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Translocation of pesticides in coconut palm by endotherapy with the addition of different adjuvants

Joana Maria Santos Ferreira[I], Jordana Alves Ferreira[II], Viviane Talamini[III]
Paulo Manoel Pontes Lins[IV], Samuel Christian Cohen Farias[V]
Carla Beatriz Grespan Bottoli[VI]

ABSTRACT

Commercial pesticides were selected, mixed and applied in coconut stems (*Cocos nucifera* Linn.) by endotherapy with various adjuvants. Tissue samples from the coconut stem were collected at different heights and days, and subjected to extraction and analysis by modified QuEChERS ("Quick, Easy, Cheap, Effective, Rugged and Safe") and UHPLC-MS/MS (ultra-high-performance liquid chromatography–tandem mass spectrometry). The translocations of 3-hydroxy-carbofuran, carbendazim, carbofuran, difenoconazole, imidacloprid, thiabendazole, thiamethoxam, thiophanate-methyl and spirodiclofen, using salts, citric acid and organosilicones as adjuvants, were evaluated and compared 2 and 30 days after the applications. The results showed that each pesticide had a different translocation profile, modified by the presence of the adjuvants. The most significant modifications were obtained using organosilicones, which enhanced the translocation process by 40% for most pesticides, followed by acidification (30%) and the addition of salts (22%).
Keywords: *Cocos nucifera* Linn; Adjuvants; Stem; Organosilicones; Acidification

RESUMO

Os defensivos agrícolas comerciais foram selecionados, misturados e aplicados no estipe de coco (*Cocos nucifera Linn.*) por endoterapia com vários adjuvantes. As amostras de tecido do estipe do coco foram coletadas em diferentes alturas e dias, e submetidas à extração e análise por pelo método QuEChERS modificado e UHPLC-MS / MS (cromatografia líquida de ultra eficiência acoplada à espectrometria de massas sequencial). Foram avaliadas as translocações de 3-hidroxi-carbofurano, carbendazim, carbofurano, difenoconazol, imidacloprid, tiabendazol, tiametoxam, tiofanato-metil e espirodiclofeno, utilizando sais, ácido cítrico e organossilicones como adjuvantes, 2 e 30 dias após as aplicações. Os resultados mostraram que cada defensivo tinha um perfil de translocação diferente, modificado pela presença dos adjuvantes. As modificações mais significativas foram obtidas com organossilicones, o que aumentou o processo de translocação em 40% para a maioria dos defensivos, seguido de acidificação (30%) e adição de sais (22%).
Palavras-chave: *Cocos nucifera* Linn; Adjuvantes; Estipe; Organossilicones; Acidificação

I Department of Agricultural Engineering, Embrapa - Aracaju, SE, Brazil - joana.ferreira@embrapa.br
II Institute of Chemistry, University of Campinas, SP, Brazil - jordanaalvesferreira@gmail.com;
III Department of Agricultural Engineering, Embrapa - Aracaju, SE, Brazil - viviane.talamini@embrapa.br
IV Sococo Agroindústria da Amazônia, Pará, Brazil - paulom@sococo.com.br
V Sococo Agroindústria da Amazônia, Pará, Brazil - samuelc@sococo.com.br
VII Institute of Chemistry, University of Campinas, SP, Brazil - carlab@iqm.unicamp.br

1 INTRODUCTION

The coconut palm (*Cocos nucifera* Linn.) is the most cultivated palm, especially due to the importance of its fruits in the oil industry worldwide, as well in the food industry of Brazil (Foale, 2003; Ferreira et al., 2015).

The attacks of diseases and pests on the coconut leaves and fruits is the major concern of researchers/producers in protecting plantations. Spraying is the traditional, and simplest method for applying pesticides to coconut palms in order to minimize outbreaks. Spraying of the coconut foliar crown shows some disadvantages in disease and pest management, mainly due to the lack of equipment appropriate to the height of the plants (Wang and Liu, 2007; Menon and Pandalai, 1958; Doccola and Wildo, 2012), to the amount of pesticide particles lost to wind during application, and higher treatment costs, as well as to the contamination caused to the environment and to human health. An innovative application method, known as endotherapy, or systemic or xylematic practice, has been studied as a tool, in order to improve pesticides to reaching their target efficiently when applied directly into the tree trunks by injection or infusion (Montecchio, 2013). Endotherapy has been used successfully in species such as apple, pear, cherry, avocado, oil palm, grape and arboriculture. Some studies on the application of pesticides using the endoterapic method of injection into the coconut palm were published using the following active principles: monocrotophos (Patel et al., 1985; Kanagarantnam and Pinto, 1988), dimethoate, phosphamidon, formotion, monocrotophos and demetone-methyl (Nadarajan et al., 1985), thiabendazole (Elliott and Broschat, 2012), phosphite (Yu et al., 2015). However the use of this alternative method for preventing/controlling palms pests and diseases is still poorly understood, due to the lack of analytical methods that might ensure the quantification of pesticides in the plant. Our research group developed a method for quantification of pesticides in the coconut stem that can be used to evaluate pesticide pathways into the plant. Results demonstrated method efficacy in detecting and quantifying pesticide residues in the coconut stem (Ferreira et al., 2015).

The main objectives of this work were to evaluate pesticide pathways in coconut palm when applied to the tree by endotherapy as well as the role played in the translocation process by the adjuvants added to the pesticide mixture.

2 MATERIALS AND METHODS

2.1Chemicals, reagents and apparatus

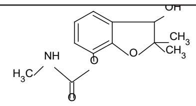
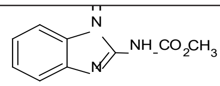
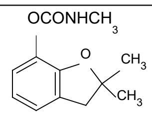
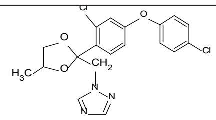
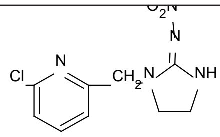
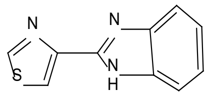
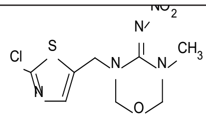
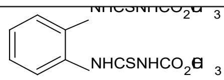
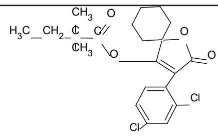
Certified standards of carbendazim, carbofuran, 3-hydroxy-carbofuran (3-OH-carbofuran), carbosulfan, difenoconazole, spirodiclofen, imidacloprid, thiabendazole, thiamethoxam and thiophanate-methyl were acquired from Dr. Ehrenstorfer (Augsburg, Germany). All standards were of at least 95% purity. They are listed in Table 1. Commercial products containing the active ingredients listed above were purchased in agricultural product stores. The adjuvants utilized in these experiments were anhydrous citric acid from Merck (Darmstadt, Germany), Break-thru® from Evonik (Richmond, USA), Silwet-L77® from Momentive (Albany, USA), urea from Fertine (Recife, Brazil), and potassium chloride and sodium chloride from Synth (São Paulo, Brazil). Propylene syringes of 20 mL and sterile plastic bags were purchased locally.

The solvents acetonitrile and methanol were from Mallinckrodt (Phillipsburg, USA) and glacial acetic acid was from J.T. Baker (Oklahoma City, USA) (grade HPLC). Ultrapure water was obtained by Direct UV3® gradient system from Millipore (Molsheim, France). Anhydrous magnesium sulphate ($MgSO_4$) and anhydrous sodium acetate (NaOAc), both reagent grade, were purchased from J.T. Baker (Tokyo, Japan). Bondesil C_{18} sorvent (particles of 40 μm) and primary secondary amine (PSA) were obtained from Agilent Technologies (Santa Clara, USA).

A chainsaw MS 250 from Stihl (São Leopoldo, Brazil), Sartorius CP-225 balance (Göttingen, Germany), PT3100 Rotofix 46 centrifuge (Hettich, Germany) and polypropylene centrifuge tubes (15 and 50 mL) were from Sarstedt (Nümbrecht, Germany).

For the development of this work a PT 3100 Polytron Ultra Turrax (Luzern, Switzerland), IKA® A11 basic analytical mill (Staufen, Germany), QL-901vortex and NT 85 centrifuge mixer were acquired from Nova Técnica (São Paulo, Brazil). The Acquity UPLC™ system (Milford, USA) was equipped with a TQD Quattro Micro API tandem quadrupole mass spectrometer from Waters (Manchester, UK) and had an electrospray ionization interface (ESI). The separations were achieved using an Acquity UPLC BEH C18 column (100 mm x 2.1 mm, 1.7 μm particle size) from Waters. Mobile phase components were: eluent A: ultrapure water:methanol (98:2, v/v) containing 0.1% formic acid and 5 mmol L^{-1} ammonium formate, and eluent B: methanol with 0.1% formic acid and 5 mmol L^{-1} ammonium formate.

Table 1 - Physicochemical properties of selected pesticides*

Pesticides	Class	Chemical Group	K_{ow} Log P	pKa	Chemical Stucture
3-OH-carbofuran	-	-	1.45	-	
Carbendazim	Fungicide	Benzimidazole	1.48	4.2 Weak acid	
Carbofuran	Insecticide, nematicide, acaricide	Carbamate	1.8	No dissociation	
Difenoconazole	Fungicide	Triazole	4.36	1.07 Strong acid	
Imidacloprid	Insecticide	Neonicotinoid	0.57	No dissociation	
Thiabendazole	Fungicide	Benzimidazole	2.39	4.73 pKa (2) 12	
Thiamethoxam	Insecticide	Neonicotinoid	-0.13	No dissociation	
Thiophanate-methyl	Fungicide	Benzimidazole	1.45	7.28 Weak acid	
Spirodiclofen	Acaricide, insecticide	Tetronic Acid	5.83	-	

Reference: Pesticide Properties Database

2.2 Samples

The coconut cultivar selected for this study was the hybrid PB-121, from a 10 years old commercial plantation of SOCOCO S/A Agroindústria da Amazônia, located at Mojú, Pará, Brazil.

2.3 Endotherapic applications with different pesticides and adjuvants into the coconut palm stem

The experimental procedure was performed with a mixture of commercial pesticides containing the active principles: carbendazim, carbofuran, carbosulfan, difenoconazole, spirodiclofen, imidacloprid, thiabendazole, thiamethoxam and thiophanate-methyl, all mixed together in a beaker. An aliquot of 19 mL of each commercial pesticide was taken and homogenized without dilution. Thiophanate-methyl was weighed and mixed with water in a ratio 1:1 (w/v) and a volume of 19 mL was taken and homogenized with the other pesticides. Table 2 presents all treatments tested and the amounts of pesticides and adjuvants for each treatment. The citric acid solutions (pH 3.0) used in treatments 3 and 4 were adjusted to a pH of 3 and the salt solution in treatments 2 and 4 contained 5 g of urea, 2 g of potassium chloride and 2 g of sodium chloride dissolved in 1 liter of water. The organosilicones (T5 and T6) did not have any dilution. Aliquots were taken and added to the mixture of pesticides. The tests were carried out with six different treatments, using two plants for each treatment, for a total of 12 randomly chosen coconut palms. The mixtures were injected into all plants on the same day.

Table 2 – Endotherapic treatments and amount of pesticides and adjuvants applied by trunk injection

Treatments	Amount (mL)
T 01 = only pesticides (mix)[a]	20 mL of mix
T 02 = mix + salts	10 mL of salt solution + 10 mL of mix
T 03 = mix + citric acid	15 mL of mix + 5 mL of citric acid
T 04 = mix + citric acid + salts	15 mL of mix + 5 mL of salt + 5 mL of citric acid
T 05 = mix + Break-thru®	10 mL of mix + 10 mL of Break-thru®
T 06 = mix + Silwet-L77®	10 mL of mix + 10 mL of Silwet-L77®

(a) mix = carbendazim, carbofuran, carbosulfan, difenoconazole, spirodiclofen, imidacloprid, thiabendazole, thiamethoxam and thiophanate-methyl

Two holes on opposite side of the coconut stem, were made at a height of 20 cm above the ground and an angle of 45° and used for the injection of 10 mL into each hole, totaling 20 mL injected into each plant. After injection, each syringe was filled with 40 mL of water and 20 mL were introduced into each hole. The holes were closed with short pieces of green wood and covered with natural tar. Tissue samples from each treatment were collected at points near to the application holes and in the upper portion of the stem, near the coconut palm frond, at intervals of 2 and 30 days after the applications. All the samples from the coconut palm stem were collected and identified in sterile plastic bags and stored in a freezer at –17° C until analysis. To avoid sample contamination, the drill bits were cleaned using formaldehyde and water as solvent between each use.

2.4 Analytical method

The samples were analyzed by an analytical method using QuEChERS and UHPLC-MS/MS, developed and validated by Ferreira *et a*l. (2015) for the determination of pesticides in coconut stem. This analytical method optimized the chromatographic and spectrometric conditions for the pesticides used in this work, as well as all steps of sample preparation, and validation of the modified QuEChERS method.

3 RESULTS AND DISCUSSION

Translocation in coconut palm stem occurs in the transport sap, present in countless bundles, due to a pressure gradient generated *in situ* by the roots when a small amount of water coming from the soil is pumped to the leaves for transpiration. Adjuvants are solutions whose intensions are to increase absorption and translocation of pesticides, enhancing the effectiveness of the active ingredient to the applied area. Adjuvants added to a pesticide solution are frequently used in field applications to improve absorption and translocation of pesticides, as well as to enhance the availability of an active ingredient to a disease or pest target (Wang and Liu, 2007). This group includes surfactants, oils, acids and salts (Doccola and Wildo, 2012).

Pesticide residues obtained from tissue samples collected at different heights above the points of applications were quantified by QuEChERS and UHPLC-MS/MS in μg kg^{-1} of treated coconut stem tissues. The UHPLC chromatographic technique when coupled with QqQ-MS/MS used in the analyses gives some advantages to the determinations, providing high detectivity and selectivity for the identification/quantification of the pesticides and their transformation products even those with high polarity, thermal degradability or low volatility.

The results of this study showed the presence of pesticide residues in the internal tissues of the coconut stem at different heights 2 and 30 days after endotherapic applications, indicating that the translocation process in the plant succeeded (Table 3).

Table 3 - Concentrations of pesticides obtained at different heights of coconut palm stems and different times

Pesticide	T	2 days after application		30 days after application	
		Point nearest of application ($\mu g\ kg^{-1}$)	In the upper portion of stem ($\mu g\ kg^{-1}$)	Point nearest of application ($\mu g\ kg^{-1}$)	In the upper portion of stem ($\mu g\ kg^{-1}$)
Thiamethoxam	T1	555 (8)	128 (1)	477 (14)	<40
	T2	468 (9)	107 (4)	989 (20)	139 (3)
	T3	878 (20)	185 (3)	817 (20)	69 (6)
	T4	534 (20)	90 (5)	66 (5)	<40
	T5	292 (12)	79 (1)	521 (5)	<40
	T6	61 (5)	<40	340 (20)	<40
Carbofuran	T1	344 (10)	62 (3)	641 (20)	74 (8)
	T2	356 (16)	108 (4)	570 (18)	51 (3)
	T3	> 1000	112 (4)	787 (11)	86 (3)
	T4	575 (9)	175 (7)	270 (12)	73 (20)
	T5	> 1000	917 (20)	521 (5)	<40
	T6	381 (9)	99 (3)	398 (20)	196 (12)
Carbendazim	T1	<40	<40	555 (20)	50 (2)
	T2	<40	<40	998 (20)	220 (6)
	T3	476 (14)	<40	>1000	266 (15)
	T4	139 (1)	<40	254 (17)	135 (2)
	T5	327 (19)	<40	963 (20)	121 (3)
	T6	<40	<40	522 (20)	90 (3)
Thiabendazole	T1	<40	<40	537 (20)	57 (3)
	T2	<40	<40	1000 (20)	227 (17)
	T3	429 (20)	<40	>1000	277 (8)
	T4	126 (7)	<40	253 (10)	136 (4)
	T5	277 (15)	<40	949 (20)	118 (7)
	T6	<40	<40	529 (20)	89 (4)
Imidacloprid	T1	268 (16)	61 (6)	278 (2)	55 (5)
	T2	208 (13)	41 (3)	508 (20)	157 (19)
	T3	549 (20)	101 (19)	692 (11)	132 (9)
	T4	217 (4)	74 (8)	133 (10)	60 (20)
	T5	218 (12)	77 (20)	436 (2)	123 (5)
	T6	<40	<40	235 (20)	65 (7)
3-OH-Carbofuran	T1	<40	<40	45 (10)	-
	T2	<40	<40	<40	-
	T3	52 (7)	<40	<40	-
	T4	<40	<40	<40	-
	T5	222 (18)	50 (6)	40 (12)	-
	T6	<40	<40	70 (5)	-
Difenoconazole	T1	<40	<40	<40	-
	T2	<40	<40	<40	-
	T3	<40	<40	<40	-
	T4	<40	<40	<40	-
	T5	437 (20)	141 (6)	355 (20)	273 (8)
	T6	47 (3)	<40	242 (20)	121 (4)
Spirodiclofen	T1	<40	<40	<40	-
	T2	<40	<40	<40	-
	T3	67 (6)	<40	<40	-
	T4	<40	<40	<40	-
	T5	983 (19)	245 (20)	41 (20)	-
	T6	128 (20)	92 (9)	123 (20)	40 (12)
Thiophanate-methyl	T1	<40	<40	<40	<40
	T2	<40	<40	<40	<40
	T3	<40	<40	<40	<40
	T4	<40	<40	<40	<40
	T5	<40	<40	<40	<40
	T6	<40	<40	<40	<40

( ) parentheses means estimate of standard deviation; - means that the concentration found were below of minimum reliable quantification limit (40 $\mu g\ L^{-1}$), Treatments: T1 – mix (carbendazim, carbofuran, carbosulfan, difenoconazole, spirodiclofen, imidacloprid, thiabendazole, thiamethoxam and thiophanate-methyl); T2 – mix + salts; T3 – mix + citric acid; T4 – mix + citric acid + salts; T5 – mix + Break-thru® + T6 – mix + Silwet-L77®. Bold numbers means better treatments for each pesticide

The addition of salts, an organic acid or organosilicon as adjuvants to the pesticide mixture modified the results obtained without these additions. It was observed that these mixtures did not inhibit the detection of the pesticide residues in the internal coconut palm tissues, and may have potentiated the translocation with a broader spectrum of fungicides and insecticides towards the coconut palm frond, which could improve performance in controlling diseases and pests.

Concentration and translocation of pesticide 2 days after application

The concentration of pesticides was obtained from tissues samples collected at a point near to the application and in the upper portion of coconut palm stem 2 days after application. All the pesticides were found at the point nearest application. However, as the pesticides have different classes and chemical structures, the results showed variations in the pesticide concentrations that indicated differences in translocation for each pesticide. Experiments showed that the pesticides were already transported in the first 2 days after the application of treatments. Various pesticides were quantified with values of more than 40 μg kg^{-1}, the limit of quantification of the analytical method used in this work, in samples collected at the point near to the application, as well as in the palm fronds. As can be seen in Table 3, thiamethoxan, carbofuran and imidacloprid were quickly translocated to the upper portion of coconut stem after just 2 days from application, with or without added adjuvants. It demonstrates the rapidity of these compounds in reaching the target, with the exception of treatment T6, in which the translocation of the thiamethoxan and imidacloprid was inhibited by the presence of the organosilicon Silwet-L77® in this time interval. Other pesticides translocated only with the addition of adjuvants, such as spirodiclofen, difenoconazole and 3-OH-carbofuran. However, some pesticides, such as carbendazim and thiabendazole, did not immediately translocate, despite systemic properties. Physicochemical properties of pesticides, such as Kow (solubility) and pKa (ability to penetrate inside through the membranes), can predict the behavior. Xylem mobility kinetics will depend on the composition of the plant tissues, especially the water content and the lipid fraction that determine transport and permeability within the vascular bundles (Sur and Stork, 2003). Some pesticide residues, inject alone or added to adjuvants, could not be quantified, either near the point of application or in the upper portion of the stem, on 2 days, indicating that more time is necessary or that a rapid degradation occurs. Carbendazim and thiabendazole had slower uptake and translocation when compared to other pesticides, while 3-OH-carbofuran (at T1, T2 e T4), difenoconazole and spirodiclofen (at T1, T2, T3 e T4) perhaps had rapid degradations. For the compounds with log K_{ow} 1-3 with different dissociation profiles (Table 1), the translocation was observed and strongly increased with acidification of the treatment solution, as well as with the addition of the organosilicon. This result shows that the flow of xylem sap through the plant membranes benefited from this application. Another hypothesis involves solvation, which can assist the movement into the aqueous phase of the cells (Sun et al., 2014; Chamberlain et al., 1998).

The adjuvants potentiated the translocation of some pesticides. For example, treatment with acidification (T3) enhanced the translocation of the pesticide by 45% for thiamethoxam, 81% for carbofuran and 66% for imidacloprid. The translocation for carbofuran was enhanced in the presence of all adjuvants, with emphasis on the organosilicon Break-thru® whose use totally translocated the pesticide to the coconut frond after only 2 days from application. This means that no residues of this pesticides was found in the 30 day samples.

Concentration and translocation of pesticide 30 days after application

The concentrations of pesticides obtained from tissues samples collected 30 days after application indicated that some pesticides are not quickly translocated into the stem tissues. For example, carbendazim and thiabendazole could only be quantified from samples collected at 30 days intervals, suggesting that partition occurred into the stem only after two days from application in all treatments. According to Table 1, carbendazim and thiabendazole are fungicides with similar chemical structures, belonging to the same chemical group (benzimidazoles) and have a pKa greater than 4 and a log K_{ow} < 3, being classified as more polar and less lipophilic compounds. Both similar behaviors and their potential mobility was not as fast as the other pesticides, even in the treatments with adjuvants. Within 30 days, the acidification of the solution proved to be more efficient in the translocation of these pesticides, with the greatest concentration levels detected near the frond, followed by the addition of salts and the other adjuvants. On the other hand, acidification, the addition of salts or the use of pesticides without adjuvants induced retardation or biodegradation of 3-OH-carbofuran, spirodiclofen and difenoconazole in the coconut stem. The translocation of spirodiclofen and difenoconazole were predominantly potentiated by using organosilicon, attenuating the degradation of the compounds even 30 days after application. No residues of difenoconazole and spirodiclofen using other treatments (T1-T4) were detected in the coconut tissues. Even though some of the pesticides tested in this study are compounds of different pKa and classes (fungicides and insecticides) with log K_{ow} >3, as well as being considered more nonpolar and lipophilic, with high bioaccumulation characteristics, the results indicated very efficient translocation in the coconut palm (Sun et al., 2014; Ferreira et al., 2015; The PPBD, 2013).

The translocation of imidacloprid in coconut was satisfactory in all treatments 30 days after application, with emphasis on T2 and T3, the two best treatments. Thiamethoxam and both neonicotinoid insecticides, with log K_{ow} < 1, and high polarity, showed similar results. Other studies also approached the uptake and translocation of imidacloprid in plants suggesting that it translocates and accumulates in leaves (Yu et al., 2015; Mota-Sanchez et al., 2009; Elliott and Broschat, 2012). Carbofuran showed a similar behavior to imidacloprid, being translocated with all adjuvants, and was better in T5, using Break-thru®, whereas high concentration levels were detected near the frond at 2 days and no longer found after 30 days. Thus, there are two hypotheses: (a) this pesticide was quickly translocated to the leaves in the presence of this adjuvant; (b) the pesticide suffered total degradation in 2 days. Furthermore, the other organosilicon surfactant, T6, enhanced pesticide translocation up to 30 days. Some pesticides, like thiophanate-methyl, 3-hydroxy-carbofuran, difenoconazole and spirodiclofen, when applied pure or with addition of salts or citric acid or both, were not found 30 days after application, although the presence of organosilicon in the solution enhanced the translocation of these pesticides, with emphasis to Break-thru®. It is thought that these pesticides may have undergone decomposition in the stem due to sensitivity to the sap (an acid medium), which can be expressed by aqueous hydrolysis DT_{50}. According to FAO (1998), thiophanate-methyl is degraded in plants to carbendazim and hydroxylated derivatives.

In general, the results showed that 56% of all treatments enhanced the concentrations of the pesticides with in the interval of 2 days in points nearest to application, while 24% caused decrease, and 20% had concentrations below the limit of quantification.

The detection/quantification of pesticides, near the coconut palm frond either on 2 days or 30 days after applications, in treatments with the presence of adjuvants, demonstrated the role played by adjuvants in potentiating translocation, accumulation and persistence of pesticides in plant tissue. In this study, the addition of organosilicone enhanced the translocation for 40% of pesticides, followed by acidification, with a 30% of increase in translocation, and addition of salts, being 22% more efficient when compared to translocation without adjuvants.

Pesticide concentrations were still quantified from samples collected nearest the point of application after 30 days for approximately 76% of all treatments. These results suggest that the pesticides did not rapidly degrade in the coconut tissues and are being slowly delivered to the coconut frond through acropetal translocation, which might enhance the action of the pesticide over time, towards its targets, ensuring the efficiency of the active ingredient for longer time periods. The acropetal translocation observed after this time interval for 63% of the compounds that reached the coconut palm frond are attributed mainly to the equilibrium transpiration-translocation of the coconut stem. Accordingly, to Carvalho *et* al. (2007), pesticides with log K_{ow} ~ 1.8 (such as carbofuran) were considered optimal for transport in aquatic plants and barley. In our study, considering the physiology and structure of the coconut palm, the translocation efficiency was better for pesticides with log K_{ow} between 0.57 and 3.09, which represented 55% of pesticides in all treatments studied and demonstrated a high capacity for tissue permeabilization/mobility (Tsipi et al., 2015).

4 CONCLUSION

The results obtained in this work showed that the adjuvants can potentiate the translocation of the pesticides and each pesticide has different translocation profiles, as noted from the concentrations in sample collected at different days and at different stem heights. The addition of adjuvants increased the translocation of some pesticides without degrading them. In other cases, the spreading and wetting action, reducing the surface tension of water, facilitated penetration and translocation of pesticides (Chamberlain et al., 1998). Treatments using adjuvants such as organosilicons (Break-thru® and Silwet-L77®) and citric acid showed higher concentrations of pesticides, indicating the potentiality of these adjuvants in the translocation process, presenting good perspectives for testing and for the treatment of diseases and pests in tall coconut palms. The treatments involved mixtures of pesticides from different classes. It is not known whether the mixture may have harmed, retarded or enhanced kinetic and/or plant-pesticide interactions, behaviors and movements of the pesticides into the palm stem.

The results on pesticide translocation do provide important information to enhance applications of pesticides by endotherapic treatments. Moreover, the technique used for extracting samples from the coconut stem tissues is non-destructive and does not require cutting down the coconut palms. The mode of action of pesticides is still not fully understood due to the complexity of plant-pesticides interaction, but this study showed the affinities of pesticides and adjuvants in potentiating pesticide translocation. It is important to say that the translocation can vary between species of the plant kingdom, accordingly to environmental conditions such as water stress or the plant growing conditions. Therefore, further studies have to be conducted to verify the appropriate pesticide dosage to control diseases and target pests and the degradation of pesticides in the coconut palm, which is still poorly understood and of great interest to agriculture, food safety and public health (Elliott and Broschat, 2012; Carvalho et al., 2007; Briggs et al., 1982).

Our study indicates that endotherapic application has great potential to be explored, although this new pesticide application method will only succeed if several important factors are considered, such as: (a) distribution of the conductors sap bundles; (b) understanding of the distribution of the leaves based on Fibonacci-phyllotaxy; (c) knowledge domains related to the causes that involve the complex reactions of chemical equilibrium related to the phenomena of translocation/transpiration. This can generate advantages for chemical treatments with broad-spectrum fungicides and insecticides against diseases and pests in coconut palms.

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