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RESEARCH ARTICLE

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Effectiveness of different traps and lures for coffee berry borer, *Hypothenemus hampei* (Ferrari, 1867) in São Tomé Island

M Carvalho[1,2], A Lopes[2], A Bento[3], L Santos[2], RNC Guedes[4] and PA Casquero[1]*

[1]*Universidad de León, Department of Engineering and Agricultural Sciences, Environment Institute Natural Resources and Biodiversity, León, Spain*
[2]*Center of Technological and Agricultural Investigation of São Tomé and Principe, Experimental Base of Industrial Crops (CIAT/STP-BECI), Potó Madalena, São Tomé*
[3]*Mountain Research Center (CIMO), ESA, Polytechnic Institute of Bragança, Santa Apolónia Campus, Bragança, Portugal*
[4]*Departamento de Entomologia, Universidade Federal de Viçosa, Viçosa, MG, 36570-900, Brazil*

Coffee berry borer, *Hypothenemus hampe*i (Ferrari, 1867), is a serious insect pest of organic coffee plantation in São Tomé Island. To date, limited information regarding the seasonal phenology of this pest species on the islands limits the implementation of integrated pest management (IPM) programmes. As part of a coffee farmer training programme, three attractants were evaluated in red *vs*. transparent traps to assess olfactory and visual stimuli. The experiment was delineated in a split-block design with three types of attractants: commercial ethanol + 40 g of ripe Robusta coffee (A1), proportion 3:1 methanol and ethanol (A2), and commercial ethanol + 10 g of ground roasted Arabica coffee (A3); and two home-made transparent (D1) and red (D2) traps. The results showed that there was significant interaction between the trap model and the attractant for borer capture. The transparent trap baited with methanol and ethanol exhibited the best result with an average of 14.3 ± 5.4 adults/trap/week. Transparent traps baited captured more borers and largest numbers of beetles were trapped late May through September. In short, home-made traps alone are not effective for controlling the coffee berry borer, but they are useful in monitoring this species.

CORRESPONDENCE
PA Casquero

EMAIL
pacasl@unileon.es

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INTRODUCTION

Coffee remains the most important export crop for many countries both in terms of earnings and its impact on socio-economic life of the rural folk engaged in its production. Many African producer countries depend almost entirely on foreign exchange earnings from coffee exports, while large sections of their population earn their livelihood from coffee cultivation, processing and marketing establishments (Kucel et al. 2009). Agriculture is the most important economic sector in the West African island nation of São Tomé and Principe, located on the Equator in the Gulf of Guinea. Coffee is the sixth most important export crop of the island after palm oil, cacao, copra, copra oil, and pepper in the islands, thriving in the volcanic soils and equatorial climate (INE 2021). In recent years, there has been a significant decline in coffee production due to phytosanitary problems (Espírito Santo 2008), especially as a result of direct and indirect damage caused by different pest species. Among the most important insect pests in coffee plantations worldwide, the coffee berry borer (CBB), *Hypothenemus hampei* (Ferrari, 1867) (Coleoptera: Curculionidae, Scolytinae) is considered the most damaging, as it reduces both crop quality and yield (Bustillo-Pardey 2006; Messing 2012; Vega & Hofstetter 2015), with losses over US$500 million annually (Infante 2018). This species originated in Central Africa (Infante et al. 2009; Gauthier 2010) and was first discovered in São Tomé and Principe in 1929 (Kaden 1930), but was of little economic significance at the time (de Carvalho 1968).

Control of this pest is carried out differently depending on the cultivation system (Bustillo-Pardey 2006), and it has been hindered by two main factors: the cryptic nature of the insect (i.e., protected inside the coffee berry), and the presence of unharvested or fallen coffee berries in the field allowing the survival of the pest from one season to the next (Infante 2018). CBB control has primarily been based on the use of synthetic insecticides (Brun et al. 1989; Souza et al. 2013). Management strategies have focused on the use of African parasitoids (*Cephalonomia stephanoderis*, *Prorops nasuta* and *Phymastichus coffea*), a fungal entomopathogen (*Beauveria bassiana*) (Bustillo-Pardey 2005; Vera-Montoya et al. 2007), and insect traps (Infante 2018).

Several trap models for CBB mass capture have been developed by many authors, since the early development (Mendoza 1991) of the "ESALQ-84" traps (Berti & Flechtmann 1986), and the multiple funnel model (Lindgren (1983). The ESALQ-84 was developed from the modification of the Luiz de Queiroz trap model at the Luiz de Queiroz School of Agriculture, University of São Paulo, Brazil (Berti & Flechtmann 1986). Lindgren's trap (multiple funnel model/party trap) was developed later in Costa Rica; this trap comprises three white disposable cups.

Apart from these experiments, and with the exception of the party trap in Costa Rica, the multiple funnel trap was not as widely used (Borbón et al. 2000). The ESALQ-84 model sparked more interest, from which similar models emerged, like the "Hampei" (Gutiérrez-Martínez et al. 1993) and the "Ecobroca" traps (Velasco et al. 1999) in Mexico. In Colombia, an artisanal trap was developed by CENICAFÉ (Herrera (1997).

PROCAFÉ in El Salvador and CIRAD of France developed the red coloured "Brocap®» trap (González & Dufour 2000), which has been validated in several Latin American countries

(Cárdenas 2000; Dufour 2002; Guzmán & Contreras 2003; Barrera et al. 2004a; García-Verdugo et al. 2004). Currently, due to demand in several countries, this trap is possibly the only patented one marketed under a trademark for borer control (Barrera et al. 2006). However, in recent years, different models of home-made traps from different types of plastic packaging, mainly polyethylene terephthalate (PET) bottle traps (Gutiérrez-Martínez et al. 1993, Barrera et al. 2006), have stood out. The "IAPAR" trap developed by researchers from the Agronomic Institute of Paraná, Brazil (Villacorta et al. 2001), defined one of the most interesting concepts of the home-made trap, combining low cost (recyclable materials) and ease of manufacturing and handling (accessible to producers) with mass capture efficiency. Taking this concept into account, the "ECOIAPAR" trap was created as a result of the combination of ECOSUR and IAPAR traps (Barrera et al. 2006). Therefore, the use of chemically-baited traps for mass capturing of CBB adults may provide an efficient and inexpensive alternative for CBB control (Moreno et al. 2010; Fernandes et al. 2011). Over the years, several studies have been carried out using trap attractants containing a mixture of alcohols, such as ethanol and methanol, for CBB mass capture (Mathieu et al. 1997; Dufour & Frérot 2008; Rostaman & Prakoso 2020). An attractant mixture of ethanol (99.9% purity) and methanol (100% purity), in the proportion of 1:3, is efficient in the mass capture of CBB adults (Barrera et al. 2004; Barrera et al. 2006; Dufour & Frérot 2008; Pereira et al. 2012).

In São Tomé and Principe, organic coffee plantations (Agroforestry) are predominant and the Biological Coffee Export Cooperative (CECAFEB) has shown enormous growth through the expansion of the domestic market. In CECAFEB, *Coffea arabica L.* and *C. canephora* Pierre ex A. Froehner (Robusta), are grown on about 560 ha, from which 552 farmers produce an estimated 86,300 kg of cherries valued at €48 328 in the 2018/2019 harvest (CECAFEB 2020). Despite the favourable economic climate, CECAFEB faces some difficulties, especially regarding pest management, including the control of the CBB. Various pests, including CBB, present major difficulties for the Islands' coffee industry, resulting in low coffee yield and quality, and reduction in product value (Barrera 2002; Bustillo-Pardey 2006; Burbano et al. 2011). Initially, CECAFEB used neem oil for CBB control with no significant impact on the pest species population (CECAFEB 2014). Neem oil was replaced by the use of *Bacillus thuringiensis* (Dipel®), which proved effective in CBB control, but was banned in organic coffee production (COLEACP 2020). Currently, CECAFEB is using home-made transparent traps with two openings with attractants containing ethanol for CBB mass capturing (CECAFEB 2020). Sanitation, including the complete removal of coffee berries from the trees and ground after the main harvest, is the most important aspect of any IPM programme for CBB (Benavides et al. 2003; Ruiz-Cárdenas & Baker 2010; Constantino et al. 2017). However, this cultural control practice is particularly difficult in regions such as São Tomé and Principe, which has year-round growing conditions that require continuous harvesting (da Silva 1958).

In the present study, we evaluated three CBB attractants in red vs. transparent traps to assess potential for using mass trapping for CBB mass trapping.

MATERIALS and METHODS

Study area

São Tomé Island is located at latitude 0° and longitude 6°30′E with an area about 859 km² and is dominated by a volcanic mountain, which culminates at 2024 m above sea level (asl). São Tomé's climate is sub-equatorial with very high rainfall. The average annual rainfall varies from 1.5 mm to 1 000 mm in the low altitude (north and northeast) to more than 230 mm to 6 000 mm in the high altitude (south and south-west). The driest months are June, July, and August and the wettest months are March, April, and May. The annual atmospheric humidity is very high and annual average temperature at sea level is 25.4 °C (Afonso 1969; World bank 2017).

Our studies were conducted in two coffee plantations of CECAFEB located in two regions. More details of experimental areas are shown in Table 1. The cultural practices on these coffee plantations are: weeding, pruning and prophylactic harvesting, with the exception of pesticide use.

Trapping design

The experiments were carried out from August to December 2018 and from January to July 2019 in two plots belonging to the Biological Coffee Export Cooperative (CECAFEB) (Bem-Posta and Novo Destino (São Tomé Island). Thirty traps were distributed per hectare to cover the entire area (Fernandes et al. 2014), and monitored monthly. The traps were spaced at 10 m intervals according (Pan-UK 2014), placed in August of 2018, and finished in July 2019. For surface areas and the characteristics, refer to the data in Table 1.

The traps used were the "ECOIAPAR" design (Figure 1). Traps were attached to the tree approximately 1.5 m above the ground level (Barrera et al. 2004; Aristizábal et al. 2016) with galvanised wire. At the bottom of the trap, 120 ml of water with 5% neutral detergent were added (Barrera et al. 2004; Dufour & Frérot 2008).

Attractant A1 consisted of 40 g of ripe Robusta coffee berry pulp in 1 l of commercial ethanol (96% purity). The coffee berry pulp was allowed to sit for 4 days in the ethanol prior to use in the traps to ensure that all volatiles contained in the pulp were

Table 1. Details of experimental coffee plots in São Tomé Island

Location	Bem-Posta	Novo Destino
Coordinates (UTM)	235805.0, 35496.0	235301.0, 34253.0
Height above sea level (m)	744	647
Annual average temperature (ºC)	23	23
Average rainfall (mm)	1514.9	1514.9
Relative humidity (%)	85.5	85.5
Plant distance (m)	2 x 2	1 x 2
Age (years)	4	4
Topography	Inclined	Inclined
Area (ha)	1.0	1.0
Trap	30	30
Variety	Caturra	Caturra

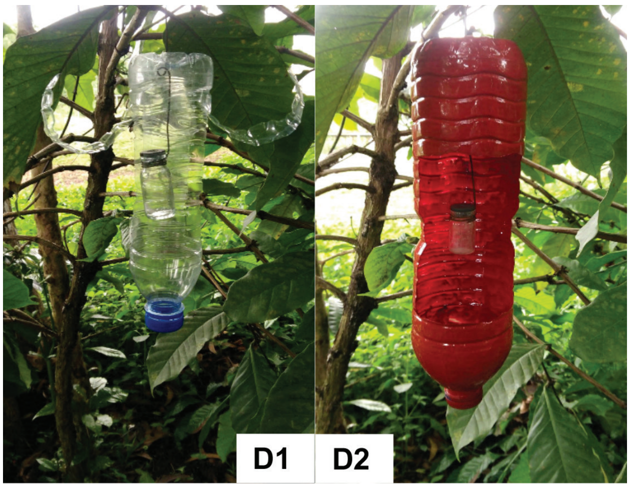

Figure 1. Trap **D1** (transparent traps made of 0.5-l "PET" bottles, with two rectangular side openings (3 × 11 cm)) and **D2** (red trap made of 1.5-l "PET" bottles, with one rectangular side opening (10 × 15 cm) and painted with red RGB (128,0,0) oil paint). Photographs by M Carvalho

adequately released into the ethanol. This mixture release rate was 0.67 ml/day. Attractant A2 contained a mixture of ethanol (96.0% purity) and methanol (100% purity) in the proportion of 1:3 (Moreno et al. 2010; Rosalía et al. 2015). This mixture release rate was 1.3 ml/day. Finally, attractant A3 was a blend of commercial ethanol (96.0% purity) + 10 g of ground roasted Arabica coffee per litre with a release rate 0.67 ml/day. The fluid inside the traps was changed at each evaluation. More details of experimental are shown in Table 2.

Experimental design

The experiment was delineated into "split blocks" where the main or large blocks were the trap types and the small blocks (sub-blocks) were the different types of attractants. Five replicates were used for each treatment. The size of each sub-block was 33 × 50 m. More details of experimental coffee plantation are shown in Table 2.

Each trap was checked monthly and the contents filtered through a fine-mesh sieve. The filtered trap contents were placed into plastic bags with 70% ethanol. CBB adults were counted under 20× magnification using a stereoscope and other insects/beetles in the traps were separated (Moreno et al. 2010; Fernandes et al. 2011; Johnson et al. 2018). We also sampled borer populations in Bem-Posta using a scheme 30-tree sampling of fruits following the "CENICAFÉ method" (Bustillo et al. 1998), to evaluate the trap effectiveness or to determine whether the trapping reduced damage to the fruits. Infestation levels were calculated by equation 1.

$$\text{Infestation level} = \frac{\text{Total infested green berries with CBB}}{\text{Total counted coffee berry}} \quad (1)$$

Data analysis

Data analysis was carried out with IBM SPSS Statistics 23. Analyses of variance (ANOVA) were performed with trap type and attractant as independent variables and the treatment means were subjected to Tukey's HSD test ($P < 0.05$), whenever appropriate. Correlation analysis (Pearson's r) was performed between numbers captured and fruit infestation levels of CBB.

RESULTS

Attractant in home-made trap baited against *Hypothenemus hampe*i

The trap D1A2 produced the highest adult numbers captured per week (14.3 ± 5.4; mean ± standard error (SE)) and the trap D2A1 had the lowest catches (1.3 ± 0.8). There was a significant interaction (df = 806, F = 13.43, $P < 0.001$ between trap model and attractant in CBB mass capture. Significant differences ($P < 0.001$) were observed between D1A2 and the other treatments, but not between D2A3 (3.2 ± 1.3), D1A1 (4.1 ± 1.1) and D2A2 (4.1 ± 1.4) (df = 806, F = 13.43, P = 0.96) (Figure 2).

The D1A2 trap captured an average 215.9 ± 61.3 adults/trap in August, September (542.4 ± 65.2), in October (218.9 ± 54.6), May (436.1 ± 164.7), June (305.1 ± 66.3), and July (448.1 ± 104.1). In contrast, D2A1 captured an average 30.4 ± 8.6 adults/trap in August, February (64.1 ± 33.0), May (47.1 ± 18.2), and June (39.8 ± 11.5). Highly significant differences (df = 806; F = 33.734, $P < 0.001$) were found in the monthly adult capture with the different traps (Figure 3). The D2 trap also captured other beetles, and the D1 trap captured *Ceratitis capitata*.

The highest adult capture rate was achieved with the D1 trap, with an average of 102.2 ± 41.7 adults captured per trap per month in Bem-Posta, and 123.4 ± 59.4 in Novo Destino. The lowest capture was obtained with D2 29.6 ± 14.3 adults captured per trap per month in Bem-Posta, and 50.5 ± 21.1 in Novo Destino. There were significant differences ($P < 0.001$) between traps D1 and D2. The highest CBB capture with the D1 trap was registered in Novo Destino and the lowest in Bem-Posta. There was significant interaction (df = 806, F = 9.842, $P < 0.001$) between trap model and attractant for CBB mass capture. The highest monthly captures were registered in Novo Destino 87.5 ± 7.8 adults/trap/month and with significant differences (P = 0.03) for Bem-Posta which had 65.9 ± 5.8 adults/trap/month (Table 3). The total of CBB captured was 65 765 females.

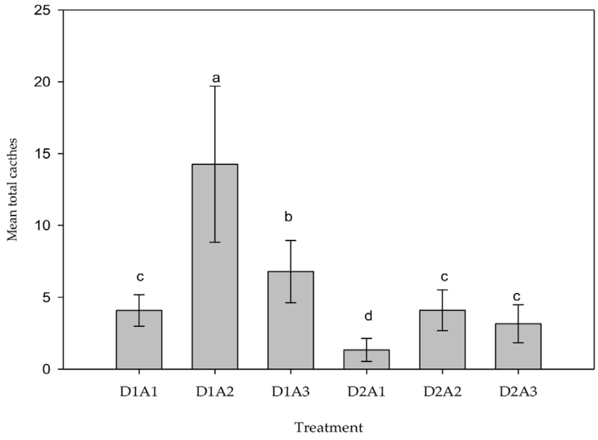

Figure 2. Mean number (± SE) of CBB adults captured per treatment per week, transparent trap baited with ethanol + 40 g of mature Robusta coffee (D1A1), transparent trap baited with 3:1 ratio of methanol and ethanol (D1A2), transparent trap baited with ethanol + 10 g of ground roasted Arabica coffee (D1A3), red trap baited with ethanol + 40 g of mature Robusta coffee (D2A1), red trap baited with 3:1 methanol and ethanol (D2A2) and red trap baited with ethanol + 10 g ground roasted Arabica coffee (D2A3) for 12 consecutive months in Bem-Posta and Novo Destino (São Tomé Island) between August 2018 through July 2019. Bars denoted with the same letters were not significantly different by Tukey HSD test ($P < 0.05$)

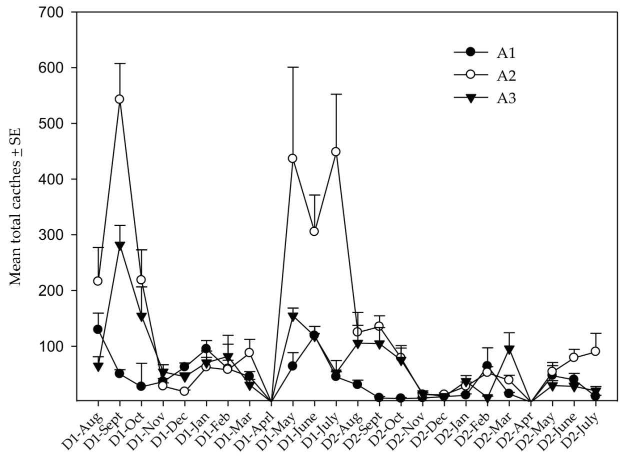

Figure 3. Monthly capture (± SE) of CBB adults (*Hypothenemus hampei*) at "Bem-Posta" and "Novo Destino" during (Augusto 2018 to July 2019) with traps (transparent (D1); red trap (D2)) and ethanol + 40 g of ripe Robusta coffee (A1); proportion 3:1 methanol and ethanol (A2) and ethanol + 10 g of ground roasted Arabica coffee (A3)

Table 2. Details of experiments and treatments

Factors	Treatments
A1: commercial ethanol (96.0%) + 40 g of ripe Robusta coffee	A1D1
A2: proportion 3:1 methanol (100%) and ethanol (96.0%)	A2D1
A3: commercial ethanol + 10 g of ground roasted Arabica coffee	A3D1
D1: transparent trap	A1D2
D2: red trap	A2D2 A3D2

Table 3. Mean total catches and monthly capture of adults of the coffee berry borer (*Hypothenemus hampei*) according to traps (D1 and D2) and different attractant (A1, A2 and A3) for 12 consecutive months in Bem-Posta and Novo Destino between the months of August 2018 and July 2019

Localities	Mean of adults captured monthly Mean ± standard error (SE)					
	Mean total catches	Trap		Attractant		
		D1	D2	A1	A2	A3
Bem-Posta	65.9 ±5.8^{b}	102.2 ± 41.7^{a}	29.6 ± 14.3^{b}	32.0 ± 12.4^{c}	102.3 ± 49.3^{a}	63.4 ± 21.4^{b}
Novo Destino	87.5 ± 7.8^{a}	123.4 ± 59.4^{a}	50.5 ± 21.1^{b}	44.7 ± 17.8^{c}	139.4 ± 67.4^{a}	78.0 ± 32.7^{b}

† ANOVA (localities: *df* =806; $F = 4.846$, $P < 0.028$; traps: df =806; $F = 63.614$. $P < 0.000$; attractants: df = 806; $F = 27.905$, $P < 0.000$ and traps*attractants: df = 806; $F = 9.842$, $P < 0.001$)

† Means followed by the same letter in the column are not significantly different by the Tukey HSD test ($P < 0.05$)

There was no positive correlation between number of CBB captured and infestation level ($r = 0.10$, df=155, $P = 0.56$).

DISCUSSION

We investigated the effectiveness of three attractants in red vs. transparent traps to assess CBB mass capture. Although the number of seasonal CBB generations is unclear, we captured CBB in all months sampled, with highest numbers from late May through September during the weeks following the main harvesting season and the formation of new green berries. The prevailing period of flight activity of CBB occurred in the dry season on São Tomé Island (June through September). In Brazil two peaks (in July and October) in CBB capture usually take place, with the highest peak in July (Oliveira et al. 2018). In this trial the highest peak of CBB capture was recorded in September. The highest number of CBB adults captured were recorded between January and March in Colombia (Aristizábal et al. 2015). High infestations were observed (>250 CBB/trap/week) during berry development, in May and June (Kona, Hawaii) and June and July (Kau, Hawaii) (Aristizábal et al. 2017). In Colombia higher numbers of CBB were captured, peaking in Jan and Feb with an average of 1.65 to 6.12 CBB per trap/week (Aristizábal et al. 2015).

A statistically significant interaction between trap model and attractant was observed in this study. Significant interaction between trap colour and attractant was also observed previously (Mathieu et al. 1997; da Silva et al. 2006a). Several factors are involved in determining the efficiency of the traps. Intrinsic factors, such as colours, attractants, release rates, height above ground, and place of setting (plant or stake), contrast with the landscape, interact with each other and likely interact with characteristics of the environment, e.g. the coffee production system (densely planted, semi-densely planted and conventional), shaded or not, variety, microclimate and relief (da Silva et al. 2006b). Transparent traps with two openings captured more CBB during the field trial, but in lower numbers when compared with another study (Leiva-Espinoza et al. 2019), which captured a maximum of 4.000 CBB/trap/week with red trap (home-made) with five openings in Peru. These results may be explained by the fact that the transparent trap had two openings and the red trap one. In a previous study, we found no statistically significant differences in CBB densities in the two study areas (Carvalho et al. 2021). The multiple funnel trap produced better results for CBB mass capture (Mendoza 1991). The same pattern was observed in Colombia with a five-funnel trap (Cárdenas 2000). Transparent traps are efficient in attracting and capturing the CBB (da Silva et al. 2006a). Transparent traps also proved to be effective in attracting and capturing CBB in this trial. In contrast, many authors highlight that red traps are more efficient than the transparent traps in mass capture of CBB adults (Mathieu et al. 1997; Barrera et al. 2006; Dufour & Frérot 2008). Red trap with alcohol as attractant without essence of coffee is more efficient in the CBB mass capture (Leiva-Espinoza et al. 2019).

Our data suggest that home-made traps can be used for monitoring the CBB, but not for CBB mass-trapping as a management tool, which requires far higher levels of capture. However, the lack of correlation between CBB field infestation and trap capture numbers invites larger scale study in different areas to validate the use of such traps for CBB capturing on São Tomé Island. Other authors have suggested that traps baited with methanol and ethanol could be used to monitor flight activity so that the timing of pesticide sprays could be improved (Aristizábal et al. 2016). Many papers highlight that traps should not be used alone for CBB control; rather they shoud be one component of multi-faceted IPM programmes to be implemented (Infante 2018).

CONCLUSIONS

From the results obtained, it can be concluded that the traps caught more CBB from late May through September, because they were more efficient when the humidity is lower in São Tomé Island. Taken together, these findings expand the understanding of the use of trapping systems as a useful strategy for IPM programmes against CBB, and will likely provide novel insights of use in the development of IPM in the near future. All of the attractants tested could be used as tools for monitoring and a possible mass trapping coffee berry borer on coffee crops on São Tomé Island at a low cost and with local availability.

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ORCID IDs

Miclay Carvalho – https://orcid.org/0000-0003-0215-695X
Alex Lopes – https://orcid.org/0000-0002-8560-1491
Albino Bento – https://orcid.org/0000-0001-5215-785X
Luís Santos – https://orcid.org/0000-0002-4709-4505
Raul Guedes – https://orcid.org/0000-0001-6229-7549
PA Casquero – https://orcid.org/0000-0002-4432-9794

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