCOA CLONES CULTIVATED IN FULL SUN

Tese apresentada à Universidade Federal de Viçosa, como parte das exigências do Programa de Pós-Graduação em Fitotecnia, para obtenção do título de *Doctor Scientiae.*

Orientador: Luiz Antônio dos Santos Dias

Coorientadores: Samuel Vitor Martins
Edson Márcio Mattiello

VIÇOSA - MINAS GERAIS
2021

Ficha catalográfica elaborada pela Biblioteca Central da Universidade Federal de Viçosa - Campus Viçosa

T
B468p
2021

Benjamin, Carolina Santos, 1987-
Physiology, biometry and mineral nutrition of cocoa clones cultivated in full sun / Carolina Santos Benjamin. – Viçosa, MG, 2021.
1 tese eletrônica (58 f.): il.

Orientador: Luiz Antônio dos Santos Dias.
Tese (doutorado) - Universidade Federal de Viçosa, Departamento de Agronomia, 2021.
Inclui bibliografia.
DOI: https://doi.org/10.47328/ufvbbt.2021.201
Modo de acesso: World Wide Web.

1. *Theobroma cacao* L. 2. Ecofisiologia vegetal. 3. Plantas - Nutrição. 4. Análise foliar. I. Dias, Luiz Antônio dos Santos, 1957-. II. Universidade Federal de Viçosa. Departamento de Agronomia. Doutorado em Fitotecnia. III. Título.

CDD 22. ed. 633.74

Bibliotecário(a) responsável: Renata de Fátima Alves CRB6/2578

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APROVADA: 19 de outubro de 2021

Assentimento:

Carolina Santos Benjamin
Autora

Luiz Antônio dos Santos Dias
Orientador

A minha filha **Laura**, que representa o meu amor mais puro e verdadeiro.

Ofereço

Ao meu pai **José Roberto Benjamin**, por tantas décadas dedicadas a cacauicultura e de quem eu me orgulho muito de ser filha.

Dedico

AGRADECIMENTOS

À Universidade Federal de Viçosa e ao Departamento de Fitotecnia pela minha formação e por todo o conhecimento adquirido.

À Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Código de Financiamento - 001, pelo apoio neste trabalho.

Ao Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), pela bolsa de estudos e auxílio financeiro.

À Fazenda Três Lagoas, em especial ao proprietário Vanderlei Ceolin e ao gerente Adriano Terci, por viabilizar essa pesquisa.

Ao meu orientador, Professor Luiz Antônio, por todo suporte didático e emocional ao longo do desenvolvimento dessa tese e, principalmente, pelo seu lado humano que sempre esteve acima de qualquer outra coisa nessa relação orientado/orientador.

Ao meu coorientador, Professor Samuel Vitor Martins, pela enorme contribuição intelectual ao longo do trabalho, além dos palpites e conselhos sempre ricos e amistosos.

Ao meu coorientador, Professor Edson Marcio Mattiello, pela amizade e suporte durante o meu doutorado.

Ao Dr. Carlos Aucique, por todos os ensinamentos, principalmente referentes ao IRGA e pela ajuda e paciência na condução dos experimentos de campo.

Ao meu marido e grande conselheiro, Wedisson, por todos os ensinamentos e principalmente pelo amor e dedicação a nossa família.

A minha filha Laura, que nasceu junto com essa tese e me trouxe as maiores lições de vida.

Aos meus pais, Jose Roberto e Grasiela, pelo apoio e incentivo.

As minhas irmãs, Rafaella e Bettina, a minha sobrinha e afilhada Valentina, a minha irmã do coração Luciana, e aos meus cunhados Ricardo e Magno, por trazerem tantas risadas, carinho e amor ao longa de toda minha trajetória.

Aos queridos amigos e colegas que Viçosa me presenteou, em especial: Lucas Rosmaninho, Tássia, Isabela, Samyra e Thalita, pela amizade e companheirismo.

Aos colegas do Laboratório de Agroenergia, pelo convívio e apoio sempre que requeridos.

Minha eterna gratidão a todos que, de forma direta ou indireta, tornaram possível a realização e conclusão deste trabalho.

BIOGRAFIA

CAROLINA SANTOS BENJAMIN, filha de José Roberto Amorim Benjamin e Grasiela Loureiro Santos Benjamin, nasceu em Itabuna- BA, em 10 de outubro de 1987.

Em agosto de 2005, iniciou a graduação em Engenharia Agronômica pela Universidade Estadual do Sudoeste da Bahia, em Vitória da Conquista, BA, concluindo o curso em agosto de 2010.

Em agosto de 2010 iniciou o mestrado em Produção Vegetal na Universidade Estadual de Santa Cruz, em Ilhéus, BA, concluindo o curso em agosto de 2012.

De 2013 a 2014 trabalhou como Docente do Curso de Educação Profissional Técnica de Nível Médio em Agronegócio na Casa Familiar Rural de Igrapiúna, em Igrapiúna, BA.

Em 2014 ingressou em um intercâmbio no *Wake Techninal Community College*, em Raleigh, North Carolina, EUA.

Em 2015 foi bolsista de inovação técnica da FAPESB na Comissão Executiva do Plano da Lavoura Cacaueira (CEPLAC), em Ilhéus, BA.

Em março de 2016, ingressou no Programa de Pós-Graduação em Fitotecnia da Universidade Federal de Viçosa (UFV), como aluna especial e foi bolsista do Laboratório de Fertilizantes, no Departamento de Solos da UFV.

Em março de 2017, ingressou no Doutorado do Programa de Pós-Graduação em Fitotecnia da Universidade Federal de Viçosa (UFV)

RESUMO

BENJAMIN, Carolina Santos, D.Sc., Universidade Federal de Viçosa, outubro de 2021. **Fisiologia, Biometria e Nutrição mineral de clones de cacaueiro cultivados a pleno sol.** Orientador: Luiz Antônio dos Santos Dias. Coorientadores: Samuel Vitor Martins e Edson Marcio Matiello.

O cultivo do cacaueiro a pleno sol busca a modernização tecnológica e aumento da produtividade da cultura, porém, pouco se conhece sobre esse novo modelo de produção. Assim, esse trabalho teve por objetivos: i) caracterizar seis clones de cacaueiro (PS 1319, CCN 51, CCN 10, SJ 02, CP 49 e PH 16), cultivados a pleno sol em Linhares, no norte do estado do Espírito Santo quanto à fisiologia, estrutura foliar, produtividade e biometria de frutos e sementes; ii) estabelecer a faixa de suficiência nutricional atraves de análise foliar e exportação de nutrientes desses 6 clones de cacaueiro. A avaliação fisiológica e de estrutura foliar ocorreu por meio de medições de trocas gasosas, fluorescência da clorofila, concentração de pigmentos cloroplastídicos, área foliar específica (AFE), densidade estomática (DE) e rendimento quântico potencial do fotossistema II - Razão *Fv/Fm*. A produtividade foi estimada pela contagem e pesagem de frutos e sementes sadias. Para a biometria de frutos e sementes foram avaliados: peso (PF), comprimento (CF) e diâmetro de fruto (DF), peso fresco da casca (PFC), peso úmido da semente (PUS), número de sementes (NS) e peso individual de semente seca (PISS). Para a amostragem foliar foram escolhidas, ao acaso, quatro plantas de cada clone, das quais foram coletadas quatro folhas diagnósticas por planta. Já para a amostragem de frutos, foram colhidos 10 frutos maduros e sadios por clone, e realizada a separação da casca e amêndoas. Após o preparo das amostras foliares e de frutos, estas foram encaminhadas ao laboratório para a quantificação dos teores de nutrientes minerais. Após verificar o alto rendimento dos clones e a distribuição normal dos dados, as faixas de suficiência adequadas foram estabelecidas considerando $\mu \pm \sigma$. O experimento foi analisado como classificação hierárquica e para cada um dos seis clones foram demarcadas, aleatoriamente, 14 parcelas que foram compostas por 1 planta cada (unidade experimental). Os clones apresentaram diferenças nas avaliações de trocas gasosas e os valores de fotossíntese líquida (*A*) encontrados foram superiores aos valores médios da literatura, o que sugere uma aclimatação à intensidade de luz dos clones cultivados a pleno sol. Além disso, sob elevada intensidade luminosa, os valores de razão *Fv/Fm* indicaram ausência de fotoinibição. Houve diferenças significativas para todos os parâmetros de biometria, exceto

PF, demonstrando expressiva variabilidade para a produção de frutos e sementes.Os clones apresentaram alta produtividade de amêndoa seca (1200 a 2900 kg ha^{-1}) e as diferenças entre clones nos teores de nutrientes, para os diferentes compartimentos foram esperadas, tendo em vista a variação de produtividade entre os materiais. As faixas de suficiência adequadas para cada clone representam uma primeira aproximação em condições de cultivo a pleno sol no Brasil. A exportação de nutrientes pela casca foi alta, apresentando potencial de utilização como fertilizante orgânico quando retornadas para cultura. Já a exportação pelo fruto de alguns nutrientes reforçou a importância da reposição nutricional via adubação, para que não ocorra redução da fertilidade natural do solo. Por fim, o cultivo intensivo de cacaueiro a pleno sol demonstrou alto potencial de produção.

Palavras-chave: *Theobroma cacao* L. Ecofisiologia. Nutrição de planta. Diagnose foliar.

ABSTRACT

BENJAMIN, Carolina Santos, D.Sc., Universidade Federal de Viçosa, October, 2021. **Physiology, Biometry and Mineral Nutrition of cocoa clones cultivated in full sun.** Adviser: Luiz Antônio dos Santos Dias. Co-advisers: Samuel Vitor Martins and Edson Marcio Matiello.

The cultivation of cocoa in full sun seeks technological modernization and yield increase; however, very little is known about this new production model. Thus, the aim of the present study was to: i) characterize six cocoa clones (PS 1319, CCN 51, CCN 10, SJ 02, CP 49 and PH 16), grown in full sun in Linhares, in the north of the state of Espírito Santo, regarding their physiology, leaf structure, yield and biometrics of fruits and seeds; ii) establishment of a nutritional sufficiency range through a leaf analysis and nutrient exportation of these six cocoa clones. The physiological evaluation and of the leaf structure took place by means of measurements of gas exchanges, chlorophyll flourescence, concentration of chloropastidic pigments, specific leaf area (SLA), stomatal density (SD) and potential quantum yield of photosystem II - Fv/Fm ratio. Yield was estimated by counting and weighing healthy seeds and fruits. For the biometrics of fruits and seeds, the following were evaluated: weight (LW); fruit length (FL) and diameter (FD), fresh weight of the shell (FWS), wet weight of the seed (WWA), number of seeds (NS) and individual weight of dry seed (IWDS). For the leaf sampling, four plants of each clone were randomly chosen, from which four diagnostic leaves were collected per plant. As for the fruit sampling, 10 ripe and healthy fruits were collected per clone and the separation of the shell and almonds was carried out. After the preparation of the leaf and fruit samples, they were sent to the laboratory for the quantification of the contents of mineral nutrients. The evaluation of almond yield was performed during the main and intercrop seasons and, for each clone, the healthy fruits and their seeds were collected, counted and weighed. After checking the high yield of the clones and the data normal distribution, the adequate sufficiency ranges were established considering $\mu \pm \sigma$. The trial was analyzed as a hierarchy classification, and for each one of the six clones, 14 plots were randomly plotted, each one composed of 1 plant (experimental unit). The clones presented differences in the evaluations of gas exchanges and the *A* values found were higher than the mean values in the literature, which suggests acclimatization of the clones grown in full sun to light intensity. Moreover, under high light intensity, the values of the *Fv/Fm* ratio indicated the absence of photoinhibition. There were significant differences for all the parameters of

biometrics, except for LW, demonstrating expressive variability for the production of fruits and seeds. The clones presented a high yield of dried almond (1200 to 2900 kg ha^{-1}) and the differences among clones in the contents of nutrients for the different compartments were expected, due to the variation of productivity among the materials. Adequate sufficiency ranges for each clone represent a first approach in conditions of cultivation in full sun in Brazil. The nutrient exportation by the shell was high, presenting potential for use as an organic fertilizer when returned to the culture. As for the exportation of some nutrients by the fruit, it reinforced the importance of nutritional replacement via fertilization, so that the reduction of the soil natural fertility does not occur. Finally, intensive cultivation of cocoa in full sun showed high production potential.

Keywords: *Theobroma cacao* L. Ecophysiology. Plant nutrition. Leaf diagnosis.

SUMÁRIO

GENERAL INTRODUCTION

The cocoa plant (*Theobroma cacao* L.) belongs to the Malvaceae family and the Malvales order and it is one of the 22 species in the Theobroma genus (Arguello et al., 1999; De Almeida and Valle 2007). It is thought to have originated in the upper Amazon basin (Soria, 1966; Zhang et al., 2008, 2012) and then spread to tropical lowland areas. The dried cocoa seed of its fruits is the basic raw material for the manufacture of chocolate, various kinds of confectionery, cocoa butter, and products for the pharmaceutical and cosmetics industries (Souza et al, 2016). However, from the seed to chocolate there is an extended chain of production, which involves from producers to buyers, processing industries, chocolatiers and finally consumers. That chain involves about 60 billion dollars annually (Rosenblum, 2006).

The current geographic center of cocoa production in the world includes three areas: the west coast of Africa, which is the world's largest producer, mainly Côte d'Ivoire, Ghana, Nigeria and Cameroon; South America, especially Brazil and Ecuador; and Asia, led by Indonesia and Malaysia (Midlej & Santos, 2012). In 2019, the world cocoa production was 5.6 million tons, with Côte d'Ivoire accounting for 39.0% of that production, followed by Ghana (14.5%), Indonesia (14.0%), Nigeria (6 .3%), Ecuador (5.1%), Cameroon (5.0%) and Brazil (4.6%), the seventh largest producer. Those countries account for about 88.4% of the world production (FAOSTAT, 2020).

In Brazil, cocoa is a significant source of agricultural income in the states of Rondônia (RO), Amazonas(AM), Pará (PA), Mato Grosso (MT), Espírito Santo (ES) and Bahia (BA). Pará (49.3%) and Bahia (45.1%) are the main national producers, while Espírito Santo has a 4% share of national production (CONAB, 2019). In Espírito Santo, the cocoa production is concentrated in the north of the state, mainly in the municipality of Linhares, with an area of 20.3 thousand ha where cocoa is cultivated (Silva et al., 2012).

Despite that large production, the cocoa region in the state of Espírito Santo has a high water deficit and for this reason cocoa is grown in full sun, in flatter areas (Souza et al, 2016). Also, the combination of irrigation and mechanization of cultural treatments helps to improve production. Besides, the exposure to the sun has affected the infestation caused by the *Moniliophthora perniciosa* fungus, and some studies indicated a significant increase in cocoa productivity, above 3 t/ha, under conditions of higher light incidence and selection of high technology (Zuidema et al., 2004; Leite, 2012).

In order to support that new way to produce cocoa in full sun additional research on nutritional requirements and nutrient export, physiology, productivity and selection of genotypes tolerant to higher light intensities is crucial. In general, for that condition, there is an increase in leaf gas exchange due to the decrease in stomatal conductance (*gs*) and mesophilic resistance to CO_2 flow, increased transpiration (*E*) and net photosynthesis (*A*). In addition, there is a greater demand for mineral nutrients in the soil and, consequently, there is an increase in the production of carbohydrates and fruit filling, resulting in an increase in the production of almonds (Almeida & Gattward, 2018).

Therefore, the lack of data justified this research, which intended to evaluate the performance of six cocoa clones (PS 1319, CCN 51, CCN 10, SJ 02, CP 49 and PH 16), commercially cultivated in full sun. This research evaluated the physiology, leaf structure, yield, fruit and seed biometrics, nutritional requirements and nutrient export. Thus, the bundle of these data exemplifies a first step for Brazil to start to recognize the importance of nutritional management, physiological aspects, biometrics and productivity of cocoa trees in full sun.

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Chapter I. Yield of Cocoa Clones Grown in Full Sun

ABSTRACT

Cocoa (*Theobroma cacao* L.) has a great socio-economic importance and chocolate production, its main by-product, mobilizes around 60 billion dollars worldwide. Cultivation in full sun seeks technological modernization and yield increase; however, very little is known about this new production model. Thus, the aim of the present study was to characterize six cocoa clones (PS 1319, CCN 51, CCN 10, SJ 02, CP 49 and PH 16), grown in full sun in Linhares, in the north of the state of Espírito Santo, regarding their physiology, leaf structure, yield and biometrics of fruits and seeds. The physiological evaluation and of the leaf structure took place by means of measurements of gas exchanges, chlorophyll flourescence, concentration of chloropastidic pigments, specific leaf area (SLA), stomatal density (SD) and potential quantum yield of photosystem II - *Fv/Fm* ratio. Yield was estimated by counting and weighing healthy seeds and fruits. For the biometrics of fruits and seeds, the following were evaluated: weight (LW); fruit length (FL) and diameter (FD), fresh weight of the shell (FWS), wet weight of the seed (WWA), number of seeds (NS) and individual weight of dry seed (IWDS). The clones presented differences in the evaluations of gas exchanges. In general, the net photosynthetic rate per unit of leaf area (*A*), the transpiratory rate (*E*) and the internal CO_2 concentration in the leaf (C_i) were superior for PH 16 and PS 1319. The *A* values found were higher than the mean values in the literature, which suggests acclimatization of the clones grown in full sun to light intensity. Other factors also contributed to this acclimatization, such as water and nutrient availability via fertirrigation and adequate plant architecture. Moreover, under high light intensity, the values of the *Fv/Fm* ratio indicated the absence of photoinhibition and adjustments were identified in the photo-chemical apparatus, such as a smaller ChT:Car ratio in clone PH 16. As for SD and SLA, there was a difference among the clones. Thus, SJ 02 presented a higher value of SD, while CCN 51 presented a higher value of SLA. However, despite the variability in physiology and leaf structure, none of the parameters evaluated showed a correlation with almond yield. There were significant differences for all the parameters of biometrics, except for LW, demonstrating expressive variability for the production of fruits and seeds. Yield ranged from 1220 kg ha^{-1} (CCN 10) to 2900 kg ha^{-1} (CCN 51). Hence, properties with cultivation in full sun have high yield potential, confirmed by clone CCN 51, when allying handling with availability of water and nutrients.

Keywords: *Theobroma cacao* L. Ecophysiology. Photosynthesis. Light. High technology.

1. INTRODUCTION

Cocoa (*Theobroma cacao* L.) is a dicotyledonous, belonging to the Malvaceae family, native of the Amazon forest, and spread along the humid tropical forests of South and Central Americas (Dias, 2001). The species is grown in several countries, having great economic and social importance worldwide. The production of chocolate, for instance, one of the main cocoa products, mobilizes about US$ 60 billion annually (CONAB, 2017). In addition, cocoa is very important for the cosmetic industry and for other foodstuffs industry (Almeida & Valle, 2007).

Brazil is the seventh cocoa producer in the world rank. In the crop season of 2019, the country produced about 259 thousand t of almonds, in almost 600 thousand hectares of harvested area (IBGE, 2019). It is grown in eight Brazilian states: Pará, Bahia, Espírito Santo, Rondônia, Roraima, Mato Grosso, Tocantins and Minas Gerais. Pará (49,3%) and Bahia (45,1%) are the main producers (IBGE, 2018). Espírito Santo has a participation of 2,6% in the Brazilian production, approximately 7 thousand t of almonds; cocoa is the second most grown fruit species and the municipality of Linhares is the greatest state producer (Leite, 2018).

Dating back to its original conditions, cocoa is traditionally grown under natural shading, in understories of tropical forests (Souza et al. 2016). Some advantages of this production system are less modification of the natural environment, higher air humidity, less light incidence, more moderate temperatures and with fewer fluctuations (Lobão et al., 2002), contributing to the maintenance of a greater stomata opening and, if light is not limiting, higher photosynthetic rates (Araújo e Deminicis, 2009). Nonetheless, high humidity in shadowy environments propitiates pathogen proliferation; the *Moniliophtora perniciosa* fungus stands out, which causes *witch's broom*, the main disease of the culture, responsible for causing a great economic and social impact on the cocoa regions in the south of Bahia and north of Espírito Santo (Luz et al., 1997).

Besides the high incidence of *witch's broom* in the shadowy cultivations, in many cases making the system unfeasible, there is also the complex shadow effect. Although cocoa is a typically shadowy species (Guers, 1985), low light intensity reduces its yield (Dias, 2001). In view of this, the stimulus for the cultivation of this species in full sun has been increasing, and some studies have demonstrated that production responds to light increase positively (Zuidema et al., 2004). In this new growing condition, yield above 3 t ha^{-1} (Leite,

2012) has been achieved, that is, up to ten times more than at the shadowing conditions, making this activity highly promising.

It is known that plant survival capacity is directly linked to the regulation of the photosynthetic process, which is directly influenced by the light available (Taiz and Zaiger, 2016). This way, knowledge on the effects of light intensity over the photosynthetic process and the responses of the plants towards the variations of environmental conditions may guarantee their adequate development and survival (Mengarda, 2009). These responses to the increase of light intensity may occur either at a leaf level, involving the acclimatization of the photosynthetic machinery, or at whole-plant level, resulting in the change of growing standards and allocation of photo-assimilates (Chazdon et al., 1996). Thus, it is assumed that cocoa exposed to higher light intensity may increment its rates of CO_2 fixation, leading to positive changes in its production components.

Additionally, knowledge on some features of fruits and seeds of these clones in this new growing environment is vital for the species breeding. The constitution of production factors might be related to the distribution of photo-assimilates or concern the final quality of the product, as, for instance, seed weight and the seeds weight per fruit (Santos et al., 2012). This way, for the success and consolidation of this new production model it is necessary to know, above all, the behavior of the clones for their adequate handling. In face of what has been shown, the aim of this work was to evaluate the performance of six cocoa clones (PS 1319, CCN 51, CCN 10, SJ 02, CP 49 and PH 16), commercially grown in full sun, regarding their physiology, leaf structure, yield and biometrics of fruits and seeds.

2. MATERIAL AND METHODS

2.1 Clones, Trial and Growing Conditions

The trial was carried out in Fazenda Três Lagoas (lat 19°17'28.3" S. long 40°10'13.3" W, 75 m alt), in Linhares, ES. According to the Köppen classification, the region has an Aw humid tropical climate, with a dry winter, annual average temperature of 23,5°C and annual average rainfall of 1291 mm (Alvares et al., 2013). The predominant soil class of the region is the fluvic Cambisol (IBGE, 2016).

The evaluations were carried out between February 2018 and February 2019, comprising the intercrop season (May to June) and the main crop season (October to January) of the culture in that region. Six cocoa clones were studied (PS 1319, CCN 10, CCN 51, PH

16, SJ 02 and CP 49) implanted in the propriety for 8 years, in the spacing of 3,5 x 2,5 m, drip fertirrigated and in full sun. As the cultivation was already implanted in the area, it was not possible to establish a classical statistical design; so, for each one of the six clones, 14 plots were randomly plotted, each one composed of 1 plant.

2.2 Climatic Monitoring

The climatic monitoring of the trial was carried out from data of rainfall, radiation and temperature collected from a meteorological station (E 5.000/IRRIPLUS model), installed between January and December 2018, near the trial.

2.3 Gas Exchanges

The analyses of gas exchanges were carried out in a closed system with a portable infrared gas analyzer - IRGA (LI-6400XT, LI-COR Inc., Lincoln, EUA) coupled to a fluorometer (LI-6400XT, LI-COR Inc., Lincoln, EUA), configured for photon flux density (PPFD) saturation of 1.000 µmol m^{-2} s^{-1}, with the leaf chamber adjusted under CO_2 concentration of 400 µmol mol^{-1}, temperature of 25 °C ± 1 °C (intercrop season) and 28 °C ± 1 °C (main crop season). The measurements were carried out in a standardized way, making use of the third leaf completely expanded from the apex of the orthotropic stem; one leaf per plant of six plants of the plots was randomly selected. In each selected plant, 6 measurements of gas exchanges were carried out, as well as the potential quantum yield of photosystem II (*Fv/Fm* ratio).

The evaluations of CO_2 assimilation or net photosynthesis (*A*, µmol m^{-2} s^{-1}), stomatal conductance (g_s, mol m^{-2} s^{-1}), transpiration (*E*, mmol m^{-2} s^{-1}), internal CO_2 concentration (*Ci*, µmol mol^{-1}) in the leaf mesophyll, deficit of water vapor pressure between the leaf and the atmosphere (Vpd_L, kPa) and efficiency of water use (*A/E*; [(µmol m^{-2} s^{-1}) (mmol H_2O m^{-2} s^{-1})$^{-1}$]) were carried out in the morning, between 9 a.m and 11 a.m. In order to measure the *Fv/Fm* ratio, the leaves were adapted to darkness, for a period of 30 minutes, before the measurements. For the intercrop season, the evaluations were performed on July 26, 2018, and for the main crop season, on November 26, 2018.

2.4 Content of Chloropastidic Pigments

The content of chlorophyll was determined according to Lichtenthaler (1987). The sample was composed of seven leaves of each one of the six clones. In order to do so, 2 g of

fresh mass was extracted from the leaf. After being weighed, they were macerated in a mortar in a dark chamber, with 7 mL of 80 % acetone (v/v) and an aliquot of washed sand. The extract was filtered through filter paper and then conditioned in volumetric balloons wrapped with aluminum paper, for protection against the light. Afterwards, the volume of the ketone extract was completed with 80% acetone (v/v), in a 25 mL balloon. The extract absorbencies were read in a Genesys spectrophometer (10S UV-Vis model), in wave lengths from 646,8 to 663,2 nm. The content of chlorophyll, expressed in mg L^{-1}, was calculated using the formula:

$$Chlorophyll\ a\ (Ca) = 12{,}25 \times A_{663{,}2} - 2{,}79 \times A_{646{,}8}$$

$$Chlorophyll\ b\ (Cb) = 21{,}5 \times A_{646{,}8} - 5{,}10 \times A_{663{,}2}$$

$$Chlorophyll\ a + b\ (T) = 7{,}15 \times A_{663{,}2} - 18{,}71 \times A_{646{,}8}$$

The content of total carotenoids was determined, using the same extract prepared for the determination of chlorophyll, and the absorbance readings were carried out in 470,0 nm. The concentration, expressed in mg L $^{-1}$, was estimated in accordance with the following formula:

$$Total\ carotenoids\ (Car) = \frac{(1.000 \times A_{470} - 1{,}82 \times Ca - 95{,}02 \times Cb)}{198}$$

The relations *Chl a/b* and *Chl T/Car* were established from the values of chlorophyll content and carotenoids content.

2.5 Specific Leaf Area

The determination of specific leaf area (SLA) was carried out in the Laboratory of Forest Soils of the Soil Department of the Universidade Federal de Viçosa (UFV). A sample composed of seven leaves per clone was collected and the area was determined by means of a Li-Cor, LI-3100C Area Meter, using its high resolution laser scanner. After the measurement, the leaves were taken to an oven at 65°C for 72 h, and its dry weight was determined. For the calculation of the SLA, the ratio between the leaf area (LA) and the mass of dry matter (DM) of the leaves was used, according to the following expression:

$$SLA = \frac{LA}{MS\ leaves}$$

2.6 Stomatal Density

For the evaluation of the stomatal density (SD), 36 leaves per clone were randomly collected. Healthy leaves and free of visible lesions were chosen and immediately conditioned in plastic bags, and taken for the preparation of blades in the laboratory. The blades to count the stomata were prepared with the application of colorless enamel on the abaxial leaf surface. After the enamel was dry, adhesive tape was placed on the same surface and withdrawn soon after that, with a "negative" of the leaf epidermis, which was separated from the tape, with the help of tweezers. The epidermis "negative" was then placed on a glass lamina for the determination of the stomatal density.

This procedure was carried out in the Microscopy Laboratory of the Vegetal Biology Department of the Universidade Federal de Viçosa, in Viçosa, MG. For the visualization of the stomata, photographs were taken by using a computer program with 40x objective lens. Next, the stomata were counted manually. The following formula was applied to the data, which were recorded in an electronic spreadsheet, for the obtainment of the stomatal density (SD).

$$SD = \frac{Number\ of\ stomata}{0{,}272902\ mm^2}$$

2.7 Biometric Characterization of Fruits and Seeds

This characterization was carried out in two stages, between March 2018 and March 2019, and the sampling consisted of 8 ripe and healthy fruits for each one of the six clones. The traits considered in the process were: weight (LW), fruit length (FL) and diameter (FD), fresh weight of the shell (FWS), fresh weight of seed (FWS), number of seeds (NS) and individual weight of dry seed (IWDS). After being collected, the fruits were identified and packed, to be sent to the laboratory later on. Firstly, they were weighed on a precision scale, and length and diameter were measured with a digital caliper. The seeds were counted and the fresh shells of fruits and of seeds were weighed. After this stage, the shells and seeds were taken to a forced air circulation oven at 60°C, where they remained until they reached constant weight, for the determination of the mass of dry matter.

2.8 Almond Yield

The evaluation of almond yield was done throughout the main crop season and the intercrop season, from February 2018 to February 2019, making up an annual cycle of the

culture. For each clone, all the healthy fruits produced in the plots (14 plants), as well as their seeds, were harvested, counted and weighed. Afterward, the yield per parcel was extrapolated to the hectare.

2.9 Statistical Analysis

The experimental data were analyzed in a scheme of hierarchy classification (Dias e Barros, 2009), considering the variable number of replicates (six for the data related to the leaf gas exchanges, eight for SLA, SD, chloroplastidic pigments and biometric characterization of fruits and seeds, and 14 for almond yield).

The Rbio (Bhering, 2017) software was used for the data analyses, and analyses of variance (ANOVA) were carried out, as well as the comparison of the means of the clones by means of the Scott-Knott test ($p<0,05$).

3. RESULTS

3.1 Climatic Monitoring

Regarding the average annual temperature, a variation from 21,51 to 29,60°C was verified, from July to September, respectively (Figure 1A). As for rainfall (Figure 1B), it was verified that the greatest rain volumes occurred in Spring (37%) and Summer (31%), and the smallest ones in Fall (23%) and Winter (9%), resulting in a rainier main crop season and a drier intercrop season. Linhares' data of solar radiation in 2018 (Figure 1C) revealed that June was the month with the least radiation (15,57 MJ/m^2/day), while January and February presented the highest solar index (22,32 and 22,42 MJ/m^2/day, respectively).

3.2 Gas Exchanges and Fluorescence

The net photosynthetic rate per unit of leaf area (*A*) was superior in clones PH 16, PS 1319, SJ 02 and CCN 51, making these clones different from the others. No significant differences were observed for this trait between the two evaluation seasons (Table 1).

The g_s values followed the same tendency as *A*, being superior for the same clones (PH 16, PS 1319, SJ 02, CCN 51). However, a significant statistical difference was observed between the two seasons, and the main crop season values were higher than the intercrop season ones. Regarding the transpiration rate (*E*) and internal CO_2 concentration in the leaf (*Ci*), no significant differences were verified among the clones, but there was a difference for the season of evaluation; the main crop season values (2,26 moL H_2O m^2 s^{-1} and 293,05 µmol

mol-1) were superior to the values of the intercrop season (1,41 mol H_2O m^{-2} s^{-1} and 244,37 µmol mol^{-1}), respectively.

The values of the *Fv/Fm* ratio did not differ significantly among the clones and the seasons evaluated. The low variation of values (0,78-0,79) allowed for the observation that there was no photo-inhibition in neither seasons. As for the deficit of water vapor pressure between the leaf and the atmosphere (*VpdL*), significant differences were noticed among the clones, with CCN 10 and CP 49 presenting higher values than the others. Concerning water use efficiency (*A/E*), there was no significant difference among the clones, but the intercrop season values (4,70 µmol CO_2 mmol H_2O^{-1}) were significantly superior to the values of the main crop season (2,61 µmol CO_2 mmol H_2O^{-1}).

3.3 Content of Chloroplastidic Pigments

The concentrations of chloroplastidic pigments (Table 2) presented significant differences between the seasons for parameters *Chl T* and *Chl a/b*, with superior values for the intercrop season in both. The concentrations of *Chl T* were not significantly different ($p < 0,05$) among clones and varied from 0,93 to 1,45 mg g^{-1}. For ratio Chl *a/b*, only clone PH 16 was different from the others (2,11 mg g^{-1}). As for ratio ChlT/Car, there was also a significant difference among the clones, an again PH 16 presented an inferior value in comparison to the others (4,03 mg g^{-1}) (Table 2).

3.4 Specific Leaf Area and Stomatal Density

Regarding the specific leaf area (SLA), significant differences were observed among the clones, being possible to fit them in three groups, from the Scott-Knott test. Clone CCN 51 presented the highest value (189,03 cm^2 /leaf dry mass), followed by SJ 02, CCN 10 and PS 1319, with SLA values of 156,24, 155,86 and 152,60 cm^2 /leaf dry mass, respectively. Clones CP 49 and PH 16 represented the group with lower values, with 134,68 and 124,87 cm^2 /leaf dry mass, respectively (Figure 2A). The values of stomatal density (SD) varied from 700 to 913 mm^2. SJ 02 presented superior SD, followed by CCN 51. Clones PS 1319, PH 16, CP 49 and CCN 10 presented lower SD values, being different from the others (Figure 2B).

3.5 Biometric Characterization of Fruits and Seeds

The evaluation of features of cocoa fruits and seeds revealed significant differences among clones (Table 3) for fruit length (FL) and diameter (FD), fresh weight of shell (FWS),

wet weight of almonds (WWA), number of seeds per fruit (NSF) and individual weight of dry seed (IWDS). The longest fruits derived from clones CP 49, CCN 51 and CCN 10. Concerning the wet weight of almonds (WWA), clones CCN 10, CCN 51, PS 1319 and PH 16 presented the highest values. When evaluating the number of seeds per fruit (NSF), the behavior of the clones was similar to component WWA, having a difference only for CCN 10, which presented a smaller number of seeds than the others (30 seeds). For individual weight of dry seed (IWDS), this same clone obtained the highest value (2,31 g), differentiating itself from the others.

3.6 Yield

With regard to almond yield, clone CCN 51 was the most productive, with yield of 2.890 kg ha^{-1} (Table 4). PH 16 and PS 1319 also presented yield considered as high productivity. Clones CP 49, SJ 02 and CCN 10 presented lower yield, the latter mainly due to a smaller number of fruits per plant, even though the three of them presented yield considered to be satisfactory for the cultivation conditions.

4. DISCUSSION

The cocoa photosynthetic capacity varies between 2 and 8 μmol CO_2 m^{-2} s^{-1} (Ávila_Lovera, 2016; Almeida et al., 2014; Tezara et al., 1998), considered to be low if compared to the other species of superior plants. The values of net photosynthetic rate (*A*) presented in this study were superior to those found in the literature (Barroso, 2014; Araque et al., 2012; Jaimez et al., 2008), which can be associated with the fact that plants developed in environments with more light availability present photosynthetic machinery able to deal with high values of irradiance, so as to present higher *A* values, high stomatal conductance (g_s) and increase of photoprotective capacity (Chazdon et al., 1996; Bazzaz, 1996).

Apart from acclimatization to light intensity, another relevant factor for the high values of *A* of some clones can be justified by the architecture of the crown of the plant observed in the experimental area. Although all of them are in similar field conditions (cultivation in full sun, spacing and handling), clones PS 1319 and PH 16 presented a more open and less dense crown. Hence, this greater opening might have made it possible better light interception across the crown, with consequent gains in the efficiency of CO_2 assimilation at a whole-plant level. Moreover, the obtainment of high values of *A* depends on

the availability of water and nutrients in the soil and on light intensity (Almeida & Valle, 2010; Hutcheon, 1977; Okali & Owusu, 1975). This way, this relationship between *A* and the factors mentioned above was confirmed in the present work, since the culture was fertirrigated and in full sun. It is also pointed out that irrigated cocoa (without water stress) tends to present growing values of carbon assimilation with the increase of solar radiation (Augusto, 1997), also indicating the contribution of irrigation to these high values obtained. In addition, the values found for efficiency of water use (*A/E*) suggest an efficient control of the plant to avoid excessive loss of water in conditions of more radiation (Mengarda et al., 2009), especially in the intercrop season (drier if compared to the main crop season).

When relating the g_s data with the *A* ones, the former followed the same tendency as the latter did, pointing out the importance of diffusive limitations in the photosynthetic control in cocoa (Burrows & Milthorpe, 1985). However, g_s did not correlate with stomatal density (SD) ($r = 0.58^{ns}$), ruling out the possibility that its higher values were related to a greater amount of stomata. Therefore, higher g_s resulted in greater stomata opening, probably because of the greater prevalence of environmental factors favorable to the occurrence of gas exchanges.

The estimate of ratio *Fv/Fm* has been frequently used as a parameter capable of detecting disturbances in the photosynthetic apparatus of the plants caused by biotic and abiotic stresses, given that its reduction indicates inhibition of the photochemistry activity (Konrad et al., 2005). In both seasons, from the values obtained from ratio *Fv/Fm,* the absence of photoinhibitory signals and of damages at the level of photosystem II were noticed (Maxwell & Johnson, 2000). However, this result was different from the one found by De Araújo et al. (2017), in which cocoa genotypes cultivated inside pots in a nursery in full sun presented a reduction of the *Fv/Fm* ratio, varying from 0,59-0,70, indicating photoinhibitory damage caused by excessive light. It is known that studies carried out in the field differ from those in greenhouses, nurseries and laboratories, mainly due to a higher evaporative demand and higher climatic variation in the field. In other words, studies whose scale is the whole plant represent a better level to integrate environmental conditions and physiological responses (Granier & Tardieu, 1998; Larcheveque et al., 2011; Ryan, 2011). Thus, comparing this study to the study of De Araújo et al. (2017), it is assumed that the plants cultivated in the field can have higher capacity of energy dissipation than those cultivated in vases, mainly due to a higher prevalence of drains and vegetative growth, for example.

Cocoa represents high genetic variability (Dias, 2001) and the variations found in the traits of its leaves, such as specific leaf area and stomatal density were reported in other works (Balasimha et al. 1985, Galyuon et al. 1996). The total concentration of photosynthetic pigments and the proportion among them and between them and chlorophylls a (Chl *a*) and b (Chl *b*) are altered according to the irradiance available for the plant (Baig et al. 2005). This way, leaves developed in environments of high irradiance present an increase in the fraction of Chl *a* in relation to Chl *b*, making ratio Chl *a/b* higher for leaves exposed to the sun than to the shadow (Lichitenthaler, 2009). Similar values of ratio Chl *a/b* of the present work were found by De Araújo et al (2017).

In environments with high irradiance it is common for plants to present a smaller ratio Chl total/Carotenoids (Mengarda, 2009), indicating that the amount of carotenoids in relation to chlorophyll is greater in full sun. Such a fact occurred with clone PH 16, when presenting the lowest value of this ratio, pointing out the photoprotective action of the carotenoids in the photochemical machinery, hence preventing photo-oxidative damage to the chlorophyll molecules. However, it is important to highlight that cocoa also presents other photoprotective mechanisms, since ratio Chl total/Carotenoids was not altered in the other clones, and these did not present photoinhibition, either.

Cocoa has a wide genetic variability for most of the traits, especially for size, shape and color of fruits and of seeds (Dias, 2001). Thus, the results of biometric data of fruits and seeds of the clones reinforce that, also in conditions of cultivation in full sun, there is an expressive variability of these morphological traits, mainly due to natural crossing and hybridization (Almeida et al., 2009; Santos et al., 2012). As a whole, the weight of fruits was similar among the clones, varying from 627 to 701 g. Alexandre et al. (2015), when studying the cultivation of cocoa combined with rubber plants in the coastal region of São Mateus (ES), found expressive differences regarding the average weight of fruit among clones CCN 10, CCN 51, PS 1319 and PH 16, clone CCN 51 standing out with the greatest weight (820 g). The same authors found higher values of fruit diameter (FD) and length (FL) than those described in this work.

Fruits with a bigger diameter and length are usually found in plants with a smaller number of fruits, which can be mainly due to less competition among the drains, resulting in more supply of photoassimilates for its growth (Lins et al., 2016). In any event, in the conditions of our study (with highly technified handling), the most limiting factor to the production of clones was the number of drains without significant influence of the source

capacity at the level of the leaf. The low number of fruits per plant (NFP) was precisely the main factor responsible for the low productive performance of materials CCN 10 and CP 49. However, the importance of the highest value of IWDS of CCN10 is highlighted as the factor that allowed it to produce yield comparable to clone SJ02, even with lower NPS and NS.

The seeds, a product of cocoa commercial value, must meet the requirements of quality required by the industry. For farmers, the consideration of this trait is also relevant, since the greater its magnitude the less work will be generated for the harvest and breakage (Carvalho et al, 2001). Therefore, the weight of dry almonds per fruit is considered to be one of the main production components (Almeida et al., 1994), and the use of clones with greater seed weight is important to meet the requirements of the chocolate industry. From the economic point of view, it is desirable to produce almonds with large fruit almonds with a high almond mass/shell mass ratio. In commercial terms, the dry seeds must present an average weight equal to or higher than 1,07 g (Toxopeus, 1987); this is a criterion of research centers in the selection of clones. Indeed, all the clones evaluated in this work presented a dry weight of almond higher than the desirable minimum, varying between 1,11 g (CP 49) and 2,31 g (CCN 10).

According to Campuzano (2007), the number of seeds in cocoa fruits varies a lot, as it is a trait directly influenced by genetic and environmental factors. For this reason, there is a great variation in the number of seeds among the fruits of the same genotype. This can explain the variations found in this work and in the work mentioned above, in which the same materials had different biometric data.

Santos & Sodré (2017) reported that in the South of Ecuador, in irrigated areas, CCN 51 yield is superior to 2.250 kg ha^{-1}. As for Puentes-Páramo et al. (2014), when evaluating clone yield under different levels of fertilization with NPK and density of 952 plants per hectare, they obtained 2.020 kg ha^{-1} $year^{-1}$ of dry almond for this clone. In the results found by Alexandre et al. (2015), clone CCN-51 also obtained a result that was superior in almond yield, if compared to PS 1319. Pereira and Valle (2012) proved that besides satisfactory yield, CCN 51 presented tolerance to fungal diseases, which contributes to its productive efficiency. Additionally, in fertirrigation conditions, its yield is incremented.

5. CONCLUSIONS

- Cocoa presents physiological traits favorable to the cultivation in full sun.
- Clone CCN 51 was the most productive.
- Clones PS 1319, CP 49, PH 16 and SJ 02 cultivated in full sun presented high yield potential, mainly due to a higher number of fruits per plant (NFP).
- The importance of the greatest IWDS is pointed out as a compensatory factor of the smallest NFP and the smallest number of seeds (NS) in clone CCN 10, allowing for yield comparable to clone SJ 02.

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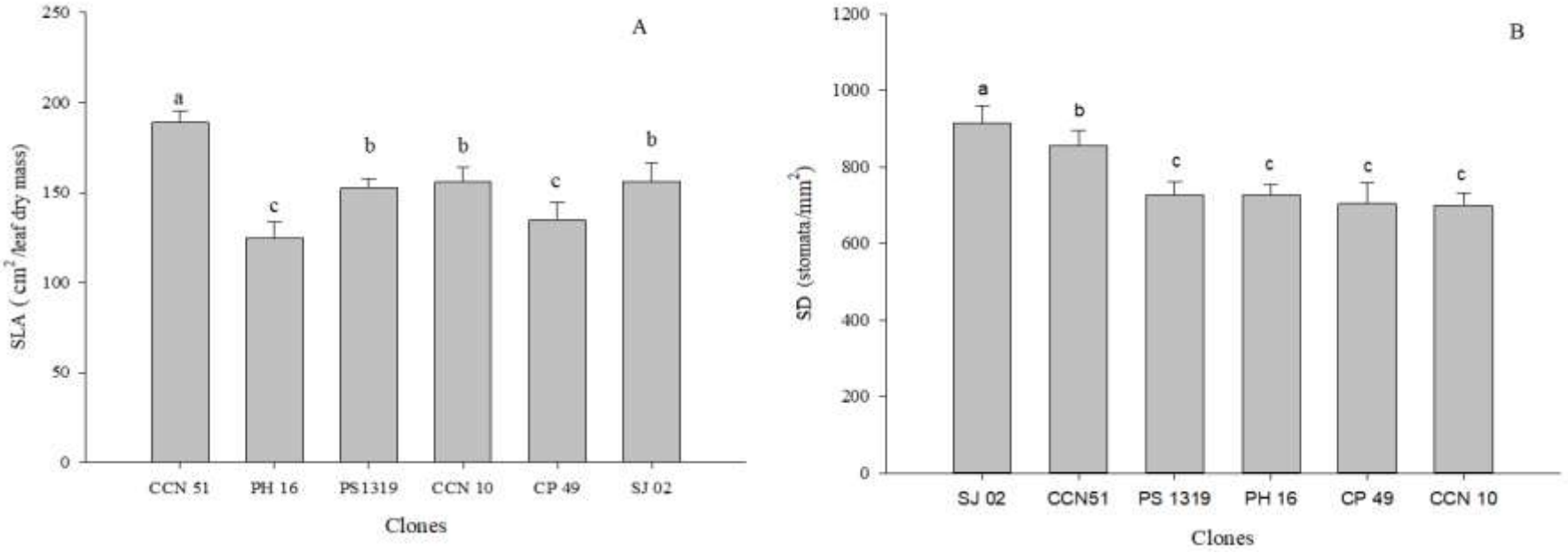

Figure 1. Data of mean temperature (A), rainfall (B) and solar radiation (C), regarding year 2018 in the municipality of Linhares, Espírito Santo, Brazil.

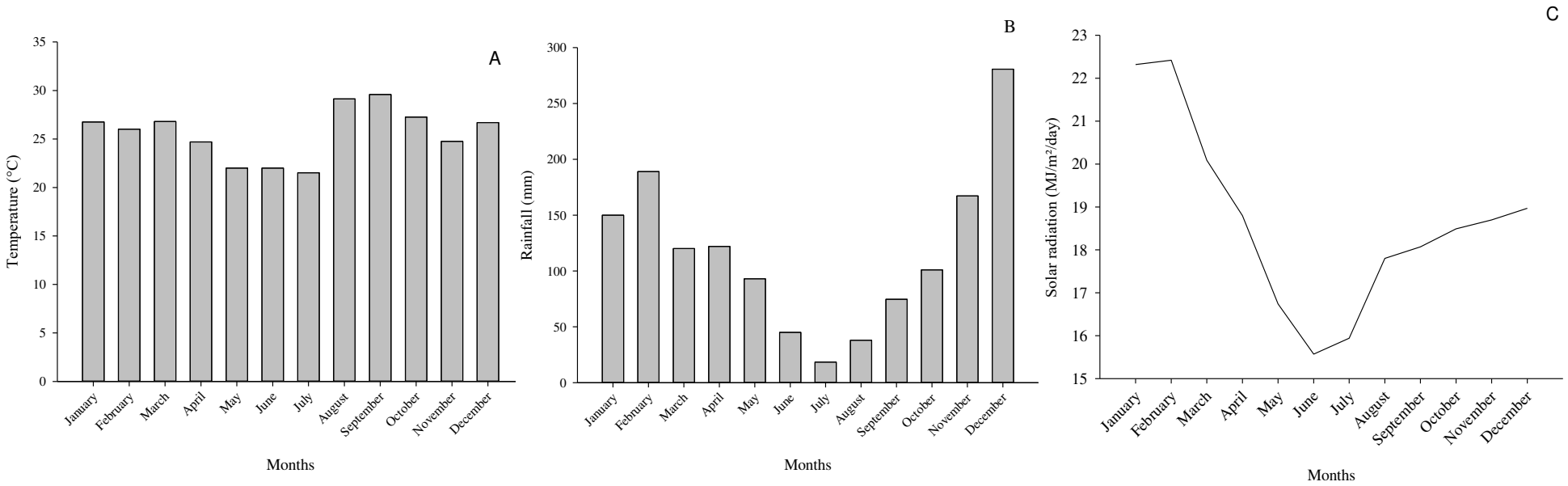

Figure 2. A) Specific leaf area (SLA – cm^2/ leaf dry mass) and B) stomatal density (SD- stomata/mm^2) in leaves of cocoa clones grown in full sun, in the municipality of Linhares, in the north of Espírito Santo.

Table 1. Means of net photosynthetic rate (*A*; µmol CO_2 m^{-2} s^{-1}), stomatal conductance to water vapor (g_s; mmol H_2O m^{-2} s^{-1}), transpiratory rate (*E*; mmol H_2O m^{-2} s^{-1}), internal CO_2 concentration (*Ci*; µmol mol^{-1}) in the leaf mesophyll, potential quantum yield of photosystem II (F*v*/F*m*), deficit of water vapor pressure between the leaf and the atmosphere (Vpd_L; kPa) and efficiency of water use (*A/E*; [µmol CO_2 mmol H_2O^{-1}]) in ripe leaves of six cocoa clones grown in full sun, in Linhares, ES

Parameters	Season	Means*	Clones*						General average
			CCN 51	PH 16	PS 1319	CCN 10	CP 49	SJ 02	
A	Main crop Intercrop	6,55 A 6,09 A	6.04 b	8.33 a	7.21 a	4.86 b	4.81 b	6.66 a	6.32
g_s	Main crop Intercrop	0,128 A 0,073 B	0.104 a	0.121 a	0.118 a	0.068 b	0.082 b	0.110 a	0.100
E	Main crop Intercrop	2,64 A 1,41 B	1.97 a	2.30 a	2.35 a	1.64 a	1.88 a	2.02 a	2.02
Ci	Main crop Intercrop	293,06 A 244,37 B	270.33 a	257.90 a	272.67 a	260.31 a	274.57 a	276.50 a	268.71
Fv/Fm	Main crop Intercrop	0,780 A 0,793 A	0.787 a	0.781 a	0.79 a	0.779 a	0.798 a	0.781 a	0.786
Vpd_L	Main crop Intercrop	2,08 B 2,21 A	1.87 c	1.91 c	1.97 c	2.49 a	2.40 a	2.22 b	2.14
A/E	Main crop Intercrop	2,61 B 4,71 A	3.77 a	4.07 a	3.36 a	2.99 a	2.73 a	5.02 a	3.66

Table 2. Means of contents of total chlorophyll (*Chl T*), chlorophyll a/b (*Chl a/b*) ratio and chlorophyll total/carotenoids (*ChlT/Car*) ratio expressed in fresh biomass (mg g^{-1}), in ripe leaves, of six cocoa clones grown in full sun in Linhares, ES

Parameters	Season	Means *	Clones*						General average
			CCN 51	PH 16	PS 1319	CCN 10	CP 49	SJ 02	
Chl T	Main crop	0,97 B	1.19 a	0.93 a	1.12 a	1.14 a	1.28 a	1.47 a	1.19
	Intercrop	1,41 A							
Chl a/b	Main crop	2,19 B	2.46 a	2.11 b	2.38 a	2.42 a	2.42 a	2.45 a	2,38
	Intercrop	2,57 A							
Chl T/Car	Main crop	4,79 A	4.99 b	4.03 c	5.23 a	4.93 b	4.84 b	4.79 b	4.80
	Intercrop	4,81 A							

* Means followed by lowercase letters on the lines differentiate clones, and by capital letters in the columns differentiate seasons (main crop and intercrop), by using the Scott-Knott test ($p \leq 0,05$).

Tabela 3. Summary of the Anova and means of fruits and seeds of six cocoa clones grown in full sun in Linhares, ES, regarding traits weight (LW), fruit length (FL), fruit diameter (FD), fresh weight of shell (FWS), wet weight of almond (WWA), number of seeds per fruit (NSF) and individual weight of dry seed (IWDS)

Sources of variation	**gl**	**Mean Squares[1]**						
		LW (g)	**FL** (cm)	**FD** (cm)	**FWS** (g)	**WWA** (g)	**NSF**	**IWDS** (g)
Clone	5	6158^{ns}	26.32*	12.33*	23839*	7679*	243.09*	1.33**
Plant/Clone	42	5324	1.66	3.37	4579	835	60.68	0.02
Average		664.28	20.45	15.90	504.84	150.97	39.56	1.52
CV (%)		10.98	6.30	11.55	13.40	19.14	19.69	10.44
		Means						
Clones[2]		**LW** (g)	**FL** (cm)	**FD** (cm)	**FWS** (g)	**WWA** (g)	**NSF**	**IWDS** (g)
CCN 51		701.3 a	22.3 a	16.3 a	503.2 b	175.3 a	44.5 a	1.54 b
PH 16		656.7 a	18.8 b	16.7 a	484.1 b	166.8 a	42.7 a	1.45 b
PS 1319		627.8 a	18.2 b	13.6 b	429.9 b	171.3 a	44.0 a	1.35 b
CCN 10		647.7 a	21.1 a	15.3 a	493.0 b	161.9 a	30.0 b	2.31 a
CP 49		692.4 a	22.4 a	16.8 a	596.6 a	94.4 c	37.1 a	1.12 c
SJ 02		659.6 a	19.7 b	16.5 a	522.0 b	135.9 b	39.0 a	1.40 b

[1] ^{ns} non-significant*and significant by the F test ($p \leq 0,05$). [2] Means of clones followed by the same letters, in the columns, do not differ from each other by the Scott-Knott test ($p \leq 0,05$).

Table 4. Means of number of fruits per plant (NFP) and yield of dry almonds (YIELD) of six cocoa clones grown in full sun in Linhares, ES.

Clone	NFP	YIELD
		(kg ha^{-1})
CCN 51	54.7 a	2.889.7 a
PH 16	42.6 a	2.083.5 b
PS 1319	48.0 a	2.470.5 b
CCN 10	24.7 b	1.220.4 c
CP 49	47.3 a	1655.1 c
SJ 02	38.5 a	1526.2 c

Means followed by the same letter, in the columns, do not differ from each other by the Scott-Knott test at 5% probability.

Chapter II. Sufficiency ranges and nutrient exportation by cocoa trees grown in full sun in the North of Espirito Santo, Brazil

ABSTRACT

Cocoa is a plant of great economic importance, due to the use of its almonds for chocolate production. In the last years, the system of clone cultivation in full sun has been a highly promising alternative for the reduction of the incidence of witch's broom, the main disease of the culture, and the expectation of high yields. However, information on its yield potential, nutritional requirements and nutrient exportation by the clones is still scarce in this new condition of cultivation. Here, we evaluated six clones (PS 1319, CCN 10, CCN 51, PH 16, SJ 02 and CP 49), grown in full sun in Linhares, ES, five years ago, aiming at the establishment of a nutritional sufficiency range through a leaf analysis and nutrient exportation. For the leaf sampling, four plants of each clone were randomly chosen, from which four diagnostic leaves were collected per plant. As for the fruit sampling, 10 ripe and healthy fruits were collected per clone and the separation of the shell and almonds was carried out. After the preparation of the leaf and fruit samples, they were sent to the laboratory for the quantification of the contents of mineral nutrients. The evaluation of almond yield was performed during the main and intercrop seasons and, for each clone, the healthy fruits and their seeds were collected, counted and weighed. After checking the high yield of the clones and the data normal distribution, the adequate sufficiency ranges were established considering $\mu \pm \sigma$. The trial was analyzed as a hierarchy classification, and for each one of the six clones, 14 plots were randomly plotted, each one composed of 1 plant (experimental unit). The concentrations of mineral macronutrients in the diagnostic leaf differed among the clones, even in the order of quantitative importance. As for the content of nutrients in the shell, there was a significant difference only for Ca and S, and for the contents of nutrients in the almond, only P presented a difference among the clones. Zn was found in higher concentrations for the three compartments. The clones presented a high yield of dried almond (1200 to 2900 kg ha^{-1}) and the differences among clones in the contents of nutrients for the different compartments were expected, due to the variation of productivity among the materials. However, direct relationships between contents of nutrients and the yield obtained were not noticed. Adequate sufficiency ranges for each clone represent a first approach in conditions of cultivation in full sun in Brazil. The nutrient exportation by the shell was high, presenting potential for use as an organic fertilizer when returned to the culture. As for the exportation of some nutrients by the fruit, it reinforced the importance of nutritional replacement via fertilization, so that the reduction of the soil natural fertility does not occur.

Keywords: *Theobroma cacao* L. Plant nutrition. Leaf diagnosis.

1. INTRODUCTION

Cocoa (*Theobroma cacao* L.) is a dicotyledonous plant, belonging to the Malvaceae family, native of the humid tropical forests of South and Central Americas (Alverson et al., 1999). Cocoa is one of the main Brazilian commodities, grown in four main regions: in the South of Bahia, in the Amazon region, on the coastal tablelands in the extreme South region of Bahia, and in the north of Espírito Santo (Cuenca & Nazário, 2004).

Pará (49,3%) and Bahia (45,1%) are the main Brazilian producers, while Espírito Santo has a 4 % participation in the national production (CONAB, 2019). Because it is an umbrophyle plant (Alverson et al., 1999), the predominant system of cultivation of cocoa in Brazil is in the understory of native forests, the so-called "cabruca". In this traditional cultivation condition, there is greater soil conservation, mainly due to the green vegetation cover that intercepts rains and decreases their erosive potential. There is also the presence of residues on the soil surface, promoting additional effects on soil conservation and biogeochemical cycling of nutrients (Santana et al., 1987). On the other hand, this environment is highly favorable to the incidence of the main fungal disease of the culture, the "witch's broom", caused by fungus *Moniliophthora perniciosa* (Luz et al., 1997).

In the face of the severity of this disease in the cultivation in "cabruca", full sun has been a highly promising alternative, since the losses in production caused by *M. perniciosa* are reduced due to the low relative air humidity, which disfavors the disease (Leite & Valle, 2000). In addition, some studies (Zuidema et al., 2004; Leite, 2012) have shown expressive yield (above 3 t/ha) in the cultivation under greater light incidence. Notwithstanding, the dynamics of nutrients in the soil, the nutritional requirements and the yield potential of different clones are unknown in cultivation in full sun.

This research represents the first approach developed in Brazil for the nutritional management of cocoa in cultivation in full sun.

2. MATERIAL AND METHODS

2.1 Conditions of Cultivation and Clones

The trial was carried out in Fazenda Três Lagoas, located in the municipality of Linhares (19° 17' 28.3" S lat, 40° 10' 13.3" W long, m asl alt), in the northern part of the State of Espírito Santo. According to the Köppen classification, the climate of the region is Aw,

with a humid summer and a dry winter, annual average temperature of 23,5 °C and annual average rainfall of 1,291 mm (Alvares et al., 2013). The predominant soil in the region, where the cocoa cultivations are, is fluvic Cambisol (IBGE, 2016).

Six clones were evaluated (PS 1319, CCN 10, CCN 51, PH 16, SJ 02 and CP 49), all of them grown in the main Brazilian producing regions. The cultivation, which has been in the field for eight years, is located in a flat terrain, under the same soil domain (fluvic Cambisol), with the same nutritional, phytosanitary and irrigation management. The experimental area has a drip fertirrigation system, and the plants are in the spacing of 3,5 x 2,5 m. The trial was carried out from 02/2018 to 02/2019, aiming at comprising the period of the main crop and intercrop seasons.

2.2 Climatic Monitoring

The climatic monitoring of the trial was carried out from data collected from a meteorological station (E 5.000/IRRIPLUS model) installed between January and December 2018, near the trial. In addition, historical climate data of Linhares between 1976 and 2014 were compiled (Medeiros et al., 2018 a, b, c, d).

2.3 Sampling of Leaves and Fruits, Digestion and Analytical Dosage of Nutrients

For the leaf sampling, four plants of each clone were randomly chosen, from which four diagnostic leaves were collected per pant, two of them being oriented to the planting line (between the trees) and the other two, between the lines. The leaves were collected at half the height of the plant canopy, newly mature and on the third position of the branch apex (Souza Jr., 2012). The leaf samples were washed with running water, and rinsed with cotton wetted with distilled water, stored in paper bags and left to dry in a forced air circulation oven at 65± 5 °C until reaching a steady weight.

Ten ripe fruits were collected per clone, and afterwards the separation of the shell (shell plus the placenta) and of the almond was carried out. After drying, the dried vegetal material (leaves, seeds and shells) was grinded in a mill of the Willey type and stored to be later sent to the Laboratory of Forest Soils (DPS-UFV) for the quantification of the contents of mineral nutrients. The extract was analyzed for P, K, Ca, Mg, S, Zn, Cu, Mn, Fe and B through argon inductively coupled plasma atomic emission spectrophotometry- ICP-OES (Perkim Elmer, 8300). The N concentrations in the plant tissues were obtained through the digestion of the materials with sulphuric acid, followed by the *Kjeldahl* distillation. As dependent variables, the contents of nutrients in the leaf, in the almond and in the shell were analyzed, as well as the nutrient

exportation by the almond and by the shell, being their sum equivalent to the exportation by the fruit.

2.4 Adequate Sufficiency Range and Yield

The data nutrient concentrations in the leaf tissues (diagnostic leaves), for each clone, were subjected to normality tests Shapiro-Wilk, Kolmogorov-Smirnov or Cramer-von Mises.

The evaluation of almond yield was performed during the main crop and intercrop seasons, from February 2018 to February 2019, making up an annual cycle of the culture. For each clone, the healthy fruits and their seeds produced in the plots were collected, counted and weighed, being 14 plots formed by 1 plant each. After checking clone yield and data normal distribution, the adequate sufficiency ranges were established considering $\mu \pm \sigma$.

2.5 Statistical Processing

The experimental data were analyzed in the hierarchical classification scheme (Dias and Barros, 2009). For each one of the six clones, 14 plots were randomly plotted, composed of 1 plant each. Analyses of variance were carried out, as well as the comparison of means by the Scott-Knott test (p=0,05), in the Rbio software (Bhering 2017).

3. RESULTS

3.1 Climatic Monitoring

The volume and distribution of rains in the municipality of Linhares in 2018 differed from the historical average (1984-2014) (Figure 1). In fact, the year of 2018 was rainier (1,478 mm in 2018, if compared to 1,318 mm of the historical data), with greater volumes in spring (37%) and summer (31%), and lower ones in fall (23%) and winter (9%). In the spring and in the summer of 2018, it rained about 69% of the annual volume, while historically this number was about 44%. In turn, the data of minimum, maximum and average temperatures in 2018 (Figure 1) demonstrate that there were few anomalies if compared to the historical behavior.

3.2 Nutrient Contents

The contents of macronutrients of the six clones in compartments diagnostic leaf, shell and almond are shown in Table 1. The concentrations of mineral macronutrients in the

diagnostic leaf differed among clones (Table 1), including the order of quantitative importance (Table 2). The highest contents of N, P and K stand out for clones PH 16 and CCN 51, and of Ca and Mg for clone CP 49 (Table 1). As for the content of nutrients in the shell, there was a significant difference only for Ca and S, clones PH 16, CCN 10 and SJ 02 standing out with higher contents of Ca. With regard to the contents of nutrients in the almond, only P presented a difference among the clones, CCN 10 standing out with the highest content.

Values of coefficients of variation of the means of the nutrient contents were presented only for diagnostic leaves, since they are used as dispersion measurements for models of nutritional diagnosis, such as the Kenworthy Balanced Indexes_KBI (Kenworthy, 1961), Diagnosis and Recommendation Integrated Systems _DRIS (Beaufils, 1973).

The order of nutrient concentration in the leaves varied among clones (Table 2). In general, N was the element in higher concentrations, except for CP 49, which highlighted Ca. The second most concentrated element alternated between Ca (PS 1319, CCN 10 and SJ 02), K (CCN 51 and PH 16) and N (CP 49). Potassium (PS 1319, CCN 10, SJ 02 and CP 49) or Ca (CCN 51 and PH 16) represented, for most of the clones, the third most concentrated element. For the fourth, fifth, sixth, seventh and eighth elements, there were no variations among clones, these being Mg, S, P, Mn and Zn, respectively. B was less concentrated than Fe only for clone CCN 10 (Table 2).

The contents of micronutrients (Table 3) indicated that Zn was found in higher concentrations in the shell and in the almond, while Mn was more concentrated in the leaf. For the leaf contents, there was a statistical difference for Cu, Zn and Mn. Clones CCN 51, PS 1319 and CCN 10 presented higher contents of Cu, while for Zn, clones CCN 51 and PH 16 where the ones that differed statistically. For Mn, only CP 49 differed.

The order of content of micronutrientes in the shell (Table 3) revealed differences among clones, being order Zn>B>Mn for CCN 51, PS 1319 and CCN 10, and Zn>Mn>B for PH 16, CP 49 and SJ 02. As for the content in the almond, there was a significant difference for most of the elements, except for Fe. Thus, the following orders were established: Zn>B>Mn>Cu for CCN 51, Zn>Cu>Mn>B for PH 16, PS 1319, CP 49 and SJ 02 and Zn>Mn>Cu>B for CCN 10.

3.3 Adequate Sufficiency Range

The occurrence of normal distribution of the nutrient contents in the diagnostic leaf, within each clone, allowed to establish adequate sufficiency ranges considering "$\mu \pm \sigma$" (Table 4). For this purpose, it was assumed that all the clones presented high yield of dried almond in that year, CCN 51: 2889,8 kg/ha; PH 16: 2083,5 kg/ha; PS 1319: 2470,5 kg/ha; CCN 10: 1220,4 kg/ha; CP 49: 1655,1 kg/ha and SJ 02: 1526,2 kg/ha.

3.4 Exportation of Macronutrients

In Table 5 there can be found data of exportation of macronutrients extrapolated for the production of 1,0 t of dried almond. Clone CP 49, in general, exported greater amounts of macronutrients. Clone CP 49 stood out in the exportation of N, P or K for the shell and fruit. For the almond, there was no statistical difference among clones for N and K, while for P, clone CCN 10 presented a higher value.

For Ca and Mg, in the shell and fruit, clones CP 49 and SJ 02 presented greater exportations. As for S, again material CP 49 exported a greater amount for the shell and fruit. For the exported amount of Mg, in the almond, there was no significant difference among clones. The order of exportation of macronutrients for the shell followed the same pattern for all the clones: K>N>Ca>Mg>S>P. For the almond, also the sequence of exportation was "N>K>Mg>P>S>Ca" for most of the clones, except for CCN 10 (N>K>P>Mg>Ca>S).

With regard to the order of exportation of macronutrients in the fruit, the first and second most exported elements altered between N and K, being N more exported by clones CCN 51, PH 16, PS 1319 and CCN 10, and K by CP 49 and SJ 02. As for Ca, P and Mg, they altered among clones for the third, fourth or fifth order of exportation. S was the element exported in the least amount by all the clones.

3.5 Exportation of Micronutrients

The exportation of micronutrients, per t of dried almond, is shown in Table 6. There was a variation in the exportation of micronutrients, among clones, in the different compartments. Zn was the most exported element in the three compartments. The exportation by the shell, in relation to the almond, was greater for all the micronutrients (Table 6). The order of exportation of micronutrients for the shell and fruit was "Zn<Mn<B<Fe<Cu", and for the almond, "Zn<Fe<Cu<Mn<B".

4. DISCUSSION

4.1 Nutrient Contents in the Different Compartments

Differences among clones in the nutrient contents for the different compartments were expected, due to the variation of yield among them. However, no direct relationships were observed between nutrient contents and yields. Variations in leaf nutrient contents among cocoa tree clones are already known (Cabala-Rosand & Mariano, 1985), which may indicate differences among them in terms of nutritional requirement, efficiency of use or acquisition of nutrients. However, it is not possible to advance these hypotheses in a more conclusive way, since the allocation of dry matter and of nutrients in the different organs of the plant (leaves, stem, roots, etc), which would allow for a more thorough understanding of partitioning and accumulation of nutrients in the different clones, was not investigated.

Comparisons between nutrient contents of commercial plantations with reference values allow for the diagnosis of the nutritional status of the culture. For this purpose, reference values, known as norms, must be obtained from populations of plants of the same species, ideally from the same cultivar, in optimal cultivation conditions, which express high yield (Martinez, 2014). Thus, in the face of the cultivation conditions and the yields achieved, which were considered high, means of the nutrients contents and their variabilities (CV) represent unprecedented parameters for the diagnosis of the nutritional status of cocoa plants grown in full sun, making it possible the use of dynamic methods of diagnosis, such as the Optimal Percentage Deviation - OPD (Montañes et al., 1993) and the Kenworthy Balanced Indexes (Kenworthy, 1961).

As for the establishment of the DRIS - Diagnosis and Recommendation Integrated Systems - norms (Beaufils, 1973), the number of samples per close is considered low. Considering data of all the clones, the number of samples would increase to 84, making DRIS viable. However, in the face of the differences among clones, the obtainment of DRIS norms of all the data population is not recommended.

4.2 Sufficiency Ranges

The method of nutritional sufficiency range is widely used for the diagnosis of the nutritional status of agriculture and forest cultures, including the cocoa culture, making it possible to classify the nutrient content as adequate, deficient or excessive, when within, below or above the range, respectively (Fontes, 2001). Thus, the establishment of ranges represents a first approach in conditions of cultivation in full sun in Brazil, since the available ranges in the literature

consider only cocoa cultivation under shading (Souza Junior et al., 2012; Silva 2015). Additionally, differences among the ranges established in this work with others can be attributed to the changes in the cultivation conditions (from shading to full sun); however, they do not allow for an evaluation at a clone level, since the traditional ranges are generic.

The greater amplitude of the ranges for the micronutrients is due to the greater data variability (greater σ), when compared to the macronutrients. Wide ranges for micronutrients, especially for Fe, Cu and Mn can be attributed to their more complex dynamics in the soil. This includes reactions of oxireduction due to variations in the contents of moisture in the soil, which may occur locally in the area because of variations of drainage in the area, compaction, excesses of rains in certain periods, affecting the availability of these nutrients (Chaves et al., 1991). Practices such as liming and phosphate fertilization may also affect the dynamics of these elements (Souza Junior et al., 2018). This way, such possibilities potentially increase the variability of the data.

Although there is an indication of adequate leaf nutrient contents for cocoa in the international (Salgado-García et al., 2006; Nelson et al., 2011; Guerrero-Lazaro, 2012) and national (Malavolta et al., 1997; Martinez et al., 1999; Bataglia & Santos, 2001; Nakayama, 2001; Souza Junior et al., 2012) literature, it is not specific for a given region, genotype or cultivation condition. In this regard, the present work reveals that there is an expressive variation among ranges for the different clones, pointing out the need to establish these parameters for each clone. Considering that the clones were grown in the same climate and soil conditions, and subjected to the same management, differences among nutritional ranges can be assigned to variations of nutritional demand or efficiency of use of nutrients, among clones.

4.3 Exportation of Macro and Micronutrients

For the production of one ton of almonds, when evaluating all the clones, N and P were more exported by almonds, and K, Ca and S were more exported by the shell. Mg was the only macronutrient whose amount exported by each compartment varied among clones; CP 49 and SJ 02 exported in a greater amount for the shell, and, for the almond there was no statistical difference. These results corroborate those found in the literature (Thong & Ng.,1980; Santana & Cabala., 1982; Malavolta, 1987; Pinto 2013; Silva 2015), except for Mg, which is often more exported by the almond.

In the total exportation of micronutrients, for the production of one ton of almonds, it is possible to observe that clones CP 49 and SJ 02 stand out in relation to the others, except for Fe. When comparing clones CP 49 and PS 1319, for example, it is noticed that the total amount exported by the former is about nine times greater than the latter. All the clones presented Zn as the first most exported element by the shell and by the almond, and this result differs from those found by Pinto (2013) and Santos (2018), who found Mn and Fe, respectively, as the most exported micronutrients. These differences are possibly due to the different places and conditions of cultivation.

In the cocoa areas, the fruits are usually broken within the plantation itself, and the shell of the fruit often remains in the field, even though it presents a potential to be used as an organic fertilizer. Thus, the return of the shell to the cultivation areas may restore, on average, 46% of N, 32% of P, 75% of K, 84% of Ca, 56% of Mg, 66% of S, 87% of Cu, 86% of Fe, 92 % of Zn and 95% of Mn and B which are exported. Additionally, the necessary enrichment of the shell with oxydroxides of Ca as a phitosanitary treatment promotes greater enrichment of the material with Ca and it may add a corrective effect of acidity to the material. The correct management of the “casqueiros” (cocoa shell that is piled in the field after the breakage) preconizes that they must be small, arranged in open areas and well distributed in the culture, avoiding the concentration of shells in the same place. After three to four months after the breakage, when these shells are partially decomposed, they must be distributed among the plants in the area around them, aiming at a better redistribution of the nutrients in the plantation (Souza Junior et al, 2012).

When comparing the total amount exported by the fruit, clone CP 49 differed from the others in terms of N, P, K and S. The total amount of exported K presented a great difference, being, for instance, twice as much as the amount exported by clone CCN 51. The clones differed more in the total amount of Ca. When analyzing the yield and exportation of cation nutrients, of some clones similar to those studied in the present work (CCN 10, CCN 51, PH 16 and PS 1319), in the south region of Bahia, Silva (2015) found different values for the exportation of macro and micro nutrients in the fruit for the production of one ton of almonds. Nutrients such as K, Mg, Cu, Fe, Mn and Zn were exported in greater amounts by the fruits, if compared to the present work.

This way, the values of nutrient exportation in the fruits demonstrate that there must be a concern on the part of producers with regard to the replacement via fertilization, since the

amount of nutrients that effectively leave (in the *in natura* fruit) the culture is very high, and it may decrease soil natural fertility.

5. CONCLUSIONS

- The cultivation of cocoa in full sun is promising, given the high yields achieved;
- Clones PS 1319, CCN 10, CCN 51, PH 16, SJ 02 and CP 49 present varied nutritional sufficiency ranges;
- The values of nutrient exportations among clones and their partitions in the fruits alert to the need of nutritional management at the clone level, for greater accuracy in the recommendations;
- The use of the shell as an organic fertilizer may represent the replacement between 32 and 95% of the nutrients exported by the fruits.

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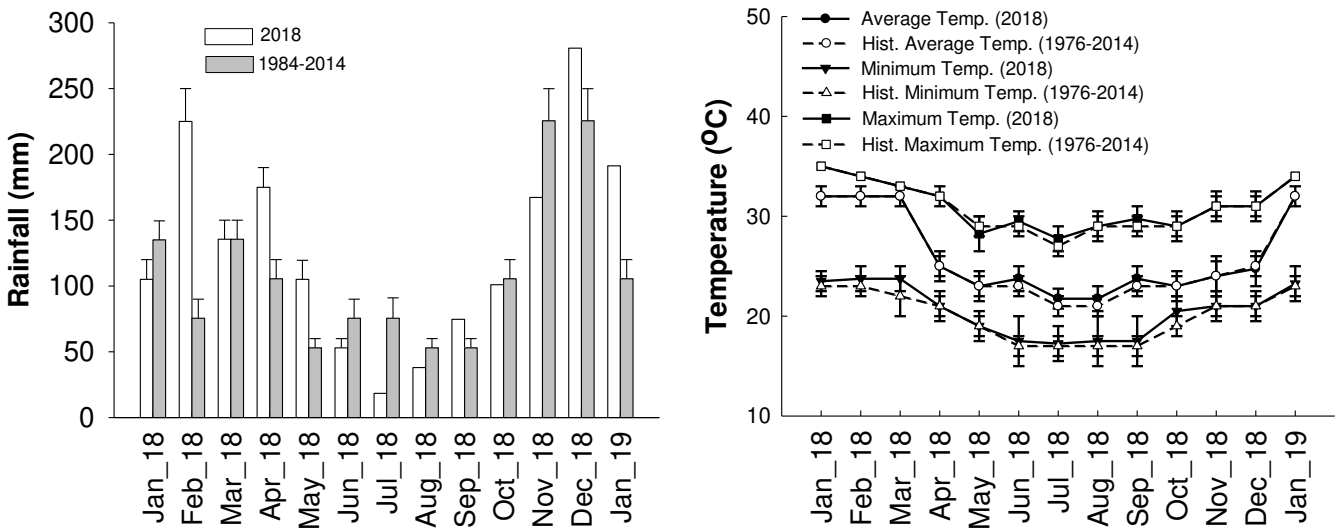

Figure 1. Data of rainfall (mm) and of temperature (average, minimum and maximum, in ^{0}C) throughout 2018 and historical data (1984 to 2014), in the municipality of Linhares, Espírito Santo, Brazil. Intervals (I) represent the variation range. The data were compiled from Medeiros et al. (2018a, b, c, d) and obtained from a climatological station installed in the location of the trial.

Table 1. Contents of macronutrients in compartments diagnostic leaf, shell and almond, in six cocoa clones, grown in full sun in the municipality of Linhares, ES.

Clone	Macronutrients					
	N	P	K	Ca	Mg	S
	Leaf Content					
	---------- g kg $^{-1}$ ----------					
CCN 51	21.04 (12.96) b	1.67 (11.51) a	14.77 (15.99) a	12.09 (20.16) c	5.97 (14.70) c	2.16 (10.63) a
PH 16	22.56 (11.26) a	1.69 (12.39) a	15.92 (17.79) a	12.04 (31.58) c	5.37 (12.90) d	2.04 (11.24) a
PS 1319	18.90 (12.85) c	1.34 (20.13) b	12.52 (15.78) b	14.56 (25.76) b	6.15 (16.40) c	1.93 (22.14) b
CCN 10	20.17 (8.71) b	1.35 (26.98) b	12.52 (18.01) b	15.22 (23.78) b	6.90 (13.96) b	2.21 (14.92) a
CP 49	18.95 (12.60) c	1.21 (28.03) b	10.07 (27.56) c	18.15 (27.58) a	7.80 (15.87) a	1.95 (18.70) b
SJ 02	17.84 (16.57) c	1.19 (21.04) b	12.49 (20.36) b	16.35 (16.41) b	6.81 (10.16) b	1.80 (19.22) b
Mean	19.91	1.41	13.04	14.73	6.50	2.01
CV (%)	12.57	19.09	18.52	25.36	14.51	15.74
	Content in the Shell					
	---------- g kg $^{-1}$ ----------					
CCN 51	12.23 a	1.43 a	19.18 a	2.95 b	2.91 a	1.88 a
PH 16	13.04 a	1.39 a	19.53 a	3.83 a	2.71 a	1.89 a
PS 1319	10.68 a	1.09 a	19.99 a	2.37 b	2.23 a	1.63 b
CCN 10	12.58 a	1.20 a	20.16 a	3.47 a	3.04 a	1.97 a
CP 49	11.76 a	1.24 a	18.90 a	3.23 b	2.60 a	1.66 b
SJ 02	11.94 a	1.37 a	19.57 a	4.34 a	3.41 a	1.79 a
Mean	12.03	1.29	19.55	3.36	2.82	1.80
CV (%)	20.04	20.60	19.82	26.35	22.2	6.61
	Content in the Almond					
	---------- g kg $^{-1}$ ----------					
CCN 51	21.30 a	4.20 b	09.44 a	0.89 a	3.34 a	1.44 a
PH 16	22.01 a	4.02 b	10.49 a	1.04 a	3.32 a	1.41 a
PS 1319	22.19 a	4.00 b	10.57 a	0.92 a	3.44 a	1.42 a
CCN 10	22.56 a	4.82 a	10.35 a	1.17 a	3.67 a	1.35 a
CP 49	22.43 a	4.19 b	10.06 a	0.91 a	3.38 a	1.41 a
SJ 02	20.33 a	3.97 b	9.61 a	1.19 a	3.20 a	1.50 a
Mean	21.80	4.2	10.08	1.02	3.39	1.42
CV (%)	12.39	8.18	10.14	22.76	8.3	7.52

Means followed by the same letter, in the columns, do not differ from each other by the Scott-Knott test at 5% probability. Numbers in brackets correspond to the coefficient of variation of the mean: CV = (SD/$\bar{x}$) * 100.

Table 2. Order of nutrient contents in the diagnostic leaves, of different cocoa clones, grown in full sun in the municipality of Linhares, ES.

Clone	Descending order of nutrient content.
CCN 51	N>K>Ca>Mg>S>P>Mn>Zn>B>Fe
PH 16	N>K>Ca>Mg>S>P>Mn>Zn>B>Fe
PS1319	N>Ca>K>Mg>S>P>Mn>Zn>B>Fe
CCN 10	N>Ca>K>Mg>S>P>Mn>Zn>Fe>B
CP 49	Ca>N>K>Mg>S>P>Mn>Zn>B>Fe
SJ 02	N>Ca>K>Mg>S>P>Mn>Zn>B>Fe

Table 3. Contents of micronutrients of compartments diagnostic leaf, shell and almond of six cocoa clones grown in full sun in the municipality of Linhares, ES.

Clone	Micronutrients				
	Cu	Fe	Zn	Mn	B
	Leaf Content				
	---------- mg kg $^{-1}$ ----------				
CCN 51	16.46 (53.20) a	31.83 (17.21) a	67.90 (24.18) a	75.46 (32.82) b	37.98 (24.82) a
PH 16	11.38 (52.51) b	35.47 (38.88) a	65.94 (21.78) a	120.35 (51.19) b	40.11 (23.96) a
PS 1319	33.58 (43.43) a	29.01 (31.30) a	56.55 (26.46) b	135.66 (44.18) b	41.03 (22.09) a
CCN 10	29.39 (50.27) a	44.55 (70.86) a	54.44 (26.38) b	111.19 (48.27) b	35.60 (19.08) a
CP 49	21.42 (85.11) b	26.95 (25.47) a	56.27 (28.58) b	398.65 (73.35) a	40.70 (21.92) a
SJ 02	4.15 (62.06) c	38.16 (49.33) a	54.44 (25.22) b	105.73 (33.60) b	38.52 (19.60) a
Mean	20.53	32.66	59.25	157.84	38.99
CV (%)	73.33	64.56	25.16	71.76	23.49
	Content in the Shell				
	---------- mg kg $^{-1}$ ----------				
CCN 51	6.01 a	16.72 a	45.38 a	11.42 b	19.69 a
PH 16	6.97 a	12.00 a	37.40 b	18.11 a	16.61 a
PS 1319	6.92 a	14.45 a	36.83 b	7.96 b	10.24 b
CCN 10	7.27 a	14.06 a	40.56 b	18.45 a	19.45 a
CP 49	6.92 a	9.18 a	37.74 b	26.90 a	16.82 a
SJ 02	7.88 a	10.51 a	39.57 b	15.35 b	10.24 b
Mean	6.99	12.82	39.58	16.36	15.51
CV (%)	24.09	77.87	13.05	48.84	26.04
	Content in the Almond				
	---------- mg kg $^{-1}$ ----------				
CCN 51	13.03 b	29.49 a	55.71 a	14.13 b	15.42 a
PH 16	17.69 a	25.19 a	50.58 b	13.92 b	11.08 b
PS 1319	15.27 b	27.18 a	42.88 c	11.04 b	9.25 b
CCN 10	17.22 a	27.03 a	47.66 b	17.87 a	15.39 a
CP 49	16.80 a	27.25 a	48.32 b	15.93 a	11.17 b
SJ 02	19.95 a	31.13 a	58.68 a	12.89 b	9.20 b
Mean	16.66	27.88	50.64	14.30	11.92
CV (%)	14.73	23.3	7.34	16.5	38.67

Means followed by the same letter, in the columns, do not differ from each other by the Scott-Knott test at 5% probability. Numbers in brackets correspond to the coefficient of variation of the mean: CV = (SD/$\bar{x}$) * 100.

Table 4. Adequate sufficiency ranges established for cocoa clones grown in full sun in the municipality of Linhares, ES.

Clone	N	P	K	Ca	Mg	S	Cu	Fe	Zn	Mn	B
	----------g kg $^{-1}$----------						----------mg kg $^{-1}$----------				
PS 1319	18-20	1.1-1.6	10.6-14.4	10.8-18.4	5.2-7.2	1.5-2.3	17.9-49.3	20.6-37.4	42.1-71.0	80.4-190.9	31.4-50.7
CCN 51	19-23	1.5-1.9	12.5-17.1	9.5-14.70	5.1-6.9	1.9-2.4	7.6-25.3	26.0-37.7	50.7-85.1	48.8-102.2	27.8-48.2
CCN 10	19-22	1.0-1.7	10.3-14.8	11.5-19.0	5.9-7.9	1.9-2.5	14.7-44.1	3.9-85.2	40.2-68.7	61.5-160.9	28.3-42.9
SJ 02	17-19	0.9-1.4	10.1-14.9	13.6-19.1	6.1-7.5	1.5-2.1	9.7-31.6	22.2-54.2	46.7-75.1	70.0-141.5	31.0-46.1
CP 49	18-20	0.9-1.5	7.4-12.70	12.9-23.4	6.5-9.1	1.6-2.3	4.7-38.1	2.6-67.6	40.5-72.0	149.7-647.6	31.4-50.0
PH 16	21-24	1.5-1.9	13.0-18.8	8.4-15.70	4.7-6.0	1.8-2.3	0.7-22.0	5.6-65.3	50.9-81.0	33.9-206.9	29.7-50.6
Average	17-23	1.1-1.7	10.0-16.1	10.5-19.0	5.3-7.7	1.7-2.4	3.5-37.6	10.1-61.3	44.7-76.0	2.1-313.6	29.9-48.1

The ranges were established considering $\mu \pm \sigma$, *n= 14*. Considering the same condition of cultivation and clone, superior or inferior values to the superior or inferior limit of the range indicate an excess or insufficiency of the nutrient, respectively. Data presented a normal distribution (Shapiro-Wilk, Kolmogorov-Smirnov or Cramer-von Mises.). Yield of dried almond- CCN 51: 2889,8 kg/ha; PH 16: 2083,5 kg/ha; PS 1319: 2470,5 kg/ha; CCN 10: 1220,4 kg/ha; CP 49: 1655,1 kg/ha and SJ 02: 1526,2 kg/ha.

Table 5. Exportation of macronutrients for shell, almond and fruit in six cocoa clones grown in full sun in the municipality of Linhares, ES.

Clone	Macronutrients								
	N			P			K		
	shell	almond	fruit	shell	almond	fruit	shell	almond	fruit
	kg t^{-1}			kg t^{-1}			kg t^{-1}		
CCN 51	13.92 b	21.31 a	35.23 b	1.67 c	4.20 b	5.87 b	21.93 b	9.44 a	31.37 b
PH 16	15.40 b	22.01 a	37.41 b	1.62 c	4.02 b	5.65 b	23.28 b	10.49 a	33.78 b
PS 1319	11.32 b	22.19 a	33.51 b	1.18 c	4.00 b	5.18 b	21.60 b	10.57 a	32.17 b
CCN 10	16.15 b	22.56 a	38.71 b	1.48 c	4.82 a	6.31 b	26.25 b	10.35 a	36.61 b
CP 49	33.00 a	22.43 a	55.43 a	3.47 a	4.19 b	7.67 a	53.27 a	10.06 a	63.33 a
SJ 02	19.94 b	20.33 a	40.27 b	2.40 b	3.97 b	6.36 b	34.25 b	9.61 a	43.87 b
Mean	18.29	21.80	40.10	1.97	4.20	6.17	30.01	10.09	40.20
CV (%)	39.26	12.40	21.16	44.61	8.16	17.00	48.54	10.14	35.96
Clone	Ca			Mg			S		
	shell	almond	fruit	shell	almond	fruit	shell	almond	fruit
	kg t^{-1}			kg t^{-1}			kg t^{-1}		
CCN 51	3.28 b	0.89 b	4.18 b	3.44 b	3.35 a	6.79 b	2.19 b	1.44 a	3.63 b
PH 16	4.42 b	1.05 a	5.47 b	3.25 b	3.32 a	6.58 b	2.25 b	1.41 a	3.66 b
PS 1319	2.57 b	0.92 b	3.49 b	2.47 b	3.44 a	5.91 b	1.78 b	1.42 a	3.20 b
CCN 10	4.50 b	1.17 a	5.67 b	3.77 b	3.67 a	7.44 b	2.52 b	1.35 a	3.87 b
CP 49	8.85 a	0.91 b	9.77 a	7.02 a	3.38 a	10.40 a	4.57 a	1.41 a	5.99 a
SJ 02	7.45 a	1.19 a	8.65 a	5.45 a	3.20 a	8.65 a	3.06 b	1.50 a	4.57 b
Mean	5.18	1.02	6.20	4.23	8.26	7.63	2.73	1.43	4.15
CV (%)	52.20	22.76	45.47	36.10	3.39	21.00	37.70	7.17	24.53

Means followed by the same letter, in the columns, do not differ from each other by the Scott-Knott test at 5% probability; Fruit = shell + almond. Yield of dried almond- CCN 51: 2889,8 kg/ha; PH 16: 2083,5 kg/ha; PS 1319: 2470,5 kg/ha; CCN 10: 1220,4 kg/ha; CP 49: 1655,1 kg/ha and SJ 02: 1526,2 kg/ha

Table 6. Exportation of macronutrients for shell, almond and fruit (shell + almond) in six cocoa clones grown in full sun, in the municipality of Linhares, ES.

Clone	Micronutrients				
	Cu	Fe	Zn	Mn	B
	Shell				
	g t^{-1}				
CCN 51	67.88 b	201.06 a	519.35 b	130.42 b	224.45 b
PH 16	83.12 b	148.76 a	441.09 b	217.91 b	192.05 b
PS 1319	74.61 b	161.70 a	402.03 b	90.72 b	107.88 b
CCN 10	88.78 b	176.35 a	517.90 b	230.81 b	258.03 b
CP 49	198.89 a	291.66 a	1062.40 a	796.84 a	478.29 a
SJ 02	136.10 a	154.03 a	659.22 b	282.51 b	246.44 b
Mean	108.23	188.93	600.33	291.53	251.19
CV (%)	54.99	108.83	38.10	91.74	48.96
Clone	Almond				
	g t^{-1}				
CCN 51	13.03 b	29.49 b	55.71 a	14.13 b	15.42 a
PH 16	17.79 a	25.20 b	50.58 b	13.92 b	11.08 b
PS 1319	15.27 b	49.68 a	42.88 c	11.04 b	9.25 b
CCN 10	17.22 a	27.03 b	47.66 b	17.87 a	15.40 a
CP 49	16.80 a	27.25 b	48.32 b	15.93 a	11.18 b
SJ 02	19.95 a	31.13 b	58.68 a	12.89 b	9.2 b
Mean	16.66	31.63	50.64	14.30	11.92
CV (%)	14.73	37.52	7.34	16.50	38.67
Clone	Fruit				
	g t^{-1}				
CCN 51	80.92 b	230.55 a	575.07 b	144.56 b	239.88 b
PH 16	100.81 b	173.96 a	491.68 b	231.83 b	203.14 b
PS 1319	89.88 b	211.40 a	444.92 b	101.77 b	117.14 b
CCN 10	106.01 b	203.38 a	565.56 b	248.68 b	273.42 b
CP 49	215.69 a	318.92 a	1110.73 a	812.78 a	489.47 a
SJ 02	156.05 a	185.17 a	717.91 b	295.40 b	255.64 b
Mean	124.89	220.56	650.98	305.83	263.12
CV (%)	48.38	94.73	35.35	87.77	47.73

Means followed by the same letter, in the columns, do not differ from each other by the Scott-Knott test at 5% probability; Fruit = shell + almond. Yield of dried almond- CCN 51: 2889,8 kg/ha; PH 16: 2083,5 kg/ha; PS 1319: 2470,5 kg/ha; CCN 10: 1220,4 kg/ha; CP 49: 1655,1 kg/ha and SJ 02: 1526,2 kg/ha.

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GENERAL CONCLUSION

- Cocoa presents physiological traits favorable to the cultivation in full sun.
- Clone CCN 51 was the most productive.
- Clones PS 1319, CP 49, PH 16 and SJ 02 cultivated in full sun presented high yield potential, mainly due to a higher number of fruits per plant (NFP).
- The importance of the greatest IWDS is pointed out as a compensatory factor of the smallest NFP and the smallest number of seeds (NS) in clone CCN 10, allowing for yield comparable to clone SJ 02.
- The cultivation of cocoa in full sun is promising, given the high yields achieved;
- Clones PS 1319, CCN 10, CCN 51, PH 16, SJ 02 and CP 49 present varied nutritional sufficiency ranges;
- The values of nutrient exportations among clones and their partitions in the fruits alert to the need of nutritional management at the clone level, for greater accuracy in the recommendations;
- The use of the shell as an organic fertilizer may represent the replacement between 32 and 95% of the nutrients exported by the fruits.