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Inventaire des plantes hôtes comestibles et évaluation du degré d'infestation par *Rastrococcus invadens* (Willams, 1986) *(Homoptera, Pseudococcidae)* au Sénégal

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Résumé

Rastrococcus invadens (Willams, 1986) *(Homoptera, Pseudococcidae)* ou cochenille farineuse est un insecte ravageur de manguier et de plusieurs autres arbres fruitiers dont les agrumes. La cochenille est originaire d'Asie du Sud-est et a été identifiée pour la première fois au Sénégal à Dakar en 1995 (Han *et al.*, 2007). Depuis lors, elle est largement répandue dans tout le pays et plus particulièrement dans les deux zones les plus productives de fruits : Casamance et Thiès. Pour mieux comprendre la dynamique des populations de *Rastrococcus invadens,* des prospections et enquêtes ont été menées dans les localités de Santhie, de Khay, de Sagnafil pour la région de Thiès et les localités de Tobor, de Diatock, de Loudia wolof pour la Casamance naturelle. Ce travail mené entre septembre 2015 et aout 2016, consiste à faire l'inventaire de toutes les plantes hôtes comestibles de l'insecte afin d'évaluer leur degré d'infestation spatio-temporel. Au total 17 espèces de plantes hôtes comestibles ont été recensées et classées en deux groupes selon le degré d'infestation : un groupe de plantes fortement infestées avec 9 espèces et un groupe de plantes faiblement infestées avec 8 espèces. Les résultats ont montré une variation du degré d'infestation non seulement en fonction des zones étudiées mais aussi en fonction des espèces de plantes et des variétés.

Mots-clés : *Rastrococcus invadens, plantes hôtes, infestation, distribution.*

Abstract

Inventory of comestible host plants and evaluation of infestation degree by *Rastrococcus invadens* (Willams, 1986) *(Homoptera, Pseudococcidae)* in Senegal

Rastrococcus invadens (Willams, 1986) *(Homoptera, Pseudococcidae)* is an insect pest mango and many other fruit trees including citrus. Inerhent to Southeast Asia, cochineal was identified at first in Senegal precisely Dakar at 1995 (Han *and al.*, 2007).Since then it widespread throughout the country and particularly in two most productive areas of fruit (Casamance and Thies). To better understand *Rastrococcus invadens* population dynamics, surveys and investigations have been conducted in localities of Santhie, Khay and Sagnafil at Thies and natural Casamance in Tobor, Diatock and Loudia Wolof localities. This work conducted between September

2015 and August 2016, have to inventory the comestible host plants and evaluate the infestation degree by *Rastrococcus invadens* in spatiotemporal. In total 17 species of comestible host plants were identified and classified into two groups according to infestation degree : 9 species of heavily infested plants and 8weakly infested specie. The work showed variation in infestation degree not only in terms of study areas but also in terms of plant species and varieties of trees.

Keywords : *Rastrococcus invadens, host plants, infestation, distribution.*

1. Introduction

Au Sénégal, la production annuelle de fruits et légumes est estimée globalement à 800.000 tonnes dont rarement 1 % est exporté [1]. Cette production provient essentiellement de la Casamance, de Thiès et de Dakar rural. La production de fruits est menacée par les problèmes phytosanitaires dont les plus importants sont les mouches des fruits (famille des Tephritidae) et la cochenille farineuse du manguier *Rastrococcus invadens* Williams *(Homoptera : Pseudococcidae)* [2]. Ce dernier ravageur a été introduit accidentellement en Afrique au début des années 1980 à partir de l'Asie du Sud-est d'où il est originaire [3]. En Afrique de l'Ouest, la cochenille farineuse a été observée pour la première fois au Togo et au Ghana avant de se propager dans la plupart des pays où elle cause des dégâts au manguier et aux autres arbres fruitiers [4]. La cochenille asiatique farineuse a été signalée pour la première fois dans la région de Dakar en 1995 [5]. Très polyphage, l'insecte est devenu très rapidement l'un des principaux ennemis du manguier et de plusieurs autres arbres fruitiers dont les agrumes et diverses plantes ornementales et d'ombrage [6]. Diverses études ont été entreprises pour la mise en place d'un programme de lutte intégrée contre ce ravageur. Malgré les méthodes de luttes utilisées contre la cochenille, les problèmes liés à son infestation demeurent. Il est donc nécessaire, d'une part, d'effectuer l'inventaire des plantes hôtes de l'insecte et d'autre part, d'évaluer le degré d'infestation spatiotemporel pour une meilleure lutte.

2. Matériel et méthodes

2-1. Présentation de l'insecte

Rastrococcus invadens est un insecte originaire d'Asie du Sud-est ***(Figures 1, 2 et 3)***. Il appartient à l'embranchement des Arthropodes, classe des Insectes, à l'ordre des Orthoptères, à la super famille des Coccoidea et à la famille des Pseudococcidae.

Figure 1 : *Rastrococcus invadens sur feuille de manguier*

Figure 2 : *Rastrococcus invadens en vue ventrale*

Figure 3 : *Rastrococcus invadens en vue dorsale*

2-2. Présentation des sites

Des prospections et enquêtes ont été menées dans les régions de Thiès et de Casamance naturelle qui sont les zones les plus productives de fruits au Sénégal. Les coordonnées géographiques, l'humidité et la température sont obtenues à l'aide respectivement d'un GPS, d'un hygromètre et d'un thermomètre.

2-2-1. Région de Thiès

La région de Thiès est l'une des quatorze régions administratives du Sénégal et couvre une superficie totale de 6 601 km^2. Elle est limitée à l'Est par les régions de Diourbel et de Fatick, à l'Ouest par la région de Dakar et l'océan Atlantique, au Nord par la région de Louga et au Sud par la région de Fatick ***(Figure 4)***. La région de Thiès présente les coordonnées géographiques suivantes : latitude 14° 45' 43 Nord et longitude 17° 17' 57 Ouest. Cette région est dotée de deux façades maritimes, l'une au nord avec la Grande-Côte abritant la zone maraîchère des Niayes et l'autre au sud avec la Petite-Côte qui est l'une des zones les plus touristiques du Sénégal. Nous avons choisi les Niayes plus particulièrement la commune de Pout, la deuxième zone la plus productive de fruit après la Casamance. Le climat de la région est influencé par des courants marins car la région se situe dans une zone de transition soumise à l'influence des alizés maritimes et l'harmattan avec une température moyenne de 32°C. La pluviométrie varie entre 300 à de 600 mm d'Est en Ouest.

2-2-2. Région de Casamance naturelle

La Casamance est une partie du Sénégal qui couvre une superficie totale de 52 000 km^2 dont le seul relief est représenté par les contreforts du Fouta Djalon au sud-est du territoire. Elle est limitée à l'Est par le Mali à l'Ouest par l'océan Atlantique, au Nord par la Gambie et au Sud par la Guinée-Bissau et la Guinée Conakry ***(Figure 5)***. Dans cette région nous avons échantillonné au niveau des départements de Bignona, Ziguinchor et Oussouye qui constituent les zones les plus productives de fruits au Sénégal. Dans le département de Bignona notre échantillonnage est réalisé dans la localité de Diatock : latitude 14° 45' 43 Nord, longitude 17° 17' 57 Ouest et altitude de 17 m de la mer. Dans le département de Ziguinchor, l'échantillonnage a lieu dans la localité de Tobor : latitude de 12° 41' 23 Nord et longitude 16° 23' 07 Ouest et altitude de 31 m de la mer. Enfin, dans le département d'Oussouye, c'est la localité de Loudia wolof qui est choisie : latitude de 12° 39' 59 Nord de longitude 16° 15' 26 Ouest et altitude de 40 m de la mer. Le climat de la région est de type soudano- guinéen caractérisé par une période humide correspondant aux mois de juin à octobre (été) mais appelée ici saison des pluies ou hivernage. La pluviométrie varie entre 800 à 2000 mm d'est en ouest. La température est sensiblement égale dans les différentes zones étudiées et tourne autour de 30°C (29,8 °C à Bignona et 30,1 °C à Ziguinchor et Oussouye).

Figure 4 : *Localité de Pout (région de Thiès)*

Figure 5 : *Localités Bignona, Oussouye et Ziguinchor (région de Casamance)*

2-3. Méthodes

2-3-1. Enquête sur le terrain

Entre septembre 2015 et aout 2016, nous avons inventorié les différentes plantes hôtes comestibles de l'insecte grâce à des prospections et des enquêtes auprès des fermiers. Les questions suivantes ont été posées :

- ✓ Quel est le nombre total de pieds présents dans chaque ferme ?
- ✓ Quelles sont les différentes plantes hôtes de l'insecte ?
- ✓ Quelles sont les plantes hôtes les plus attaquées par l'insecte ?
- ✓ Quel est le nombre total de pieds de manguier, de citronnier et d'oranger présents dans chaque ferme ?
- ✓ Parmi ces trois plantes d'espèces différentes choisies, quelle est la plus infectée ?

2-3-2. Échantillonnage

Notre étude est menée dans les régions de Thiès (Sagnafil, Khay et Santhie) et de Casamance naturelle (Tobor, Diatock et Loudia wolof). Dans chaque région, nous avons choisi 3 fermes et dans chaque ferme nous avons déterminé le nombre total de pieds (N) dans le champ. Le nombre total de pieds à échantillonner (N') qui correspond à 10 % du total des pieds est calculé par la ***Formule 1*** ci-dessous. Ensuite nous avons déterminé le nombre total de pieds (n) pour les espèces à échantillonner et le nombre total de manguiers (n'm), de citronniers (n'c) et d'orangers (n'o). La ***Formule 2*** nous permet de connaitre proportionnellement le nombre de pieds à échantillonner pour les manguiers (n''m), les citronniers (n''c) et les orangers (n''o). Les 10 feuilles (F) à échantillonner sont réparties de manière proportionnelle au nombre de pieds de chaque type de plante. Enfin, nous avons utilisé la ***Formule 3*** pour calculer le nombre de feuilles à récolter pour les espèces manguier (fm), citronnier (fc) et oranger (fo). Les feuilles sont cueillies au hasard et nous avons compté le nombre d'insecte présent sur chacune. Ce travail est répété 5 fois pour chaque campagne d'échantillonnage. Les résultats sont regroupés dans le ***Tableau 1*** ci-dessous.

$$\mathbf{N'} = \frac{\mathbf{N}}{\mathbf{10}} \tag{1}$$

$$\mathbf{n''} = \frac{\mathbf{n' \times N'}}{\mathbf{n}} \tag{2}$$

$$\mathbf{f} = \frac{\mathbf{n'' \times F}}{\mathbf{N'}} \tag{3}$$

N : Nombre total de pieds dans le champ ; N' : Nombre total de pieds à échantillonner ; n : Nombre total de pieds pour les espèces à échantillonner ; n' : Nombre total de pieds de l'espèce dans le champ (manguier, citronnier et oranger) ; n'' : Nombre de pieds pour chaque espèce à échantillonner (manguier, citronnier et oranger) ; F : Nombre total de feuilles à récolter ; f : Nombre de feuilles récoltées pour chaque espèce (manguier, citronnier et oranger)

Tableau 1 : *Nombre total de pieds de plante et de feuilles à échantillonner en fonction des zones agro-écologiques*

Localités / Paramètres	Thiès			Casamance		
	Sagnafil	Khay	Santhie	Tobor	Diatock	Loudiawolof
N	238	443	326	426	627	251
N'	24	44	33	43	63	25
n	133	248	71	371	486	69
n'm	50	145	37	200	238	27
n'c	70	87	20	105	155	20
n'o	13	16	14	66	93	22
n''m	9	26	17	23	31	10
n''c	13	15	9	12	20	7
n''o	2	3	7	8	12	8
F	10	10	10	10	10	10
fm	4	6	5	5	5	4
fc	5	3	3	3	3	3
fo	1	1	2	2	2	3

3. Résultats et analyse

3-1. Plantes hôtes

Dans ces deux zones, *Rastrococcus invadens* a été observé sur des espèces végétales appartenant à diverses familles avec des degrés d'infestation différents. Nous avons identifié deux groupes de plantes-hôtes en fonction du degré d'infestation. Le premier groupe est constitué d'espèces les plus fortement infestées qui présentent une importante population de cochenille. Ces espèces sont : *Mangifera indica* (manguier), *Citrus limon* (citronnier), *Citrus sinensis* (oranger), *Carica papaya* (papayer), *Citrus reticulata* (mandarinier), *Annona muricata* (corossol), *Anacardium occidentalis* (anacardier), *Psidum guajava* (goyavier), *Persea americana* (avocatier). Le deuxième groupe est constitué d'espèces faiblement infestées c'est-à-dire présentant une faible population de cochenille. Il s'agit : *Punica granatum* (grenadier), *Citrus maxima* (pamplemoussier), *Manilkara zapota* (sapotillier), *Prunus cerasus* (cerisier ou surelle), *Abelmoschus esculentus* (gombo), *Musa sp* (bananier), *Nerium oleander* (laurier-rose), *Capsicum annuum* (piment). Dans la zone de Casamance pratiquement toutes les plantes cultivées sont en général attaquées.

3-2. Degré d'infestation en fonction des plantes

La moyenne dans les deux zones étudiées (Casamance et Thiès) montre une infestation beaucoup plus importante sur le manguier que sur les autres arbres fruitiers ***(Tableaux 2 ; 3 ; 4 5 ; 6 et 7)***. C'est la raison pour laquelle l'insecte est appelé cochenille farineuse du manguier. Nous constatons aussi que l'infestation est plus importante en Casamance qu'à Pout ***(Tableau 8)***. Dans la zone de Casamance les villes sont plus infestées que les villages. La variance nous montre que la dispersion des insectes est beaucoup plus importante chez le manguier. Une forte dispersion est enregistrée mais elle est plus accentuée chez l'espèce manguier dans les différentes zones étudiées.

Tableau 2 : *Degré d'infestation en fonction des plantes à Loudia wolof (Casamance)*

Périodes	Espèces végétales	Nombre de cochenille / feuille						Caractère de dispersion		
		T1	T2	T3	T4	T5	Total	Moyenne	variance	Ecart-type
1er Semestre (sept 2015 et fév. 2016)	Manguier	1	5	0	1	0	7	1,4	17,2	4,15
	Citronnier	0	1	0	0	0	1	0,2	0,8	0,89
	Oranger	0	0	0	0	0	0	0	0	0
2 éme Semestre (Mars à Aout 2016)	Manguier	101	92	56	204	159	622	122,4	13789,2	117,43
	Citronnier	28	101	42	66	39	273	55,2	3390,8	58,23
	Oranger	42	11	63	22	21	159	31,8	1722,8	41,51

Tableau 3 : *Degré d'infestation en fonction des plantes à Diatock (Casamance)*

Périodes	Espèces végétales	Nombre de cochenille / feuille						Caractère de dispersion		
		T1	T2	T3	T4	T5	Total	Moyenne	variance	Ecart-type
1er Semestre (sept 2015 et fév. 2016)	Manguier	2	3	1	6	1	13	2,6	18,04	4,24
	Citronnier	0	0	0	3	0	3	0,6	7,2	2,68
	Oranger	0	0	0	0	0	0	0	0	0
2éme Semestre (Mars à Aout 2016)	Manguier	107	64	49	126	94	440	88	3938	62,75
	Citronnier	56	33	22	29	53	193	38,6	909,2	30,15
	Oranger	13	10	34	27	14	98	19,6	429,2	20,72

Tableau 4 : *Degré d'infestation en fonction des plantes à Tobor (Casamance)*

Périodes	Espèces végétales	Nombre de cochenille / feuille						Caractère de dispersion		
		T1	T2	T3	T4	T5	Total	Moyennes	variance	Ecart-type
1er Semestre (sept 2015 et fév. 2016)	Manguier	0	9	2	8	3	22	4,4	61,2	7,88
	Citronnier	0	0	0	3	4	7	1,4	15,29	3,91
	Oranger	0	0	0	0	2	2	0,4	3,2	1,79
2éme Semestre (Mars à Aout 2016)	Manguier	34	91	78	27	39	269	53,8	3298,8	57,44
	Citronnier	68	101	26	14	9	218	43,6	6273,2	79,2
	Oranger	17	0	11	26	8	62	12,4	381,2	19,52

Tableau 5 : *Degré d'infestation en fonction des plantes à Sagnafil (Thiès)*

Périodes		Nombre de cochenille / feuille						Caractère de dispersion		
		T1	T2	T3	T4	T5	Total	Moyennes	variance	Ecart-type
1 er Semestre (sept 2015 et fév. 2016)	Manguier	0	2	2	3	0	7	1,4	7,2	2,68
	Citronnier	0	1	0	2	0	3	0,6	3,2	1,79
	Oranger	0	0	0	1	0	1	0,2	0,8	0,89
2 éme Semestre (Mars à Aout 2016)	Manguier	17	38	11	3	24	93	18,6	709,2	26,63
	Citronnier	0	12	13	11	4	40	8	130	11,40
	Oranger	8	0	7	9	11	35	7	70	8,37

Tableau 6 : *Degré d'infestation en fonction des plantes à Khay (Thiès)*

		Nombre de cochenille / feuille						Caractère de dispersion		
Périodes		T1	T2	T3	T4	T5	Total	Moyennes	variance	Ecart-type
1er Semestre (sept 2015 et fév. 2016)	Manguier	1	1	1	2	3	8	1,5	3,25	1,80
	Citronnier	0	0	2	0	2	4	0,8	4,32	2,08
	Oranger	1	1	0	1	0	3	0,6	1,2	1,09
2 éme Semestre (Mars à Aout 2016)	Manguier	18	26	48	27	104	223	44,6	4903,2	70,02
	Citronnier	23	18	16	8	43	108	21,6	689,2	26,25
	Oranger	39	17	6	11	24	97	19,4	661,2	25,71

Tableau 7 : *Degré d'infestation en fonction des plantes à Santhie (Thiès)*

		Nombre de cochenille / feuille						Caractère de dispersion		
Périodes		T1	T2	T3	T4	T5	Total	Moyennes	variance	Ecart-type
1er Semestre (sept 2015 et fév. 2016)	Manguier	1	1	0	2	1	5	1	2	1,41
	Citronnier	0	1	0	0	1	2	0,4	1,2	1,09
	Oranger	0	0	0	0	0	0	0	0	0
2éme Semestre (Mars à Aout 2016)	Manguier	47	28	56	49	33	213	42,6	545,2	23,35
	Citronnier	31	12	14	28	16	101	20,2	300,8	17,34
	Oranger	8	32	11	5	12	68	13,6	453,14	21,29

Tableau 8 : *Évaluation du degré d'infestation en fonction des régions étudiées*

Périodes	**Espèces**	Nombre de cochenilles par région			
		Casamance	Thiès	% Casamance	% Thiès
1er Semestre (sept 2015 et fév. 2016)	Manguier	42	20	68	32
	Citronnier	11	9	55	45
	Oranger	9	4	33	67
2éme Semestre (Mars à Aout 2016)	Manguier	1331	529	72	28
	Citronnier	684	249	73	27
	Oranger	319	200	61	39

4. Discussion

Dans cette étude les espèces de plantes hôtes inventoriées sont classées en deux groupes en fonction du degré d'infestation. L'existence des deux groupes de plantes hôtes est liée à de multiples facteurs. Certaines plantes sont plus attaquées par rapport aux autres à cause de leur sensibilité vis-à-vis de l'insecte. Cette différence de sensibilité selon le degré d'infestation entre espèces de plantes hôtes est rapportée par plusieurs auteurs [7 - 9]. Entre les espèces de plantes hôtes, les larves se développent à des vitesses différentes. Le développement est plus rapide sur feuille de manguier (21 jours pour les femelles et 24 jours pour mâles) que sur feuille de *Citrus* (26 jours pour les femelles et 24 jours pour mâles) [10]. Des sensibilités différentes sont même notées entre variétés de manguiers, [8, 11 - 13]. Dans les deux régions étudiées, les variétés locales (« Boukodiékhal » et « Séwé ») sont généralement plus attaquées que les variétés améliorées destinées à l'exportation (« kent » et « keit »). En effet, il a été vérifié que les femelles sur le manguier le plus attaqué avaient une période pré reproductive plus courte et une plus grande fécondité que celles sur le manguier faiblement attaqué. Ces résultats peuvent s'expliquer par l'effet de groupe qui fait que plus le nombre est important plus la multiplication est rapide. La densité des populations de cochenille est généralement plus élevée sur les jeunes que sur les vieilles feuilles [14]. Elle est aussi plus élevée sur les fruits mûrs [15] que sur les fruits non mûrs et cela grâce à la qualité des éléments nutritifs (potassium, phosphore, sodium). Ce qui montre alors la synchronisation entre le cycle annuel de fluctuation des populations et la saison de fructification du manguier [16]. Les fluctuations d'abondance semblent être liées davantage au cycle phénologique de la plante hôte, lequel est déclenché par les variations de température [17]. Au Sénégal, ces populations de cochenille farineuse sont faibles de septembre à février et particulièrement pendant l'harmattan. Les effectifs les plus importants sont observés de mars à août, avec un maximum entre juin et août [6]. Cette faible population de cochenille pourrait s'expliquer par le fait que d'une part entre août et septembre la plus part des insectes sont lessivés par les pluies et d'autre part, les cochenilles sont attaquées par d'autres insectes prédateurs tels que les gardes rouges, les crabes ou encore les parasitoïdes. Le développement de ce parasitoïde avec la cochenille invasive du manguier a été étudié par [18]. Les degrés d'infestation observés au sénégal sont presque identiques à ceux décrits par [19, 20]. Les fluctuations des populations de cochenille farineuse semblent être fonction d'une part, des facteurs climatiques et, d'autre part, des facteurs biotiques dont les ennemis naturels. Les fortes infestations dans les villes et les villages, ainsi que les faibles niveaux dans les plantations sont décrits par [21]. Pour une parcelle déjà attaquée, les populations de cochenilles croissent d'une année à l'autre [22]. Ce qui entraine la réduction de la croissance, du développement et de la production des plantes infestées. La durée du développement, la fécondité et la survie de *R. invadens* dépendent des facteurs abiotiques (en particulier la température) et biotiques (qualité de la plante hôte et ennemis naturels) [23]. La dissémination de la cochenille semble être assurée essentiellement par l'homme à travers ses activités : transport du matériel végétal attaqué (plants, greffons, feuilles, bois) et matériel de travail (charrettes, habits) [6].

5. Conclusion

La cochenille farineuse constitue une contrainte majeure à la production de fruits comestibles au Sénégal. Ce ravageur dont la propagation est favorisée par l'activité humaine (transport dematériel végétal) a atteint très rapidement une grande partie du territoir sénégalais et plus particuliérement les régions de Thiés et Casamance naturelle qui représentent les principales zones de production de fruits.
Son degré d'infestation varie non seulement en fonction des zones étudiées mais aussi en fonction des espéces de plantes et des variétés.

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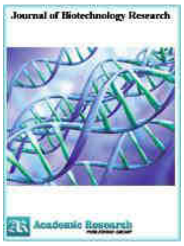

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Evaluation Damage Caused By Rastrococcus Invadens (Willams. 1986) (Homoptera. Pseudococcidae) on Mango in Casamance (Senegal)

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Abstract: Rastrococcus invadens Williams [1] (Homoptera, Pseudococcidae) is an insect pest mango and many other fruit trees including citrus. Originated in Southeast Asia, this cochineal was identified at first in Senegal precisely Dakar in 1995. Since then it has spread throughout the country and particularly in one most productive area of fruit (Casamance). To evaluate damage of Rastrococcus invadens on mango tree, a study was carried out on farm in Diatock located in natural Casamance. This study took place between may and september 2016. In arm, we chose after study the four varieties mango most attacked namely "Kent", "Keitt", "Sewe" and "Bouko diekhal". For each variety, we harvested 10 non-infested and 10 infested fruits. These fruits are then weighed to determine weight average of infested fruits and non-infested fruits in order to evaluate the losses and yields obtained. The results showed that a loss of 37% for mangoes weight of sewe variety, 36% of keitt variety, 24% of kent variety and 16% of bouko diekhal variety. However, this damage is more pronounced on some varieties (sewe and keitt) than others. Attacks are more common in June, July and August. Local variety (sewe) and improved variety (keitt) are more sensitive than others.
Keywords: Rastrococcus invadens; Damage; Mangifera indica.

1. Introduction

Fruits have generally a higher nutritional and commercial value [2]. They contribute to the improvement of social well-being and health status of populations [3].

In Senegal, the annual production of fruit represents about 1.3 million tons or nearly 4% of world production with post-harvest losses of between 40% and 50% [4]. This production comes mainly from Casamance, Thiès and rural Dakar [5]. Apart from importance of fruit production in general and mango in particular, one can also mention its market and financial value which provides an important currency for producers [2].

In Senegal, as in most West African countries, fruit production is threatened by phytosanitary problems. The most important of which are fruit flies (Tephritidae family) [6] and mealybug Mango tree *Rastrococcus invadens* Williams (Homoptera: Pseudococcidae) [7]. Damage losses from these insects are estimated to be multi-billion-dollar worldwide according to [6]. In contrast to conventional methods, control of these pests is more complex than conventional chemical control [8] and has harmful effects for the environment, producers and consumers. The mango mealybug *Rastrococcus invadens* infests mango trees in various West African countries and poses a threat to orchards [9].

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Various studies have been undertaken to develop an integrated pest management program. Despite the methods of control used against the cochineal, the problems related to its infestation remain. It is therefore necessary to evaluate damage caused by cochineal on mango tree for better control.

2. Materials and Methods

Rastrococcus invadens is an insect originating from Southeast Asia. It belongs to the branch of Arthropods, class of Insects, order of Orthoptera, super family Coccoidea and family Pseudococcidae.

Surveys were carried out in natural Casamance region, which is one of main areas of fruit production in Senegal. Geographical coordinates, humidity and temperature are obtained using GPS, hygrometer and thermometer respectively. Casamance is in Senegal and covers a total area of 52 000 km^2. It is bounded on east by Mali, west by Atlantic Ocean, north by Gambia and south by Guinea-Bissau and Guinea Conakry. In this region we sampled at departments of Bignona, which constitute one of the most fruitful areas in the region. Our sampling is done in Diatock locality: latitude 14 ° 45 '43 North, longitude 17 ° 17' 57 West and altitude of 17 m from the sea. Climate of region is Sudano-Guinean type characterized by a corresponding wet period from June to October (summer) but here called rainy season or winter. Rainfalls vary between 800 to 2000 mm from east to west. In this zone, temperature is substantially equal to 29.8 °C.

In Senegal, mango has been identified as one of value chains in horticultural sector with an interesting potential in the USA, European and sub-regional markets [4]. Indeed there are several varieties among which one can quote: "Kent", "Keitt", "Sewe" and "Bouko diekhal".

Flowering and fruiting plant (spermaphyte) the mango tree (*Mangifera indica*) belongs to dicotyledonous class, order of Spindales and Anacardiaceae family. It is native to northern India at foot of Himalayan range [10]. It is a tree with large crown spread rounded and dense which can reach 30 m of height [11] with a trunk monopode well individualized. It has a rotating root system with some ramifications for a good ground anchorage well suited to the search for water table under conditions of water stress [3]. The foliage of dark green mango on upper part of tree is pale in its basal part and usually reddish in young stage [12]. The simple and persistent leaves are whole with an alternate disposition and an elliptic limb with a long stalk up to 5 cm long [11]. The inflorescence is a terminal panicle that carries about 1000 flowers with a pedicel between 2 to 3 millimeters long. The mango tree has flowers either hermaphroditic, or males yellowish to their bloom and which become orange later. These flowers have 5 sepals and 5 petals with a perfect perennial stamper and a superior ovary containing a single egg [13]. A tropical climate plant, mango trees grow in rainfall areas between 600 and 1200 mm per year and develop well in temperature range 2.2 ° C to 43.5 ° C and his optimum growth temperature between 23 and 27 ° C [14].

Study took place between may and september 2016 on farm in Diatock located in natural Casamance. Our study focuses on damage caused by *Rastrococcus* on mango tree which is the most attacked species. In this farm, we chose four varieties of mango most attacked namely "Kent", "Keitt", "Sewe" and "Bouko diekhal". For each variety of mango, we harvested 10 uninfested and 10 infested fruits. A total of 20 fruits are harvested from each variety of mango trees. These fruits are then weighed one by one to determine the average weight of infested fruits and uninfested fruits in order to evaluate losses and yields obtained. This work is repeated every month from may to september for each sampling campaign. We are used Microsoft Excel to draw these graphs. The loss mango weight is evaluated by this formula:

$$\mathbf{LW} = \frac{\mathbf{WMNI} - \mathbf{WMI}}{\mathbf{WMNI}}$$

LW: Loss Weight (%); **WMNI:** Weight Mango None Infested; **WMI:** Weight Mango Infested

3. Results

Figures 1, 2, 3 and 4 showed attacks were most frequent in june, july and august. For Sewe variety (Figure 4), since the error bars do not overlap, we can say damage caused by *Rastrococcus invadens* is very significant and that from beginning the end of mango production. Local variety (Sewe) and improved variety (keitt) are more attacked than others. In all varieties, infestation is proportional to fruit maturation. For kent, keitt and sewe varieties, infestation affects weight mango from june to september but infestation is not significant for bouko diekhal variety in september.

Figure-1. Influence of the infestation on mangoes weight of kent variety

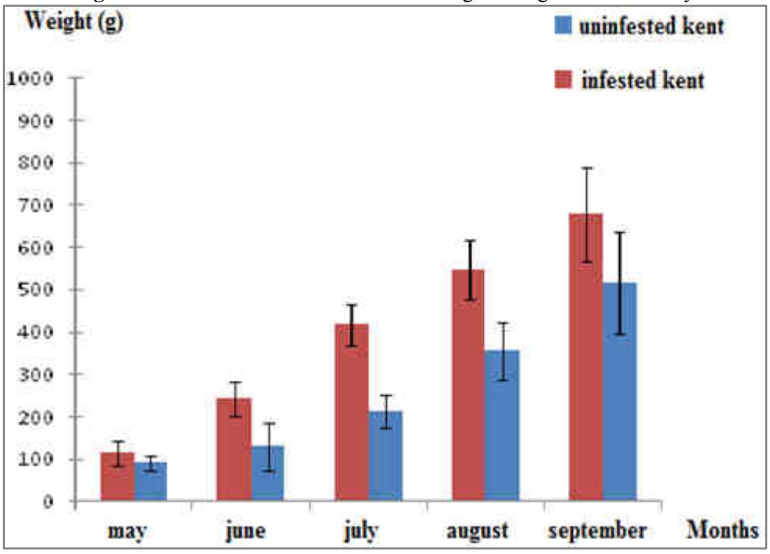


Figure-2. Influence of the infestation on mangoes weight of keitt variety

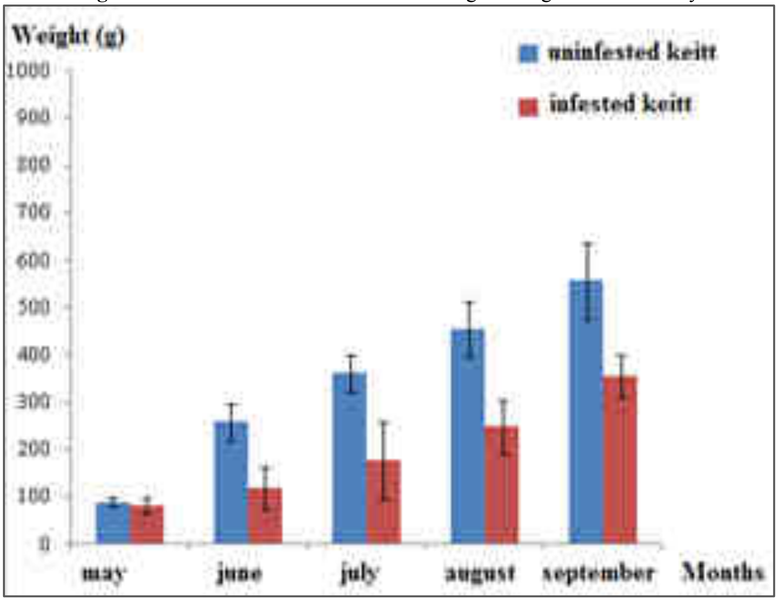


Figure-3. Influence of the infestation on mangeos weight of bouko diekhal variety

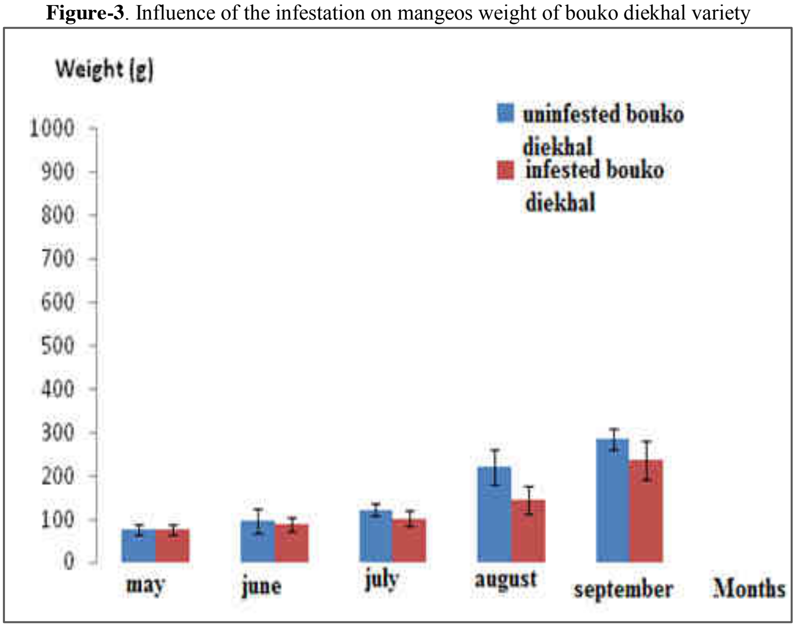
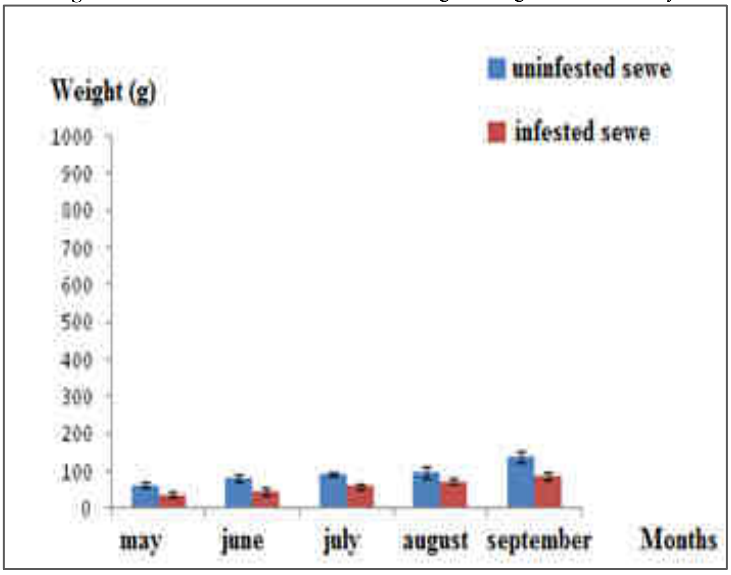


Figure-4. influence of the infestation on mangoes weight of sewe variety



Tables give information on different varieties of mangoes studied: average yield per variety, average fruit weight (infested and not infested), period of production, estimated loss and condition status. Results showed damage was observed for all varieties studied. However, lost weight of fruit (table 2) is more pronounced for sewe (37%) and keitt (36%) than bouko diekhal (16%) and kent (24%).

Table-1. Comparison of different varieties mangoes weights according the months

Months	Varieties							
	Kent		Keitt		Bouko diékhal		Séwé	
	I	NI	I	NI	I	NI	I	NI
May	91.9 ±128	114.5 ± 28.2	81.9 ±16.28	88.7 ± 9.3	71.2 ± 11	75.5 ± 11.5	36.2 ± 8.08	62.5 ± 7.8
June	130.5 ±564	243.7 ± 41.1	119.5 ± 43.7	257.6 ± 39.92	89.3 ± 15.76	96.6 ± 27.84	45.8 ± 8.6	81.4 ± 8.4
July	213.3 ±37.16	418.9 ±49.8	177.7 ± 81.64	361.4 ± 39.2	102.7 ± 16.5	122.1 ± 14.68	60.0 ± 7.2	91.0 ± 6.8
August	356.2 ±68.24	547.1 ± 71.1	247.5 ± 57.6	454.0 ± 57.8	146.3 ± 31.56	221.5 ± 40.5	73.5 ± 6.6	98.8 ±15.96
September	516.1 ±119.8	679 ± 110.4	355.5 ± 45.5	556.2 ± 80.8	236.9 ± 44.3	285.1 ± 22.3	86.1 ± 8.9	136.7 ± 14.64

Table-2. Evaluation of loss mango weight

	Kent	Keitt	Bouko diékhal	Séwé
Weight Mango Non Infested (g)	679	556.2	285.1	136.7
Weight Mango Infested (g)	516.1	355.5	236.9	86.1
Loss Weight (%)	24	36	16	37

4. Discussion

In our study, results reveled that kent, keitt and sewe varieties are more attacked (as a very significant weight reduction). This means that *R. invadens* is more susceptible to attacks these varieties than bouko diekhal. In September, the low infestation on bouko diekhal could be explained by reduction production [15]. Indeed, during this period, kent and bouko diékhal are at the end of the fruit production cycle and insects are attracted by the other varieties that are in full production. Generally, fruit or vegetable growth is related to fluctuations in abundance of mealybug populations [16]. Kent and sewe varieties are more susceptible to be attacked, we consider they present best development conditions for *Rastrococcus invadens*. Among these conditions, we can emphasize tender aspect of pericarp, which facilitates bite by the insect, and probably its richness in nutrients. This may also justify the fact for same variety, damage is more pronounced on ripe fruit than on unripe [17]. Results confirm these showed by Ndimanya and Strebelle [18].

Damage on tree by this insect has affected several organs: young twigs, inflorescences, peduncles, fruits and leaves. The insect causes direct damage by bites on inflorescences (abortion of flowers), leaves and indirect damage by production of honeydew and fumagine that forms on the surface [19]. On most attacked trees, loss leaves and drying branches were noted. Moreover, soot affects quality of mangoes: even after washing and brushing, most of fruits showed discolored areas on epidermis, thus becoming non-exportable. Populations of mealybug are weak from october to february and especially during harmattan. From march to august, numbers are higher between june and august. [20].

A delay in flowering was noted on untreated plots [19]. Emission of new branches has been slowed down. Losses ranged from 19% to 60% respectively, for panicles and tree height. Yield dropped by 53%, the most attacked trees (entirely covered with sooty mold) having not flowered. Losses of production in peasant environments have sometimes reached 100% and planters are forced to destroy their orchards or non-productive trees. On most attacked trees (Kent and sewe), loss of leaves and drying of branches were generally noted. Moreover, soot affected the quality of mangoes and also causes a slowing down of the growth resulting in decrease of mass. The presence of mealybug colonies and black fungus on fruit causes discolorations and loss of quality of them. It is for this reason that these fruits attacked or soiled, even after washing and brushing, have for the most part discolored areas on the epidermis, thus becoming non-exportable; which is a real shortfall for the farmer.

On same farm, these fluctuations in abundance of cochineal populations are different between varieties of mango trees (more accentuated on sewe and keitt). When plant is attacked, more its fruit production advances, greater loss of mass (Table 1). These weight losses on fruits are due to a slowing down of growth, which consequence of deposition of soils on fruits and leaves by compromising photosynthesis [21].

According to the surveys carried out in this zone, mechanical or physical methods (slaughter and burning of the trees or branches attacked) are generally practiced by producers, in view of the seriousness of damage. Compared to other agro-ecological zones of the insect in Asia first identified in India, surveys have shown that *Rastrococcus* scale insects cause problems only locally and occasionally [22]. In Senegal we are close to 30% in this present study. Damage varies not only according to mango tree varieties but also according to the agro-ecological zones.

Similarly, ornamental and shade plants, strongly attacked (leaves and stems covered with sooty, droplets of honeydew falling to the ground), and no longer able to perform their primary functions (ornamentation, shelter) were destroyed. In Ghana, losses have been estimated at 80% in peasant environments [23]. Fluctuations in mealybug populations appear to be a function of both climatic factors and biotic factors, including natural enemies [20].

5. Conclusion

This study evaluated losses caused by *Rastrococcus invadens* on four varieties mangoes "Kent", "Keitt", "Sewe" and "Bouko diekhal". Study is valuable because of importance that sector brings to country. It has allowed us to have in-depth knowledge of mango sector, constraints it faces in order to identify measures to better control and increase productivity.

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Morphometric Characterization of the Mango Tree's Mealy Cochineal, *Rastrococcus invadens*, on the Mango Tree in Senegal

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Abstract: ***Fruit production in Senegal is mainly for national consumption. The major critical point of mangoes and citrus fruits production is fruit ravaging insects such as Rastrococcus invadens (Homoptera, Pseudococcidae) (Willams, 1986). Originated in Southeast Asia, this cochineal was first identified in Senegal. Since then it has spread throughout this country and particularly in Natural Casamance region and Thies region. In each region we chose two farms in two different localities. In Casamance, we chose one farm in Diatock locality and another one in the locality of Oussouye. In Thies region, we sampled in Santhie and Khay localities. In each farm, we chose the mango tree which represents the major host plant of R. invadens. From each plant we collected 10 specimens. This enabled us to get 20 specimens from Casamance and 20 other specimens from Thies. Specimens were coded with regard to both the area and the type of plant they were collected from. The present work aims to take stock of the morphological and morphometric characteristics of the pest into space and time, as well as its socio-economic consequences since it has been reported in Senegal. The results revealed morphometric groups more or less distinct especially between the Niayes zone and low Casamance.***

Keywords: Rastrococcus invadens, mango tree, morphometry, agro-ecological zones

1. Introduction

Fruit production in Senegal is mainly for national consumption. This production would reach 100 to 120 000 tonnes per year and concerns mangoes, citrus fruits, and bananas in proportion of 67; 23; and 5% respectively [1]. Nevertheless, the lack of statistics does not allow us to point at these figures as reliable values [1].

Currently, the major critical point of mangoes and citrus fruits production is fruit ravaging insects such as *Rastrococcus invadens* [2]. The mango tree's mealy cochineal has become pandemic and represents an agronomic, economic, social, and biodiversity threat.

Exports of mangoes account for only 5 to 6% of national production [3].

Although the small volume exported with respect to production, Senegal, over the last 10 years, has significantly increased his foreign trade to Europe especially, reaching, on average 5,000 to 6,000 tons per year, despite the 50% fall in 2010 (around 3,000 tons) due to the quality mangoes as well as the attacks of insect pests that compromised the marketing campaign [3].

In Senegal, since 1981 (first exports in the French market), fruit production has become the third agricultural source of income in southern Senegal, behind cotton and cashew nut [4]. In fact, from 71 tons exported in 1981), Ivory Coast exports yearly more than 10 000 tonnes since 1999 [5] for an estimated annual production of 100 000 tonnes [6]. However, mangoes production is threatened by phytosanitary problems, of which the most important are fruit flies, belonging to the Tephritidae family, and the mealy cochineal, *Rastrococcus invadens* Williams (Homoptera: Pseudococcidae) [7]. The latter was accidentally introduced in Africa in the early 1980s from the Southeast Asia, its area of origin [2].

The mealy cochineal was first observed in Togo and Ghana before spreading in most of West African countries, damaging mango trees and other fruit trees [8].

Its appearance was reported in Ivory Coast, in 1989 [9]. Highly polyphagous, *R. invadens* quickly became one of the major enemies of mango trees and several other fruit trees including citrus trees and various ornamental and shade plants.

R. invadens is a species of bisexual and ovoviviparous cochineal that lives in colonies on the leaves of host plants [10]. On mango trees, mealy cochineal can also be found on leaves' petioles, fruits and peduncles [10].

Various studies have been carried out in order to set up an integrated pest management program. Morphometric data are useful additional information that enables an accurate

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identification of the different stages of development of an insect [11].

The present work aims to take stock of the morphological and morphometric characteristics of the pest into space and time, as well as its socio-economic consequences since it has been reported in Senegal.

2. Material and methods

2.1 Sampling

Two populations of *R. invadens* [2] were compared during this analysis: one population from Natural Casamance region and another from Thies region. In each region we chose two farms in two different localities. In Casamance, we chose one farm in Diatock locality and another one in the locality of Oussouye. In Thies region, we sampled in Santhie and Khay localities.

In each farm, we chose the mango tree which represents the major host plant of *R. invadens*.

From each plant we collected 10 specimens. This enabled us to get 20 specimens from Casamance and 20 other specimens from Thies. Specimens were coded with regard to both the area and the type of plant they were collected from. Data are clustered in Table 1 below. In general, morphometric analysis of *R. invadens* larvae is usually destructive. Actually, it requires prior death of the specimens and their fixation in alcohol [12].

2.2 Morphometric study

We chose 10 measurable variables with a reasonable degree of accuracy. These mainly include body length, body width, length and width of head, length of rear, median, and front legs. To these are added lengths of abdomen, thorax, and average diameter of sternum (Figure 1).

Table 1: Choice of values

Body	Head	Thorax	Abdomen
Lc :Body length	LT : Head length	Th : Thorax length	La :length of abdomen
lc : body width	lt : Head width	Lp1 : length of the first pair of legs	
		Lp2 : length of the second pair of legs	Ls1 : length of first sternum
		Lp3 : length of the third pair of legs	

The relevant parts were mounted on a binocular stereoscope equipped with a camera connected to a computer. Observations were made on L3 (3rd larval stage) specimens which correspond to pre-pupa for males. Specimens are then cleaned in alcohol 70 before proceeding to measurements, each relevant part being carefully separated from the next one.

Each specimen of a given sample is associated to a code, using the capital letter of the gender name followed by the first letter of the specific epithet of the corresponding plant, the first letter of the locality of origin and finally the first letter of the region of origin (Table 2).

Table 2: Summary table of the sampling

Codes	Plant species	Localities	Number of specimens	Regions
CDM	Mango tree	Diatock	10	Casamance
COM	Mango tree	Oussouye	10	Casamance
TSM	Mango tree	Santhie	10	Thies
TKM	Mango tree	Khay	10	Thies

CDM: Casamance-Diatock-Mango tree **COM:** Casamance-Oussouye-Mango tree **TSM:** Thies-Santhie-Mango tree **TKM:** Thies-Khay-Mango tree.

2.3 Statistical analyses

2.3.1 Raw measurements

A discriminant factor analysis (DFA) of populations with raw measurements of variables in regard to the sampled agro-ecological zones was carried out with the help of the software R version 3.2.3 [13]. This analysis enables to set off the contribution of each variable with respect to their bald measurement, in order to see the most discriminating ones, and to bring out morphometric groups regarding the agro-ecological zones, too.

2.3.2 Converted measurements

Size effect

According to [14] size effect appears by a circle of correlation that groups all the variables in a single plane for a given axis. This concerns a very undesirable effect which metrical studies try to overcome. The principle of elimination is then to bring all specimens to the same size so as to observe on the PCA only differences in shape.

Data conversion

Eliminating the size effect that affects almost all biometric studies was done using the following approach by Santos (2015):

- Log-transformation of data: initial data table consists of the variables X1, X2, ..., Xp, subsequently a new data table consisting of the variables log (X1), log (X2), ..., log (Xp)) has been created.
- For each specimen, the average over all Log-transformed variables was calculated. This average score is a good idea of the "size" for this specimen.
- Finally, for each specimen, the average size obtained with Log-transforms was deducted from each of these raw measurements.

Size effect is thus eliminated and only the difference in shape will be observed on the PCA. Decreasing the weight of this factor (Size) results in a decrease of the global discrimination between populations and the reduction of the distance between centres of gravity of populations. This transformation was performed in Excel version 2011.

2.3.2.1 Discriminant Factor Analysis (DFA)

A discriminant factor analysis (DAF) of the populations with the transformed data of the variables according to the localities and host plants sampled was carried out with the software R version 3.2.3 [13]. This analysis aims to bring out the contribution of each variable after elimination of the size effect in order to see the differences in form between

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population groups revealed by the discriminating power of each of the variables.

2.3.2.2 Correspondence Factor Analysis (CFA)

Factorial Correspondence Analysis (CFA) is performed to visualize relationships between specimens of different populations from converted data and test for possible metric similarities between these populations. It is a multi-varied analysis method that considers converted measurements of all populations as variables [15]. For this purpose, a graphical representation is produced from the transformed data that are adapted using the Genetix version 4.05.2 program [16] to estimate the distribution of morphological diversity at all levels (individuals, populations and total population).

2.3.2.3 Confusion matrix for cross-validation results

The confusion matrix summarizes the reclassifications of specimens to infer both rates of good and bad ranking. This makes it possible to determine the "correct%" which is the ratio of the number of well-ranked specimens to the total number of specimens. Cross-validation is done using transformed data according to agro-ecological zones and plant species sampled with the XLSTAT software version 2016.03.30882 [17].

2.3.2.4 Hierarchical Ascending Classification (CAH)

It represents a method of trees construction that is often delicate and difficult to generalize if the learning data are poorly representative of reality. Automatic classification methods that do not require learning are of great interest when data are completely unknown. They thus make it possible to release subsequent classes that are not obvious a priori. Therefore, the CAH consists of grouping specimens regarding their resemblance or difference. The ascending hierarchical classification is carried out in Excel version 2011.

3. Results

3.1 Raw Data

3.1.1Contribution of the variables with raw measurements in terms of the localities of origin of specimens collected from mango tree

The discriminant factor analysis obtained from specimens collected from mango tree shows that the first two factorial axes (dimension) best explain the morphometric variability with 87.74% of inertia power. Following the factorial axis 1 (dimension 1), we find that variables such as Lc (F1 = 13.1), lc (F1 = 12.3), LT (F1 = 11.8), lt (F1 = 11.3), (F1 = 11.3), Lp2 (F1 = 9.69), Lp3 (F1 = 9.67), Lp1 (F1 = 8.86), and Ls1 (F1 = 8.24) have largely participated in the construction of the first factorial axis with 69.17% of the power of inertia. Only the variable Th (F1 = 3.66) contributes slightly to the construction of the first axis. The factorial axis 2 (dimension 2), with a low power of inertia (18,57) is constructed largely by the variables Th (F2 = 30.4), Lp1 (F2 = 15.3), Lp2 (F2 = 15.3), Lp3 (F2 = 14.1), Ls1 (F2 = 10.9) and It (F2 = 8.01). Other variables such as Lc (F2 = 4.37), La (F2 = 0.72), lc (F2 = 0.57) and LT (F2 = 0.17) contribute little to the construction of this axis. On the first factorial axis, all the variables are positively correlated. Obviously, the size effect affects our ACP. (figure1) A globally positive correlation for the variables, along the factorial axis of dimension 1, seems to suggest an influence of the data by the "size effect".

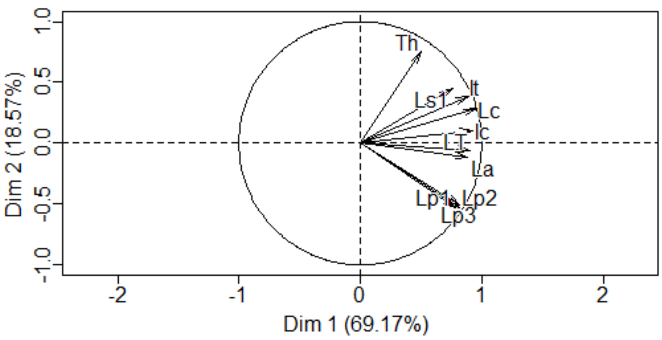

Figure 1: Contribution of mango tree populations' variables

3.1.2 Discrimination of populations according to raw measurements according to the localities of individuals from the mango tree

Following the two factorial axes with a power of inertia of 87.74%, the AFD (Discriminant Factor Analysis) reveals two groups. A group consisting of the populations of Santhie and Khay and another group composed by that of Diatock and Oussouye with a zone of significant introgression between the two populations. Khay specimens have some resemblance to those from Diatock.

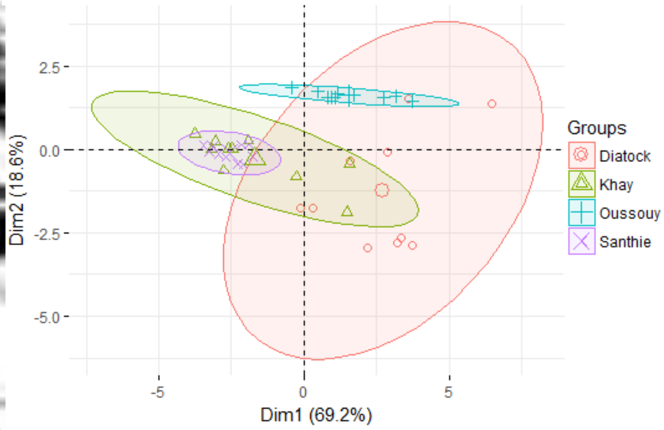

Figure 2: Representation in the main AFD plan of the populations of *Rastrococcus invadens* on the mango tree

3.1.3 Variables allowing the discrimination of mango tree populations

In regard to the Tukey test, among the 10 variables studied, except the length of thorax (Th), all the other variables make it possible to differentiate Diatock and Khay populations. Between Diatock and Santhie, except for the body width (lt) and the length of the thorax (Th), all the variables make it possible to discriminate between these two populations. Between Oussouye and Khay, the differentiation noted is due to variables such as body length (Lc), body width (lc), head length (Lt), head width (lt) and length of the first sternum (Ls1). Between Oussouye and Santhie, variables such as body length (Lc), body width (lc), head length (Lt), length of the abdomen (La), thoracic length (Th) and length of the first sternum (Ls1) discriminate their populations.

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Table 3: Morphometric study of specimens (*Rastrococcus invadens*) collected from mango tree

localities / variables	Diatock	Khay	Oussouye	Santhie
Lc	3.95 ± 0.6^{b}	2.86 ± 0.43^{a}	4.12 ± 0.33^{b}	2.67 ± 0.15^{a}
lc	2.47 ± 0.57^{b}	1.75 ± 0.31^{a}	2.28 ± 0.35^{b}	1.54 ± 0.14^{a}
Lt	1.09 ± 0.18^{b}	0.64 ± 0.20^{a}	1.05 ± 0.86^{b}	0.56 ± 0.07^{a}
lt	1.72 ± 0.41^{b}	1.09 ± 0.21^{a}	2.01 ± 0.13^{b}	1.02 ± 0.08^{b}
La	2.26 ± 0.22^{c}	1.91 ± 0.40^{ab}	2.06 ± 0.25^{bc}	1.64 ± 0.13^{a}
Lth	0.61 ± 0.46^{a}	0.38 ± 0.23^{a}	1.01 ± 0.04^{b}	0.46 ± 0.14^{a}
Lp1	1.57 ± 0.29^{b}	0.89 ± 0.14^{a}	1.08 ± 0.07^{a}	0.91 ± 0.06^{a}
Lp2	1.68 ± 0.24^{b}	1.06 ± 0.26^{a}	1.14 ± 0.12^{a}	0.98 ± 0.09^{a}
Lp3	1.74 ± 0.24^{b}	1.17 ± 0.33^{a}	1.20 ± 0.16^{a}	1.04 ± 0.09^{a}
Ls1	0.37 ± 0.12^{bc}	0.30 ± 0.04^{ab}	0.41 ± 0.04^{c}	0.27 ± 0.03^{a}

3.2 Converted data

3.2.1 Contribution of the variables with converted measurements in terms of the localities of origin of specimens collected from mango tree

Unlike raw data, the factor analysis with the converted data shows a reduction of the inertia percentage of 14.87% for the first dimension (factorial axis 1) following a decrease in the discriminating power of most of contributory variables namely : LT (F1 = 13.4), F1 (F1 = 13.2), Lc (F1 = 12.1), Lp2 (F1 = 12.1), Lp3 (F1 = 11.7), Lp1 (F1 = 10.8), La (F1 = 10.7), F1 (F1 = 9.15) and Ls1 (F1 = 6.79).

The second factorial axis with a very noticeable decrease (6.33%), shows a situation almost identical, compared to the results with the raw data, with an increase in the discriminating power of almost all the variables and a significant contribution of some variables such as Th (F2 = 29.6), lt (F2 = 18.5), Lc (F2 = 12.4), Lp1 (F2 = 11.5), Lp2 (F2 = 11.2) and Lp3 (F2 = 10.0).

The best quality of representation is always obtained with the plane formed by axis 1 and 2 with a total inertia percentage of 79.2%.

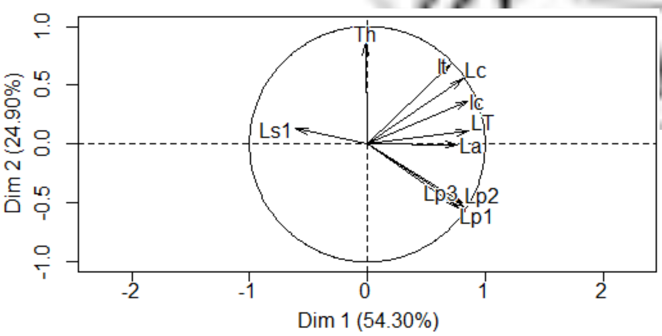

Figure 3: Contribution of mango tree population variables

3.2.2 Discrimination of the populations, according to the converted measurements, in terms of the localities of origin of specimens collected from mango tree

With the converted measurements, according to the two factorial axes, the localities show a strong discrimination. Thus with an increase in the percentage of inertia, the first dimension allows a discrimination of the populations of Khay, Diatock and Oussouye. On the other hand, the second dimension reveals discrimination between the populations of Oussouye, those of Khay and Santhie, and between the population of Santhie and that of Diatock

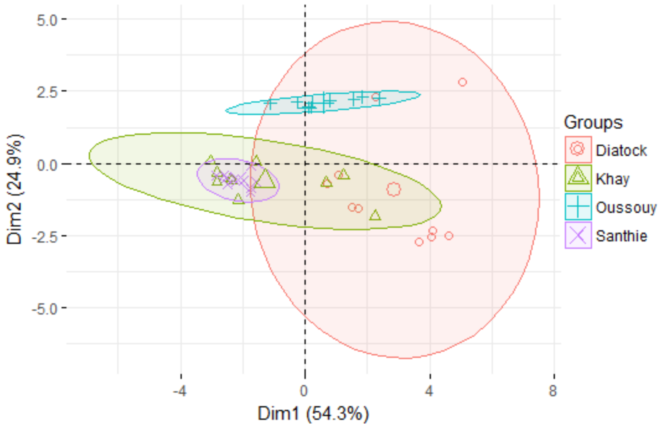

Figure 4: Representation in the main AFD plan of *Rastrococcus invadens* populations on the mango tree

3.2.3 Variables allowing the discrimination of mango tree populations

According to the Tukey test, among the 10 variables studied, except the length of the thorax (Th), all the other variables make it possible to differentiate the Diatock and Khay populations. Between Diatock and Santhie, except for the width of the body (lt) and the length of the thorax (Th), all the variables make it possible to discriminate between these two populations. Between Oussouye and khay, the differentiation noted is due to variables such as body length (Lc), body width (lc), head length (Lt), head width (lt) and length of the first sternum (Ls1). Between Oussouye and Santhie, variables such as body length (Lc), body width (lc), head length (Lt), length of the abdomen (La), thoracic length (Th) and length of the first sternum (Ls1) discriminate their population.

Table 4: Variables allowing the discrimination of mango populations (converted data)

	Casamance	Thies	Total	% correct
Casamance	20	0	20	100.00%
Thies	0	20	20	100.00%
Total	20	20	40	100.00%

3.2.4 Confusion matrix for the results of cross-validation of populations

The confusion matrix summarizes reclassifications of specimens to infer the rates of good and bad ranking. This makes it possible to determine the "correct%" which is the ratio of the number of well-ranked specimens to the total number of specimens. Thus, specimens from different populations are well ranked in their original populations.

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Table 5: Confusing mastery of cross-validation of specimens from mango tree

localities / variables	Diatock	Khay	Oussouye	Santhie
Lc	3.82±0.53^{b}	2.89±0.39^{a}	3.98±0.30^{b}	2.71±0.12^{a}
lc	2.32±0.52^{c}	1.77±0.26^{ab}	2.14±0.31^{bc}	1.57±0.13^{a}
Lt	0.95±0.19^{b}	0.67±0.16^{a}	0.91±0.05^{b}	0.60±0.07^{a}
lt	1.57±0.35^{b}	1.12±0.17^{a}	1.87±0.09^{c}	1.06±0.07^{a}
La	2.11±0.17^{b}	1.94±0.36^{ab}	1.91±0.22^{ab}	1.67±0.12^{a}
Lth	0.47±0.41^{a}	0.41±0.21^{a}	0.86±0.05^{b}	0.50±0.13^{a}
Lp1	1.43±0.28^{b}	0.91±0.10^{a}	0.94±0.04^{a}	0.95±0.04^{a}
Lp2	1.54±0.22^{b}	1.09±0.22^{a}	1.01±0.09^{a}	1.02±0.06^{a}
Lp3	1.60±0.21^{b}	1.20±0.28^{a}	1.06±0.12^{a}	1.08±0.07^{a}
Ls1	0.23±0.08^{a}	0.33±0.04^{b}	0.28±0.01^{ab}	0.31±0.03^{b}

3.3 Hierarchical Ascending Classification (HAC)

The hierarchical ascending classification brings out several morphometric groups based on similarities, from variables. On the mango tree 3 groups were noted: a group where we find the populations of Diatock and Oussouye, a group made up only of Diatock populations and a third group including populations of Diatock, Khay and Santhie. The population of Oussouye is only found in one group; which shows then that it is a homogeneous population. This same result is also observed in the Khay and Santhie populations. On the other hand, the population of Diatock is very heterogeneous because it is found in all groups.

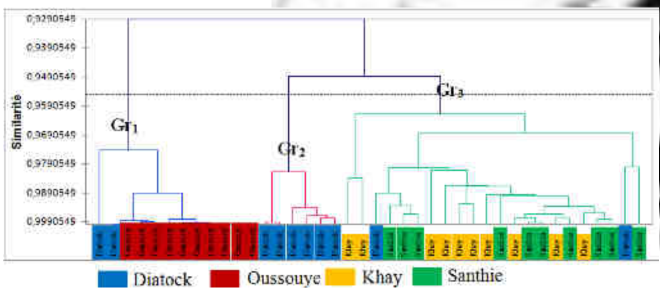

Figure 5: Ascending classification of specimens from the mango tree

Gr1: group 1 Gr2: group 2 Gr3: group 3

3.4 Correspondence factor analysis (CFA)

The discriminant factorial analysis reveals that the first five factorial axes explain all the morphometric variability of this cochineal. However, the plan formed by the first three axes best explains the discriminative situation of agro-ecological zones with an inertia of 99.6%. The first factorial axis with an inertia of 36.39 %, discriminates the group formed in majority by the individuals of Diatock (Casamance). The second factorial axis with inertia of the order of 34.39% discriminates the groups containing all the specimens from Khay. The third factorial axis with an inertia of 28.82%, allows the discrimination of the group which contains all the specimens from Santhie and Oussouye.

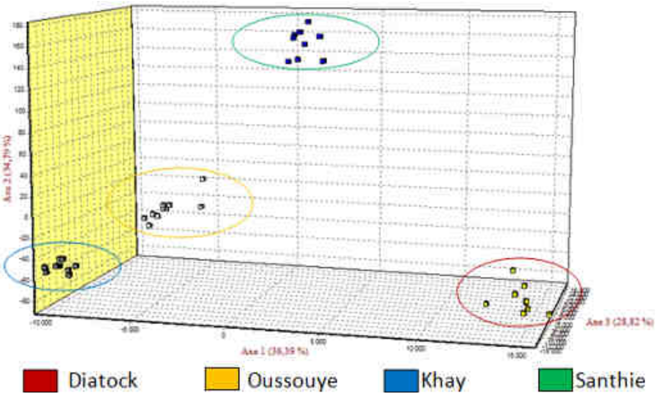

Figure 6: Simulation of the morphometric variability of specimens of *R. invadens* on mango tree following the first three axes of the AFC

4. Discussion

Morphometric measurements carried out on *R. invadens* specimens show various values. For most variables, measurements vary more or less according to a certain average. However, variables such as thoracic length (Th) and length of first sternum (Ls1) show consistent values in all specimens. These two variables do not allow to discriminate specimens from different populations. Thus, out of the 10 variables chosen, only 8 variables (Lc, lc, Lt, lt, La, Lp1, Lp2 and Lp3) are used to obtain relevant information on the morphometric variability of the species.

The first two factorial axes explain 87.74% of the morphometric variability. Following these same factorial axes, a slight discrimination is observed between 2 groups: specimens of Diatock and Oussouye on the one hand and Khay and Santhie on the other hand. In fact, populations from these different agro-ecological zones do not seem to have a great deal of difference at first glance, because of the roximity of their cloud of points, which could suggest a large gene flow between the different populations. But a more in-depth study of the centroids representative of each population has shown a slight discrimination. However, an apparent correlation of most variables is largely due to a common factor that can be assimilated as a first approximation to a size factor.

Decreasing the weight of this factor results in a slight decrease in overall discrimination between agro-ecological zones, and a slight increase in the distance between centroids. Thus converted data lead to a reduction of the inertia percentage of 14.87%, for the first dimension (factorial axis 1) and 6.33% for the second factorial axis. This offers a better redistribution of variables in relation to their contribution to the axis.

With the converted data, along the factorial axis 1 the first dimension allows a discrimination of the populations of Khay, Diatock and Oussouye. On the other hand, the second dimension reveals a discrimination between the populations of Oussouye, those of Khay and Santhie, and between the population of Santhie and that of Diatock. Correspondence factor analysis shows that the first five factorial axes explain

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all the morphometric variability of this cochineal and give a better insight into the discrimination between ecotypes.
The plan formed by the first three axes best explains the discriminative situation of agro-ecological zones with an inertia of 99.6%. The first factorial axis with an inertia of 36.39%, discriminates the group formed in majority by specimens of Diatock (Casamance). The second factorial axis with an inertia of the order of 34.39%, discriminates the groups containing all specimens of Khay. The third factorial axis, with an inertia of 28.82%, allows the discrimination of the group which contains all specimens of Santhie and Oussouye.

From these results we can say that some specimens belonging to a previously defined area have more similarities with other specimens from neighboring agro-ecological zones: this is the case of Santhie and Khay specimens who are all in the same agro-ecological zone but also with specimens from lesser agro-ecological zones like Diatock and those from Thies (Khay and Santhie).

The distance seems to correspond to a discriminative criterion, and thus intervenes in the variation of the morphology of the species and climatic conditions. Apart from this appearance of homogeneity, Khay is revealed as the most homogeneous population while Diatock is the most heterogeneous. This could lead to consider Niayes area as the focus of the infestation [18]. The agro-ecological zone is thus at the origin of this difference in size according to the [19] and development performance of insects is strongly influenced by the nutritional quality [20].

With respect to the agro-ecological zones, we can consider that specimens are more homogeneous in Thies than in Casamance. The morphological homogeneity of the intra-group specimens of Thies is explained by the fact that the plants in Niayes zone constitute the primary speculation of *R. invadens* [18].

Results with the ascending hierarchical classification show 3 groups: a group where we find the populations of Diatock and Oussouye, a group made up only of the populations of Diatock and a third group comprising at the same time populations of Diatock, Khay and Santhie. The population of Oussouye is only found in one group; which shows then that it is a homogeneous population. This result is observed in the Khay and Santhie populations too. On the other hand, the population from Diatock is very heterogeneous because it is found in all groups. This shows that the infestation is more accentuated in Casamance than in Thies [21], knowing that the development cycle of *R. invadens* can be influenced by the availability of food; adult males being long-flight specimens migrate from infested areas in search of new food resources [22], when mango tree is inaccessible or stops production.

5. Conclusion

The study of the morphometric characterization of *Rastrococcus invadens* populations aims to verify whether the distribution of the insect has an impact on its morphology. It revealed morphometric groups more or less distinct especially between the Niayes zone and low Casamance. However, additional studies are needed to understand what is behind the existence of these more sub-distinct groups. A genetic study is also needed to see whether the morphometric differences detected between groups are observable at the molecular level by using mitochondrial genes that are little variable genes.

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Evaluation des pertes causées par *Rastrococcus invadens* (Willams, 1986) (*Homoptera, Pseudococcidae*) sur la mangue au Sénégal (Casamance)

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RESUME

Objectif : Au Sénégal, *Rastrococcus invadens* représente une des espèces ravageuses de manguiers la plus répandue dans les zones de fortes productions d'agrumes telle que la Casamance. Notre étude consiste à déterminer les dégâts causés par cet insecte sur quatre variétés de manguier et leur incidence sur le prix après récolte.

Methodology and results : Cette étude a été réalisée dans trois fermes (Diatock, Loudia wolof et Tobor) situées toutes dans la Casamance naturelle. Le travail s'est déroulé pendant les mois de juillet, août et septembre 2016. Dans chaque ferme, nous avons choisi après étude, les quatre variétés de manguiers les plus attaquées à savoir : Kent, Keitt, Bouko diékhal et Séwé. Pour chaque variété de manguier, à la production, nous avons récolté au hasard 20 fruits classés en deux groupes (infestés et non infestés). Ces fruits sont ensuite pesés pour connaitre le poids moyen des fruits infestés et des fruits non infestés afin d'évaluer les pertes et les rendements obtenus. Les résultats ont montré une perte de 778,8 dollar pour la variété Kent, 650,9 pour la variété Séwé, 440,6 pour la variété Keitt et 217,5 pour la variété Bouko diekhal. Cependant, les dommages sont plus accentués sur les variétés (Séwé et Keitt) car plus sensibles que les autres mais puisque le prix de la variété Kent est plus élevé le coût des pertes y est plus important.

Conclusion : Dans la zone de Casamance, l'infestation de *Rastrococcus invadens* rend moins rentable la production des variétés de mangue (Séwé et Keitt) comparé à celle de Kent et Boucco diékhale par contre la variété Kent moins attaqué présente plus de perte en termes de cout après récolte.

Mots clés: *Rastrococcus invadens*, mangue, variétés, coût des pertes, évaluation.

Evaluation of losses caused by *Rastrococcus invadens* (Willams, 1986) (Homoptera, Pseudococcidae) on mango in Senegal (Casamance)

ABSTRACT

Objective: In Senegal, *Rastrococcus invadens* is one of the most prevalent mango tree pests in areas of high citrus production such as Casamance. Our study consists in determining the damage caused by this insect on four mango varieties and their impact on the post-harvest price.

Methodology and Results: This study was carried out on three farms (Diatock, Loudia Wolof and Tobor) all located in natural Casamance. The work took place on July, August and September 2016. In each farm, we chose four varieties mango most attacked: Kent, Keitt, Bouko diékhal andSéwé. For each mango variety, we randomly collected 20 fruits classified into two groups (infested and uninfested). These fruits are weighed for the average weight of infested fruit and non-infested fruit in order to evaluate losses and yields obtained. Results showed that a loss of 778.8 $ of Kent variety, 650.9 $ of Séwé variety, 440.6 of Keitt variety and 217.5 of Bouko diekhal variety. However, damage is more pronounced on some varieties (Séwé and Keitt) because more sensitive than others, but since the price of Kent variety is higher, cost of losses is higher.

Conclusion: In the Casamance, the infestation of *Rastrococcus invadens* makes the production of mango varieties (Séwé and Keitt) less profitable compared to that of Kent and Bouko Diekhale, whereas the less attacked variety has more losses in terms of cost after harvest.

Keywords: *Rastrococcus invadens,* mangoes, variety, losses, evaluation.

INTRODUCTION

Au Sénégal comme dans la plupart des pays d'Afrique de l'Ouest, les fruits constituent des produits alimentaires à haute valeur nutritive et commerciale (Dembélé et *al*, 2013). Ils contribuent à l'amélioration du bien-être social et à l'état de santé des populations (FAO, 1999). La production annuelle des fruits représente environ 1,3 million de tonnes, soit près de 4 % de la production mondiale, avec des pertes pouvant atteindre entre 40 % et 50 %, (MCSI, 2016). Cette production provient essentiellement de la Casamance, de Thiès et de Dakar rural. La valeur marchande et financière apporte une devise importante aux producteurs (Dembélé et *al*., 2013). De nos jours, la production de fruits est menacée par les problèmes phytosanitaires dont les plus importants sont les mouches des fruits (famille des Tephritidae) Norrbom (2004) et la cochenille farineuse du manguier *Rastrococcus invadens* Williams (*Homoptera* : *Pseudococcidae*) (N'guetta, 1995). Originaire de l'Inde (Williams, 1986), la cochenille farineuse du manguier *Rastrococus invadens* Williams (Homoptera, Pseudococcidae) a été observée sur 45 espèces végétales appartenant à 22 familles en Afrique de l'ouest (Agounké *et al.,* 1988). Les pertes liées aux dégâts de ces insectes sont estimées à travers le monde à plusieurs milliards de dollars selon Norrbom (2004). Face au mode d'agression des plantes par les insectes, la lutte contre ces ravageurs est d'autant plus complexe que la lutte chimique conventionnelle reste peu efficace et présente des effets néfastes pour l'environnement, les producteurs et les consommateurs (Vayssières et *al*., 2008). Ainsi, il devient important de gérer à la fois les facteurs édaphiques, climatiques et biotiques qui influencent la pullulation d'insectes en général et de la cochenille farineuse du manguier en particulier. L'objectif de cette étude est d'évaluer les dégâts causés par la cochenille sur le manguier pour une meilleure lutte.

MATÉRIEL ET MÉTHODES

Présentation de l'insecte : *Rastrococcus invadens* est un insecte originaire d'Asie du Sud-est. Il appartient à l'embranchement des Arthropodes, classe des Insectes, à l'ordre des Orthoptères, à la super famille des Coccoidea et à la famille des Pseudococcidae.

Présentation des variétés: Au Sénégal, la mangue a été identifiée comme une des chaines de valeurs du secteur horticole disposant d'un potentiel intéressant sur les marchés sous régionaux, américain et européen (MCSI, 2016). Notre étude porte sur les quatre variétés les plus attaquées par *R. invadens* :

- la variété Kent qui représente plus de 70 % des mangues exportées, elle donne un gros fruit de coloration externe rouge pourpre avec une chair orangée fondante et juteuse, sans fibre. Sa qualité gustative est excellente. Elle résiste bien au transport maritime ;
- la variété Keitt est la deuxième variété exportée par les pays de sous-région. Plus tardive, d'une coloration rouge rosée, elle a une chair jaune ferme, sans fibre, mais sa peau est fine et fragile, sensible aux manipulations. Cependant son processus de maturation lente la rend adaptée au transport maritime
- la variété Bouko diékhal est une variété locale généralement non appréciée à l'exportation. Elle dispose d'une verte, devenant légèrement orangée, à la chair orange, et présence de fibres et de très bonne qualité gustative ;
- la variété Séwé est aussi une variété locale. Elle présente des fruits de très petite taille et de couleur jaune à maturité avec un goût sucré mais très riche en fibres et non exportées vers le marché international.

Présentation du site : Des enquêtes et prospections sont menées dans la région de Casamance qui est l'une des principales zones de production de fruits au Sénégal. Les coordonnées géographiques, l'humidité et la température sont obtenues à l'aide respectivement d'un GPS, d'un hygromètre et d'un thermomètre.

La Casamance est située au sud du Sénégal et couvre une superficie totale de 52 000 km^2 dont le relief est représenté par les contreforts du Fouta Djalon au sud-est du territoire. Elle est limitée à l'Est par le Mali à l'Ouest par l'océan Atlantique, au Nord par la Gambie et au Sud par la Guinée-Bissau et la Guinée Conakry. Dans cette région nous avons échantillonné au niveau des départements de Bignona, d'Oussouye et de Ziguinchor qui constituent les zones les plus productives de fruits. Notre échantillonnage est réalisé dans les localités de Diatock, de Loudia wolof et de Tobor. Le climat de la région est de type soudano-guinéen caractérisé par une période humide correspondant aux mois de juin à octobre (été) mais appelée ici saison des pluies ou hivernage. La pluviométrie varie entre 800 à 2000 mm d'est en ouest et la température est sensiblement égale à 29,8 °C.

Description du manguier : Plante à fleurs et à fruits (spermaphyte), le manguier (*Mangifera indica* L,) appartient à la classe des dicotylédones, à l'ordre des Sapindales et la famille des Anacardiaceae. Il est originaire du nord de l'Inde au pied de la chaîne Himalayenne (Arbonnier, 2002). C'est un arbre à grande cime étalée arrondie et dense qui peut atteindre 30 m de hauteur avec un tronc monopode bien individualisé (Arbonnier 2000). Il dispose d'un système racinaire pivotant avec quelques ramifications pour un bon ancrage au sol bien adapté à la recherche de nappe phréatique dans des conditions de stress hydrique (FAO, 1999). Le feuillage du manguier vert foncé à la partie supérieure de l'arbre, est pâle dans sa partie basale et d'ordinaire rougeâtre au stade jeune (C.R.F.G., 1996). Les feuilles simples et persistantes, sont entières avec une disposition alterne et un limbe elliptique avec un long pétiole pouvant atteindre 5 cm de long (Arbonnier, 2000). L'inflorescence est une panicule terminale qui porte environ 1000 fleurs munies d'un pédicelle de 2 à 3 millimètres de long. Le manguier a des fleurs soit hermaphrodites, soit mâles jaunâtres à leur épanouissement et qui deviennent orangées par la suite. Ces fleurs comportent 5 sépales et 5 pétales avec en général une étamine par fleur parfaite et un ovaire supère contenant un seul ovule (de Laroussilhe, 1980). Le manguier est une plante de climat tropical qui pousse dans des zones à pluviosité comprise entre 600 et 1200 mm par an et se développe bien dans l'intervalle de température 22 à 43,5°C avec une température optimale de croissance comprise entre 23°C et 27°C (Ouedraogo, 2011).

Méthodologie : Le travail s'est déroulé pendant les mois de juillet, août et septembre 2016 dans 3 fermes de 3 localités de la région de Casamance naturelle (Diatock, Loudia wolof et Tobor). Dans chaque ferme, nous avons choisi les quatre variétés de manguiers les plus attaquées à savoir : Kent, Keitt, Bouko diékhal et Séwé. Pour chaque variété de manguier, nous avons récolté au hasard 20 fruits classés en deux groupes (infestés et non infestés). Ces fruits sont ensuite pesés pour connaitre le poids moyen des fruits infestés et des fruits non infestés afin d'évaluer les pertes et les rendements obtenus. Nous avons déterminé le poids perdu (PP) exprimé en (%) en utilisant la formule suivante :

$$PP = \frac{PMNI - PMI}{PMNI}$$

PP : Poids Perdu (%) ; **PMNI :** Poids des Mangues Non Infestées ; **PMI :** Poids des Mangues Infestées

Dans cette ferme nous avons évalué avec le producteur, le poids total des mangues (PTM) pour chaque variété ; ce qui nous a amené à calculer le poids total des pertes (PTP) pour chacune des variétés selon l'équation suivante :

$$PTP = \frac{PTM \times PP}{100}$$

PTP : Poids Total Perdu ; **PTM :** Poids Total des Mangues; **PP :** Poids Perdu (%)

Le coût des pertes (CP) en dollars pour chaque variété dans une ferme d'un hectare a été évalué selon la formule ci-dessous :

$$CP = PTP \times PM$$

CP : Coût des Pertes ; **PM :** Prix Moyen au Kg ; **PTP :** Poids Total des Mangues

RESULTATS

Les tableaux 1 et 2 renseignent sur les différentes variétés de mangues étudiées, le poids moyen des fruits infestés et non infestés et la perte estimée due à l'infestation à la fin de la production. Le tableau 1 montre que dans toutes les fermes, la variété locale (Séwé) et la variété améliorée (Keitt) sont plus attaquées que les autres avec respectivement 40,6% et 38,7% de perte. Par contre, pour les variétés Kent et Bouko diékhal), les pertes enregistrées sont respectivement 25% et 18,6%.

Tableau 1 : Evaluation des pertes de poids dues à l'infestation à maturité

	Kent			Keitt			Bouko diékhal			Séwé		
	Fd	**Fl**	**Ft**	**Fd**	**Fl**	**Ft**	**Fd**	**Fl**	**Ft**	**Fd**	**Fl**	**Ft**
Poids des mangues non-infestées (g)	679	712	592	489	556,2	603,2	347	285,1	297	128	136,7	177
Poids des mangues infestées (g)	516,1	533,6	437	286	355,5	369	291	236,9	227	73	86,1	103
Poids de mangues per dues (%)	24	25	26	41,5	36	38,8	16,1	16	23,6	43	37	41,8
Poids de mangues perdues par variété (%)	25			38,7			18,6			40,6		

Fd : Ferme de Diatock ; **Fl :** Ferme de Loudia wolof; **Ft :** Ferme de Tobor.

Le tableau 2 renseigne sur le poids total des mangues infestées et des mangues non infestées pour chaque variété étudiée durant la saison et le coût des pertes. Le poids des mangues perdues en pourcentage varient de 18,6 pour la variété Bouko diékhal à 38,7 pour celle de Keitt. En revanche, le coût des pertes estimées 217,5 dollars pour la variété Bouko diékhal à 778,8 pour celle de Kent.

Tableau 2 : Evaluation du coût des pertes de poids dues à l'infestation à maturité

	Kent			**Keitt**			**Bouko diékhal**			**Séwé**		
	Fd	**Fl**	**Ft**	**Fd**	**Fl**	**Ft**	**Fd**	**Fl**	**Ft**	**Fd**	**Fl**	**Ft**
Poids total des mangues (kg)	5760	5328	7841	3008	2889	2650	3728	3900	3456	6992	6937	5878
Poids total des mangues infestées (kg)	1382	1385,3	1960,2	1167,1	1040	1099,7	596	627,9	815,6	3006,6	2567	2457
Coût des pertes ($)	691	692,6	980,1	446,8	416	439,9	190,72	200,9	261	721,6	641,75	589,6
Coût total des pertes par variété ($)	**778,8**			**440,6**			**217,5**			**650,9**		

Fd : Ferme de Diatock ; **Fl :** Ferme de Loudia wolof; **Ft :** Ferme de Tobor

DISCUSSION

Les résultats montrent que les pertes de poids dues à *R. invadens* concernent le manguier, qui demeure la plante hôte la plus infestée sont importantes. Le coût de perte est beaucoup plus élevé sur la variété Kent (778,8$ à l'hectare) qui constitue la variété la plus cultivée car plus adaptée à l'exportation (Hala et *al*., 2004). Cependant, comme Bouko diékhal est la variété la moins attaquée, elle a un coût de perte (217,5 $ à l'hectare) moins important que les autres. Ce faible coût de perte s'explique par la faible production contrairement aux autres variétés (Kent, Keitt etSéwé). Les pertes sont plus importantes sur Séwé (40,6%) et Keitt (38,7%), mais le coût des pertes n'est pas plus élevé pour ces deux variétés car d'autres résultats ont montré que l'infestation est proportionnelle à la production de fruits (Fall *et al*., 2017). Ainsi, plus la production de fruits augmente plus l'infestation est importante. C'est pourquoi la variété Kent qui est la plus cultivée, présente un coût de perte plus élevé que Keitt (440,6$ à l'hectare) et Séwé (650,9$ à l'hectare) qui sont plus attaquées. Il faut aussi ajouter que sur le marché national le prix d'un kilogramme de mangue de la variété Kent (0,5$) est plus élevé que celui de Keitt (0,4$), de Bouko diékhal (0,32$) et de Séwé (0,25$). Ces attaques ont des conséquences très néfastes sur les exportations de mangues fraîches en direction de l'Union Européenne car une baisse de l'ordre de 10% due aux problèmes phytosanitaires dont les plus importants sont les mouches des fruits (famille des Tephritidae) et la cochenille farineuse du manguier *R. invadens*, a été enregistrée au Burkina Faso entre 1995 et 2002 (Dabiré, 2001).Au Sénégal et plus précisément dans la localité de Diatock, les plantes très attaquées c'est-à-dire entièrement couvertes de fumagine n'arrivent pas à fleurir ou arrêtent précocement la production de fruits. Devant la gravité des dégâts, les méthodes mécaniques ou physiques (abattage et brûlage des arbres ou branches attaqués) sont généralement pratiquées par les producteurs (Vanniére et *al*., 2004). Comparé aux autres zones agro écologiques comme l'Asie où l'insecte a été identifié pour la première fois en Inde, des enquêtes ont montré que les cochenilles du genre *Rastrococcus* ne provoquent des problèmes que localement et ponctuellement (Moore, 2004) alors qu'au Sénégal sur les quatre variétés de manguier étudiées (Kent, Keitt, Séwé et Bouko diékhal), nous sommes à près de 30,7% de pertes avec un coût global de 2087,8$ pour la saison de 2016. Les dégâts varient non seulement en fonction des variétés de manguier mais aussi en fonction des zones agro écologiques. De même, nous pouvons aussi noter que plus la surface emblavée n'est grande, plus le coût des pertes deviennent important. Ces pertes de poids entraînant l'augmentation du coût financier perdu sont dues à un retard de la croissance des fruits du à l'insecte. Ce dernier cause des dégâts directs par les piqûres qui entrainent la perte de sève et des dégâts indirects par la production du miellat et la fumagine qui se forment à la surface des feuilles et des fruits (Hala et *al*. 2004). Ces résultats confirment les travaux de Moore en 2005. Selon Moore, le retard de la croissance noté sur les fruits est dû au dépôt de fumagine sur les fruits et les feuilles empêchant ainsi la photosynthèse. Généralement, les producteurs de mangues sont confrontés à deux contraintes étroitement liées l'une à l'autre : défaut de qualité du fruit imputable aux dépôts de fumagine par la cochenille farineuse du manguier et insuffisance de techniques adéquates de conservation post-récolte (Dembélé et *al*., 2013). La présence des colonies de cochenilles farineuses du manguier et de la fumagine sur les fruits entraîne des décolorations et une perte de la qualité. Ces fruits attaqués ou souillés, même après lavage et brossage, présentent, pour la plupart, des plages décolorées sur l'épiderme, devenant ainsi non exportables. En comparant les dégâts causés par *R. invadens* sur les fruits en fonction des mois pendant la période de production, nous pouvons dire que le poids perdu est beaucoup plus élevé sur les fruits mûrs que sur ceux non mûrs (Tobih et *al*., 2002).

CONCLUSION

Ce travail a permis d'évaluer les pertes causées par *Rastrococcus invadens* sur quatre variétés de mangues « Kent », « Keitt », « Séwé » et « Bouko diékhal ». Cette étude est indispensable compte tenu de l'importance que la filière mangue au pays. Elle nous a permis d'avoir des connaissances approfondies sur cette filière, les contraintes auxquelles elle fait face afin d'adopter des mesures pour mieux maitriser et augmenter la productivité.

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MORPHOMETRIC CHARACTERIZATION OF THE MANGO TREE'S MEALY COCHINEAL: RASTROCOCCUS INVADENS ON CITRUS TREE IN SENEGAL

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ABSTRACT

Morphometric data is a useful complement of information that allows precise identification of the different parts of Rastrococcus invadens in Senegal. This study was carried out in four farms (Diatock and Oussouye) all located in natural Casamance and (Santhie and Khay) in the region of Thies. The work took place in February 2016 where citrus production is important. In each farm, we chose the lemon tree and the orange tree which are host plants of R. invadens.

From each plant we collected 10 specimens. This enabled us to get 40 specimens from Casamance and 40 other specimens from Thies. Specimens were coded with regard to both the area and the type of plant they were collected from. The average measurements of the different parts of the insect showed a difference between the populations of the two agro-ecological zones with homogeneity of the populations of Thies and a heterogeneity of the populations of Casamance with a large zone of introgression. The results of this study should allow easier recognition of the different parts of R. invadens.

Keywords: Morphometric data, Rastrococcus invadens, Introgression

1. INTRODUCTION

Fruit production in Senegal, mainly concentrated on mango, citrus fruits and bananas in respective proportions of 67, 23 and 5%, was destined for domestic consumption (Parfonry, 1989).

Since 1981 (the year of the first exports to the French market), it has become the third largest agricultural production in southern Senegal, after cotton and cashew (COLEACP, 1995). Although the volume exported is small relative to production, Senegal has strongly increased trade abroad and especially to Europe during the last 10 years, reaching average quantities between 5,000 to 6,000 tons per year, despite the fall of 50% in 2010 (about 3,000 tones) due to the quality of the fruits as well as the attacks of insect pests which compromised the marketing campaign (Strebelle, 2013).

However, fruit production is threatened by phytosanitary problems, the most important of which are fruit flies belonging to the family Tephritidae and the mordant scale mango *Rastrococcus* *invadens* (Willams, 1986) (Homoptera: Pseudococcidae) (N'guetta, 1995). This latter pest was accidentally introduced in Africa in the early 1980s from the Southeast Asia where it originates (Williams, 1986). Mealybug was first observed in Togo and Ghana before spreading to most West African countries, causing damage to mango and other fruit trees (Agounké *et al*., 1988).

In Côte d'Ivoire, its appearance was reported in 1989 (Neuenschwander *et al*., 1994). Very polyphagous, *R. invadens* quickly became one of the main enemies of mango and several other fruit trees including citrus and various ornamental and shade plants.

R. invadens is a species of bisexual and ovoviviparous cochineal that lives in colonies on the leaves of host plants (ANSES, 2015). On plants, mealybugs can be found on leaf petioles, on fruits and peduncles (ANSES, 2015).

Various studies have been undertaken with a view to setting up an integrated pest management program against this pest. Morphometric data is a useful complement of information that allows precise identification of different stages of insect development (Berkani, 2003).

The present work aims to take stock of the morphological and morphometric characteristics of the pest of fruit plants in space and time since its appearance in Senegal.

2. MATERIAL AND METHODS

21 Sampling

Two populations of *R. invadens* (Williams, 1986) [2] were compared during this analysis: one population from Natural Casamance region and another from Thies region. In each region we chose two farms in two different localities. In Casamance, we chose one farm in Diatock locality and another one in the locality of Oussouye. In Thies region, we sampled in Santhie and Khay localities.

In each farm, we chose the lemon tree and orange tree which represents the host plant of *R. invadens*.

From each plant we collected 10 specimens. This enabled us to get 40 specimens from Casamance and 40 other specimens from Thies. Specimens were coded with regard to both the area and the type of plant they were collected from. Data are clustered in Table 1 below. In general, morphometric analysis of *R. invadens* larvae is usually destructive. Actually, it requires prior death of the specimens and their fixation in alcohol (Osafune *et al*., 2005) [12].

2.2 Morphometric study

We chose 10 measurable variables with a reasonable degree of accuracy. These mainly include body length, body width, length and width of head, length of rear, median, and front legs. To these are added lengths of abdomen, thorax, and average diameter of sternum (Figure 1).

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Table 1: Choice of values

Body	Head	Thorax	Abdomen
Lc :Body length	LT : Head length	Th : Thorax length	La :length of abdomen
lc : body width	lt : Head width	Lp1 : length of the first pair of legs	
		Lp2 : length of the second pair of legs	Ls1 : length of first sternum
		Lp3 : length of the third pair of legs	

The relevant parts were mounted on a binocular stereoscope equipped with a camera connected to a computer. Observations were made on L3 (3rd larval stage) specimens which correspond to pre-pupa for males. Specimens are then cleaned in alcohol 70 before proceeding to measurements, each relevant part being carefully separated from the next one.
Each specimen of a given sample is associated to a code, using the capital letter of the gender name followed by the first letter of the specific epithet of the corresponding plant, the first letter of the locality of origin and finally the first letter of the region of origin (Table 2).

Table 2: Summary table of the sampling

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Codes	Plant species	Localities	Number specimens	Regions
CDC	Lemon tree	Diatock	10	Casamance
CDO	Orange tree	Diatock	10	Casamance
COC	Lemon tree	Oussouye	10	Casamance
COO	Orange tree	Oussouye	10	Casamance
TSC	Lemon tree	Santhie	10	Thies
TSO	Orange tree	Santhie	10	Thies
TKC	Lemon tree	Khay	10	Thies
TKO	Orange tree	Khay	10	Thies

CDC: Casamance-Diatock-Lemon, **CDO:** Casamance-Diatock-Orange**.** **COC:** Casamance- Oussouye- Lemon. **COO :** Casamance-Oussouye-Orange. **TSC:** Thies-Santhie- Lemon. **TSO:** Thies-Santhie-Orange. **TKC:** Thies-Khay- Lemon. **TKO:** Thies-Khay-Orange

2.3 Statistical analyses

2.3.1 Raw measurements

A discriminant factor analysis (DFA) of populations with raw measurements of variables in regard to the sampled agro-ecological zones was carried out with the help of the software R version 3.2.3 (Bloomfield, 2014) [13]. This analysis enables to set off the contribution of each variable with respect to their bald measurement, in order to see the most discriminating ones, and to bring out morphometric groups regarding the agro-ecological zones, too.

2.3.2 Converted measurements

- **Size effect**

According to Santos (2015) [14] size effect appears by a circle of correlation that groups all the variables in a single plane for a given axis. This concerns a very undesirable effect which metrical studies try to overcome. The principle of elimination is then to bring all specimens to the same size so as to observe on the PCA only differences in shape.

- **data conversion**

Eliminating the size effect that affects almost all biometric studies was done using the following approach by Santos (2015) [14]:

-Log-transformation of data: initial data table consists of the variables X1, X2, ..., Xp, subsequently a new data table consisting of the variables log (X1), log (X2), ..., log (Xp)) has been created.

- For each specimen, the average over all Log-transformed variables was calculated. This average score is a good idea of the "size" for this specimen.
- Finally, for each specimen, the average size obtained with Log-transforms was deducted from each of these raw measurements.

Size effect is thus eliminated and only the difference in shape will be observed on the PCA. Decreasing the weight of this factor (Size) results in a decrease of the global discrimination between populations and the reduction of the distance between centres of gravity of populations. This transformation was performed in Excel version 2011.

2.3.2.1 Discriminant Factor Analysis (DFA)

A discriminant factor analysis (DAF) of the populations with the transformed data of the variables according to the localities and host plants sampled was carried out with the software R version 3.2.3 (Bloomfield, 2014) [13]. This analysis aims to bring out the contribution of each variable after elimination of the size effect in order to see the differences in form between population groups revealed by the discriminating power of each of the variables.

2.3.2.2 Correspondence Factor Analysis (CFA)

Factorial Correspondence Analysis (CFA) is performed to visualize relationships between specimens of different populations from converted data and test for possible metric similarities between these populations. It is a multi-varied analysis method that considers converted measurements of all populations as variables (Hoda and Marsan, 2012) [15]. For this purpose, a graphical representation is produced from the transformed data that are adapted using the Genetix version 4.05.2 program (Belkhir *et al*., 2004) [16] to estimate the distribution of morphological diversity at all levels (individuals, populations and total population).

I.3.2.3 Confusion matrix for cross-validation results

The confusion matrix summarizes the reclassifications of specimens to infer both rates of good and bad ranking. This makes it possible to determine the "correct%" which is the ratio of the number of well-ranked specimens to the total number of specimens. Cross-validation is done using transformed data according to agro-ecological zones and plant species sampled with the XLSTAT software version 2016.03.30882 (Addinsoft, 2018) [17].

I.3.2.4 Hierarchical Ascending Classification (CAH)

It represents a method of trees construction that is often delicate and difficult to generalize if the learning data are poorly representative of reality. Automatic classification methods that do not require learning are of great interest when data are completely unknown. They thus make it possible to release subsequent classes that are not obvious a priori. Therefore, the CAH consists of grouping specimens regarding their resemblance or difference. The ascending hierarchical classification is carried out in Excel version 2011.

3. RESULTS

3.1 Raw data

3.1.1 Contribution of the variables with raw measurements in terms of the localities of origin of specimens collected from lemon tree

The discriminant factor analysis obtained from specimens collected from lemon tree shows that the first two factorial axes (dimension) best explain the morphometric variability with 83.14% of inertia power. Following the factorial axis 1 (dimension 1), we find that variables such as Lp2 (F1=12.8), Lp1 (F1=12.3), Lp3 (F1=12.2), La (F1=12.2), lt (F1=11.6), Lc (F1=11.2), lc (F1=10.9), LT (F1=9.6) and Ls1 (F1=7.10) have largely participated in the construction of the first factorial axis with 70.70% of the power of inertia. Only the variable Th (F1=0.003) contributes slightly to the construction of the first axis. The factorial axis 2 (dimension 2), with a low power of inertia (12.44) is constructed largely by the variables Th (F2=80) and Lc (F2=11.9). Other variables such as lt (F2=3.29), La (F2=2.82), LT (F2=1.36), Lp3 (F2=0.34), Lp1 (F2 = 0.09), Ls1 (F2= 0.009), Lp2 (F2 = 0.08) and lc (F2=0.003) contribute little to the construction of this axis. On the first factorial axis, all the variables are positively correlated. Obviously, the size effect affects our ACP. (figure1) A globally positive correlation for the variables, along the factorial axis of dimension 1, seems to suggest an influence of the data by the "size effect".

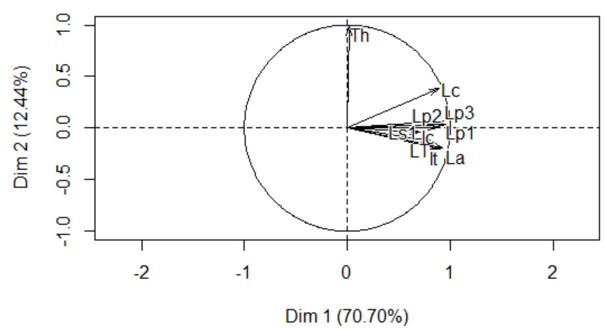

Figure 1: Contribution of lemon tree populations' variables

3.1.2 Discrimination of populations according to raw measurements according to the localities of individuals from the orange tree

The discriminant factor analysis obtained from specimens collected from mango tree shows that the first two factorial axes (dimension) best explain the morphometric variability with 87.33% of inertia power. Following the factorial axis 1 (dimension 1), we find that variables such as LT (F1=11.9), lt (F1=11.7), Lp1 (F1=11.6), Lp2 (F1=11.3), lc (F1=10.8), Lc (F1=10.2), Lp3 (F1=10.1), La (F1=9.16) and Ls1 (F1=8.7) have largely participated in the construction of the first factorial axis with 74.46% of the power of inertia. Only the variable Th (F1=4.41) contributes slightly to the construction of the first axis. The factorial axis 2 (dimension 2), with a low power of inertia (12.87) is constructed largely by the variables Th (F2=45.2), Ls1 (F2= 21.8), lc (F2=10.8) and Lc (F2=9.89). Other variables such as Lp3 (F2=4.13), Lp2 (F2=2.89), Lp1 (F2=2.07), La (F2=1.27), lt (F2=0.93) and LT (F2=0.91) contribute little to the construction of this axis. On the first factorial axis, all the variables are positively correlated. Obviously, the size effect affects our ACP. (Figure 2) A globally positive correlation for the variables, along the factorial axis of dimension 1, seems to suggest an influence of the data by the "size effect".

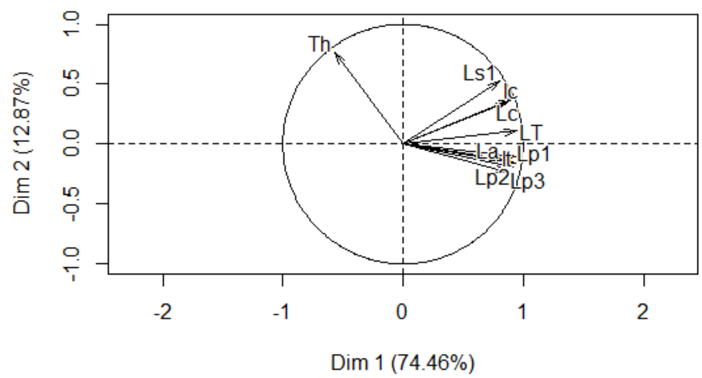

Figure 2: Contribution of orange tree populations' variables

3.1.4 Discrimination of populations according to raw measurements according to the localities of individuals from the lemon tree

With the lemon tree, following the two factorial axes with a power of inertia of 83.10%, the AFD (Discriminant Factor Analysis) reveals two groups. A group consisting of Santhie and Khay populations and another group composed by that of Diatock and Oussouye with a zone of significant introgression between the two populations. Khay specimens have some resemblance to those from Diatock.

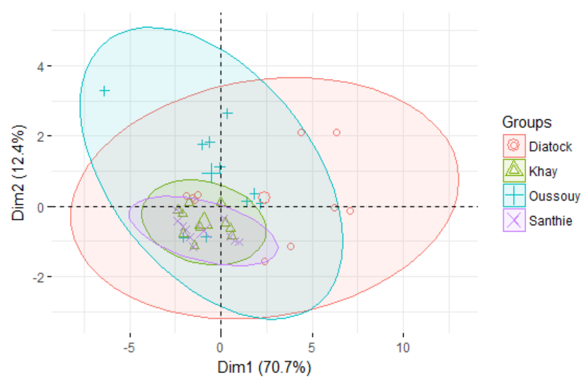

Figure 3: Representation in the main AFD plan of the populations of *Rastrococcus invadens* on the lemon tree

3.1.4 Discrimination of populations according to raw measurements according to the localities of individuals from the orange tree

Following the two factorial axes with a power of inertia of 87.40%, the AFD (Discriminant Factor Analysis) reveals two groups. A group consisting of the populations of Santhie and Khay and another group composed by that of Diatock and Oussouye with a zone of significant introgression between the two populations. Khay specimens have some resemblance to those from Diatock.

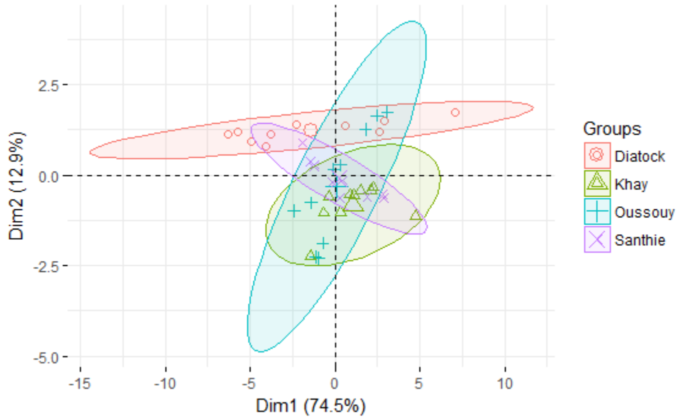

Figure 4: Representation in the main AFD plan of the populations of *Rastrococcus invadens* on the orange tree

3.1.5 Variables allowing the discrimination of lemon tree populations

In regard to the Tukey test, among the 10 variables studied, only the length of the body (Lc), length of the head (Lt), length of the first pair of legs (Lp1), intermediate leg length (Lp2) and the length of the third pair of legs (Lp3) make it possible to differentiate Diatock and Khay populations. The same result is obtained between Diatock and Santhie. Between Oussouye and khay, practically all variables are identical except body length (Lc) and thoracic length (Lth). This is the same result that was observed between Oussouye and Santhie.

Table 3: Morphometric study of specimens (*Rastrococcus invadens*) collected from lemon tree

localities / variables	Diatock	Khay	Oussouye	Santhie
Lc	2,69±0,68 a	2,81±0,42 a	2,66±0,54a	3,08±0,18a
lc	1,52±0,54 a	1,63±0,23 a	1,56±0,42a	1,63±0,14a
Lt	0,57±0,35a	0,75±0,09 a	0,63±0,22a	0,61±0,17 a
lt	0,75±0,40 a	1,09±0,14 b	0,84±0,15ab	0,97±0,16 ab
La	1,16±0,55a	1,63±0,36bc	1,46±0,21ab	1,98±0,22c
Lth	0,94±0,23b	0,42±0,16 a	0,57±0,19a	0,48±0,20a
Lp1	0,53±0,35a	0,76±0,12 a	0,71±0,16 a	0,60±0,17a
Lp2	0,61±0,35a	0,85±0,14a	0,81±0,08a	0,64±0,19a
Lp3	0,66±0,35a	0,91±0,13 a	0,89±0,04a	0,68±0,20a
Los1	0,31±0,17a	0,26±0,05 a	0,29±0,11a	0,26±0,03a

3.1.6 Variables allowing the discrimination of orange tree populations

According to the Tukey test, among the 10 variables studied, except the length of the thorax (Th), all the other variables make it possible to differentiate Diatock and Khay populations. Between Diatock and Santhie, except the body width (lt) and the length of the thorax (Th), all the variables make it possible to discriminate these two populations. Between Oussouye and khay, the differentiation noted is due to variables such as body length (Lc), body width (lc), head length (Lt), head width (lt) and length of the first sternum (Ls1). Between Oussouye and Santhie, variables such as body length (Lc), body width (lc), head length (Lt), length of the abdomen (La), length of the thorax (Th) and length of the first sternum (Ls1) discriminate their populations.

Table 4: Morphometric study of specimens (*Rastrococcus invadens*) collected from orange tree

localities / variables	Diatock	Khay	Oussouye	Santhie
Lc	3,95±0,6[b]	2,86±0,43[a]	4,12±0,33[b]	2,67±0,15[a]
lc	2,47±0,57[b]	1,75±0,31[a]	2,28±0,35[b]	1,54±0,14[a]
Lt	1,09±0,18[b]	0,64±0,20[a]	1,05±0,86[b]	0,56±0,07[a]
lt	1,72±0,41[b]	1,09±0,21[a]	2,01±0,13[b]	1,02±0,08[b]
La	2,26±0,22[c]	1,91±0,40[ab]	2,06±0,25[bc]	1,64±0,13[a]
Lth	0,61±0,46[a]	0,38±0,23[a]	1,01±0,04[b]	0,46±0,14[a]
Lp1	1,57±0,29[b]	0,89±0,14[a]	1,08±0,07[a]	0,91±0,06[a]
Lp2	1,68±0,24[b]	1,06±0,26[a]	1,14±0,12[a]	0,98±0,09[a]
Lp3	1,74±0,24[b]	1,17±0,33[a]	1,20±0,16[a]	1,04±0,09[a]
Ls1	0,37±0,12[bc]	0,30±0,04[ab]	0,41±0,04[c]	0,27±0,03[a]

3.2 Converted data

3.2.1 Contribution of the variables with converted measurements in terms of the localities of origin of specimens collected from lemon tree

Unlike raw data, the factor analysis with the transformed data of individuals from the lemon tree shows a reduction of the inertia percentage of 14.68% for the first dimension (factorial axis 1) following a decrease in the discriminating power of most of the variables taxpayers namely: Lp2 (F1=15.2), Lp1 (F1=13.9), Lp3 (F1=13.9), La (F1=13.8), lt (F1=11.3), Lc (F1=11.1), lc (F1=10.7) and LT (F1=6.28).

Only the variables Th (F1 = 2.41) and Ls1 (F1 = 1.33) contribute weakly to the construction of this first axis.

The second factorial axis with a very noticeable decrease (2.04%), shows a situation almost identical, compared to the results with the raw data, with an increase in the discriminating power of almost all the variables and a significant contribution of some variables such as Th (F2 =

50.9), Ls1 (F2 = 18.6), Lc (F2 = 11.3) and LT (F2 = 6.26) The best quality of representation is always obtained with the plane formed by axis 1 and 2 with a total inertia percentage of 70.5%.

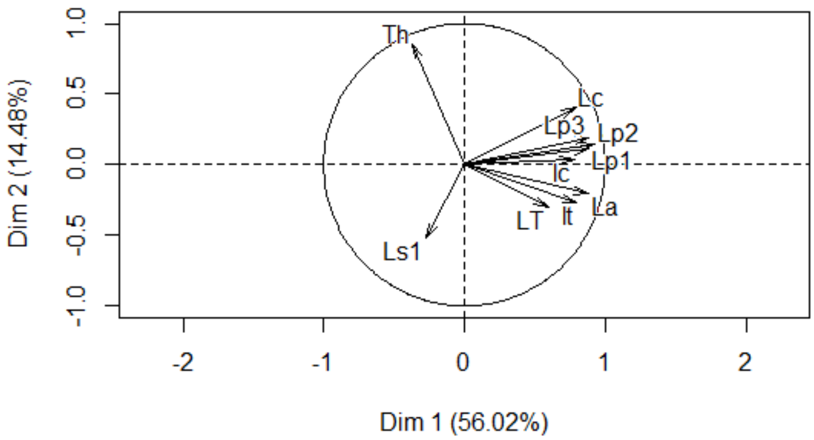

Figure 5: Contribution of lemon tree population variables

3.2.2 Contribution of the variables with converted measurements in terms of the localities of origin of specimens collected from orange tree

In contrast to raw data, the factor analysis with the transformed data of individuals from the orange tree shows a reduction of the inertia percentage of 14.68% for the first dimension (factorial axis 1) following a decrease in the discriminating power of most taxpayer variables namely: Th (F1 = 13.7), F1 (F1 = 12.8), Lp1 (F1 = 12.3), Lp2 (F1 = 11.7), LT (F1 = 10.5), La (F1 = 9.69), Lp3 (F1 = 8.92), 1c (F1 = 8.32), Lc (F1 = 8.32). Only the variable Ls1 (F1 = 3.61) contributes slightly to the construction of the first axis.

The second factorial axis with a very noticeable decrease (2.04%), shows a situation almost identical, compared to the results with the raw data, with an increase in the discriminating power of almost all the variables and a significant contribution of some variables such as Lc (F2 = 23.1), lc (F2 = 18.6), Lp3 (F2 = 15.5), Ls1 (F2 = 12.1), Lp2 (F2 = 11.1) and Lp1 (F2 = 6.29). The best quality of representation is always obtained with the plane formed by axis 1 and 2 with a total inertia percentage of 76.2%.

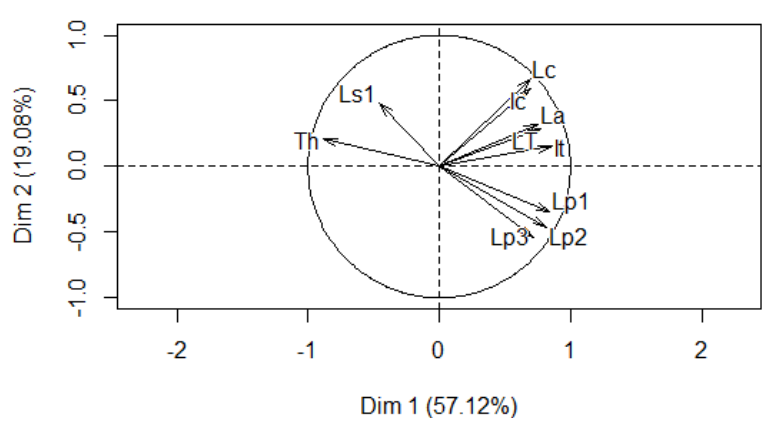

Figure 6: Contribution of orange

tree population variables

3.2.3 Discrimination of the populations, according to the converted measurements, in terms of the localities of origin of specimens collected from lemon tree

With the lemon tree, following the two factorial axes with a power of inertia of 83.10%, the AFD (Discriminant Factor Analysis) reveals two groups' one constituted by the populations of Santhie, Khay and another composed of individuals from Diatock and Oussouye. However, we note a certain similarity between the populations of different agro-ecological zones.

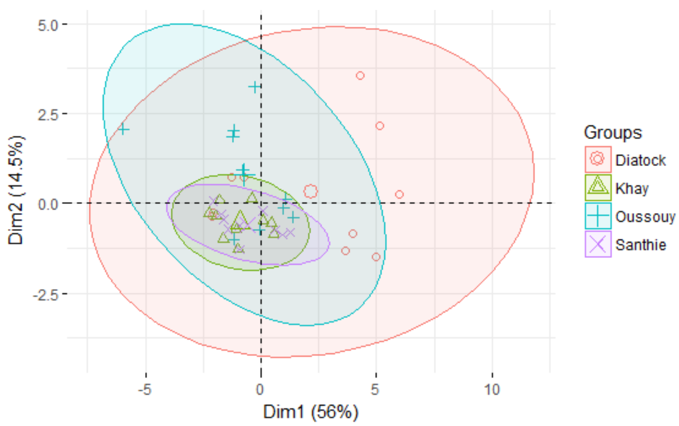

Figure 7: Representation in the main AFD plan of *Rastrococcus invadens* populations on the lemon tree

3.2.4 Discrimination of the populations, according to the converted measurements, in terms of the localities of origin of specimens collected from orange tree

On the orange tree, along the two factorial axes with a power of inertia of 87.40%, the AFD (Discriminant Factor Analysis) reveals two groups. A group consisting of the populations of Santhie and Khay and another group composed by that of Diatock and Oussouye with a zone of significant introgression between the two populations. Khay individuals have some resemblance to Diatock individuals.

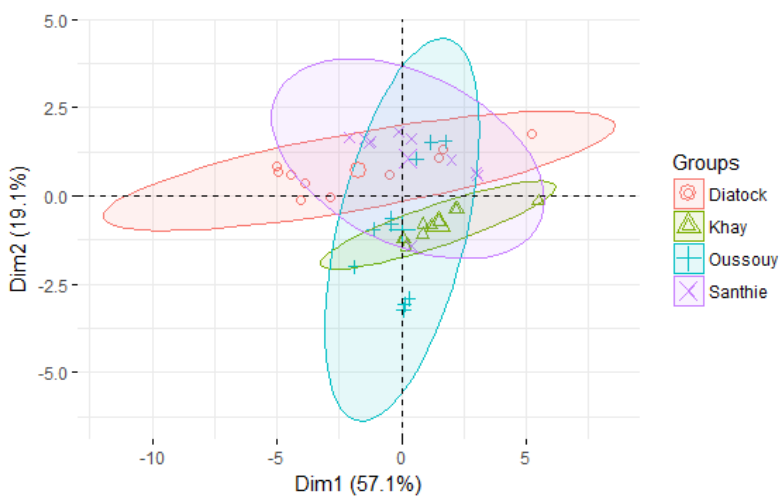

Figure 8: Representation in the main AFD plan of *Rastrococcus invadens* populations on the orange tree

3.2.5 Variables allowing the discrimination of lemon tree populations

According to the Tukey test, among the 10 variables studied, only the length of the body (Lc), head length (Lt), length first pair of legs (Lp1), length intermediate leg (Lp2) and the length of the third pair of legs (Lp3) make it possible to differentiate the Diatock and Khay populations. The same result is obtained between Diatock and Santhie. Between Oussouye and khay, practically all variables are identical except body length (Lc) and thoracic length (Lth). This is the same result that was observed between Oussouye and Santhie.

Tableau 5: Variables allowing the discrimination of lemon populations (converted data)

localities / variables	Diatock	Khay	Oussouye	Santhie
Lc	$2,82\pm0,50^{a}$	$2,86\pm0,36^{a}$	$2,73\pm0,46^{a}$	$3,16\pm0,14^{a}$
lc	$1,66\pm0,36^{a}$	$1,66\pm0,18^{a}$	$1,63\pm0,34^{a}$	$1,71\pm0,10^{a}$
Lt	$0,71\pm0,18^{a}$	$0,80\pm0,07^{a}$	$0,69\pm0,14^{a}$	$0,69\pm0,13^{a}$
lt	$0,89\pm0,23^{a}$	$1,14\pm0,08^{b}$	$0,91\pm0,09^{a}$	$1,05\pm0,13^{ab}$
La	$1,30\pm0,38^{a}$	$1,68\pm0,31^{b}$	$1,53\pm0,14^{ab}$	$2,06\pm0,18^{c}$
Lth	$1,08\pm0,41^{b}$	$0,47\pm0,15^{a}$	$0,64\pm0,14^{a}$	$0,56\pm0,24^{a}$
Lp1	$0,67\pm0,17^{a}$	$0,81\pm0,06^{a}$	$0,78\pm0,13^{a}$	$0,68\pm0,12^{a}$
Lp2	$0,74\pm0,17^{ab}$	$0,91\pm0,09^{c}$	$0,88\pm0,06^{bc}$	$0,72\pm0,14^{a}$
Lp3	$0,80\pm0,17^{a}$	$0,96\pm0,08^{b}$	$0,96\pm0,07^{b}$	$0,76\pm0,16^{a}$
Ls1	$0,45\pm0,06^{c}$	$0,30\pm0,02^{a}$	$0,36\pm0,04^{b}$	$0,34\pm0,02^{ab}$

3.2.6 Variables allowing the discrimination of orange tree populations

According to the Tukey test, among the 10 variables studied, except the length of the thorax (Th), all the other variables make it possible to differentiate the Diatock and Khay populations. Between Diatock and Santhie, except for the width of the body (lt) and the length of the thorax (Th), all the variables make it possible to discriminate between these two populations. Between Oussouye and khay, the differentiation noted is due to variables such as body length (Lc), body width (lc), head length (Lt), head width (lt) and length of first sternum (Ls1). Between Oussouye and Santhie, variables such as body length (Lc), body width (lc), head length (Lt), length of the abdomen (La), thoracic length (Th) and length of the first sternum (Ls1) discriminate their populations.

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Tableau 6: **Variables allowing the discrimination of orange populations (converted data)**

localities / variables	Diatock	Khay	Oussouye	Santhie
Lc	3,36±0,53[b]	2,64±0,16[a]	3,15±0,25[b]	2,63±0,19[a]
lc	1,83±0,20[a]	1,67±0,11[a]	1,80±0,24[a]	1,67±0,13[a]
Lt	0,82±0,13[b]	0,58±0,05[a]	0,69±0,18[ab]	0,61±0,04[a]
lt	1,14±0,18[b]	1,07±0,05[ab]	0,99±0,11[a]	1,08±0,07[ab]
La	1,88±0,33[a]	1,65±0,15[a]	1,69±0,25[a]	1,69±0,18[a]
Lth	0,56±0,28[ab]	0,48±0,11[a]	0,81±0,39[b]	0,42±0,10[a]
Lp1	1,11±0,32[b]	0,87±0,08[a]	0,74±0,15[a]	0,88±0,08[a]
Lp2	1,20±0,29[b]	0,97±0,08[a]	0,92±0,17[a]	0,99±0,09[ab]
Lp3	1,27±0,27[b]	1,04±0,09[ab]	1,02±0,22[a]	1,07±0,10[ab]
Ls1	0,29±0,12[a]	0,35±0,01[a]	0,30±0,05[a]	0,32±0,01[a]

3.2.7 Matrice de confusion pour les résultats de la validation croisée des populations

The confusion matrix summarizes reclassifications of specimens to infer the rates of good and bad ranking. This makes it possible to determine the "correct%" which is the ratio of the number of well-ranked specimens to the total number of specimens. Thus, specimens from different populations are well ranked in their original populations.

Table 7: confusing mastery of cross-validation of specimens from lemon tree

	Casamance	Thies	Total	% correct
Casamance	20	0	20	100.00%
Thies	0	20	20	100.00%
Total	20	20	40	100.00%

Table 8 : confusing mastery of cross-validation of specimens from orange tree

	Casamance	Thies	Total	% correct
Casamance	20	0	20	100.00%
Thies	0	20	20	100.00%
Total	20	20	40	100.00%

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3.3 Hierarchical Ascending Classification (HAC)

3.3.1 Hierarchical ascending classification on the orange tree

The hierarchical ascending classification brings out several morphometric groups based on similarities, from the variables. On the orange tree, the ascending hierarchical classification allows to have 4 groups with group 1 where we find only the populations of Diatock, the group 2 in which we meet all the populations (Oussouye, Diatock, Khay and Santhie), in the group 3 we find only the populations of Santhie and in group 4 we find all the populations except that of Khay. These results show that the population of Diatock is very heterogeneous because it is almost present in all groups. The populations of Oussouye and Santhie are not very heterogeneous because of the 4 groups, they are present on both. Only the population of Khay is homogeneous because it is present only in group 2.

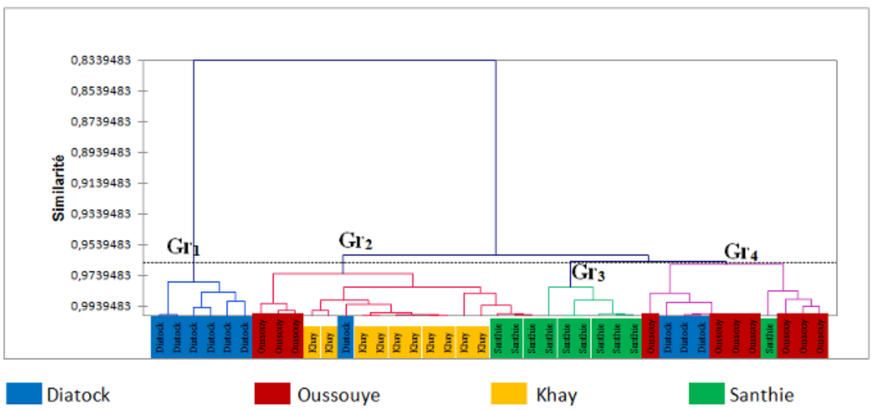

Figure 9: **Ascending classification of specimens from the orange tree**

Gr1: group 1 Gr2: group 2 Gr3: group 3 Gr4: group 4

3.3.2 Hierarchical ascending classification on the lemon tree

The hierarchical ascending classification brings out several morphometric groups based on similarities, from the variables. On the lemon tree we can distinguish 4 groups with the group 1 which consists mainly of Diatock and Oussouye populations, the group 2 includes all the populations (Diatock, Oussouye, Santhie and Khay). In groups 3 and 4 we find respectively of Oussouye and Diatock populations. These results show that Khay and Santhie populations are homogeneous while those of Diatock and Oussouye are heterogeneous because they are found in all groups.

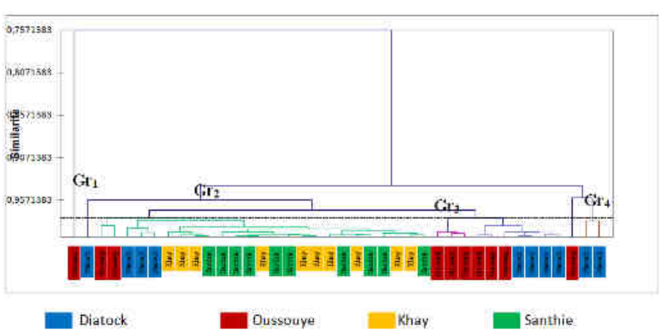

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Figure 10: Ascending classification of specimens from the lemon tree

Gr1: group 1 Gr2: group 2 Gr3: group 3 Gr4: group 4

3.4 Correspondence factor analysis (CFA)

3.4.1 Correspondence factor analysis (CFA) on the lemon tree

The discriminant factorial analysis reveals that the first five factorial axes explain all the morphometric variability of this cochineal. However, the plan formed by the first three axes best explains the discriminative situation of agro-ecological zones with an inertia 100%. The first factorial axis with an inertia of 37.2% discriminates the group formed in majority by the Oussouye individuals. The second factorial axis with an inertia of the order of 34.6% discriminates the other groups of the one containing almost all the individuals of Diatock. The third factorial axis with an inertia of 28.19%, allows the discrimination of the group which contains the majority of the individuals of Khay and Santhie, of the group formed in majority by the individuals of the area of Thies.

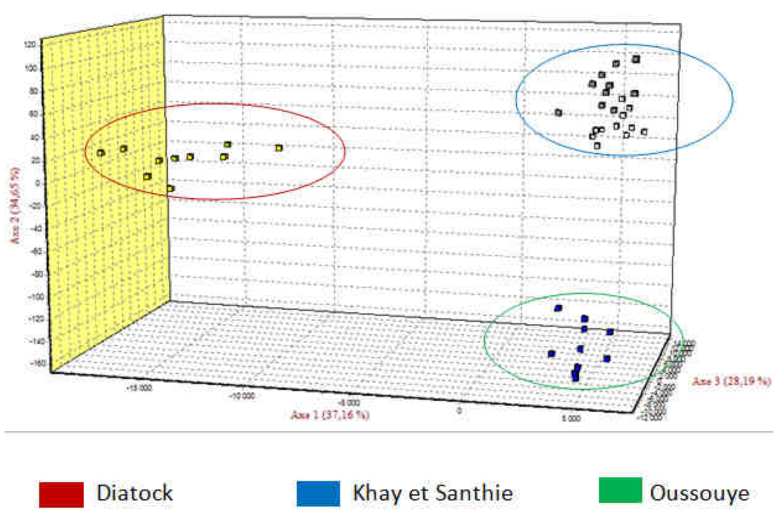

Figure 11: Simulation of the morphometric variability of specimens of *R. invadens* on lemon tree following the first three axes of the AFC

3.4.2 Correspondence factor analysis (CFA) on the orange tree

The discriminant factorial analysis reveals that the first five factorial axes explain all the morphometric variability of this cochineal. However, the plan formed by the first three axes best explains the discriminative situation of agro-ecological zones with 100% inertia. The first factorial axis with an inertia of 34.41% discriminates the group formed in majority by the Oussouye individuals. The second factorial axis with an inertia of the order of 34.01%, discriminates the other groups of the one containing only the individuals of Santhie. The third factorial axis with an inertia of 31.58%, allows the discrimination of the group which contains all the individuals of Diatock, and a large part of the individuals of Khay with introgressions of some individuals of the other ecotypes.

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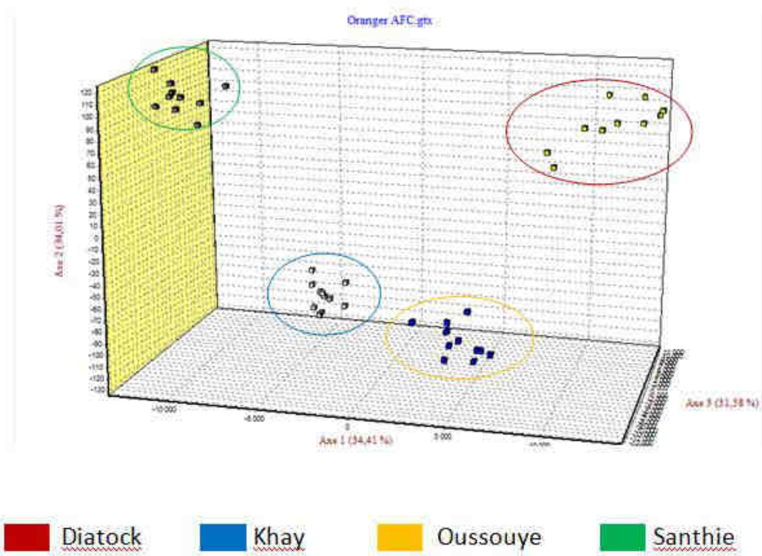

Figure 12: Simulation of the morphometric variability of specimens of *R. invadens* on orange tree following the first three axes of the AFC

4. DISCUSSION

The raw data with the lemon tree reveal two groups made up on the one hand by the populations of Santhie and Khay and on the other by those of Diatock and Oussouye. Considering the measurement of each variable obtained after transformation, we can see that the individuals harvested from lemon trees have a certain dissimilarity with, on the one hand, individuals from the Niayes zone that form a group and, on the other hand, individuals from Casamance.

On the orange tree, they also reveal two groups. A group consisting of the populations of Santhie and Khay and another composed by that of Diatock and Oussouye with a zone of significant introgression between the two populations. Considering the measure of each variable obtained after transformation, we find that Khay individuals have a certain resemblance to Diatock individuals. But also we can say that the individuals of Diatock have the largest dimensions for all the variables: length of the body (3,82mm), width of the body (2,32mm), length of the head (0,95mm), width head (1.57mm), length of the abdomen (2.11mm), length first pair of leg (1.43), length second pair of leg (1.54mm), length third pair of leg (1, 60mm) while on the lemon tree the largest dimensions of the length of the first segment (0.35mm) are observed in the individuals of Khay and Santhie.

The discriminant factorial analysis of the lemon tree reveals the group formed mainly by the Oussouye individuals and discriminates the other groups from the one containing almost all the Diatock individuals. It also allows the discrimination of the group which contains the majority of the individuals of Khay and Santhie, the group formed mainly by individuals from the region of Thies.

On the orange tree, it makes it possible to discriminate the group formed in majority by the Oussouye individuals, that containing only the individuals of Santhie and a third group which

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contains all the individuals of Diatock, and a large part of the individuals of Khay with introgressions of some individuals from other ecotypes.

From these results we can say that some individuals belonging to a previously defined area have more similarities with other individuals from neighboring agro-ecological zones: this is the case of Santhie and Khay individuals who are all in the same Ecological agro zone but also with less close area individuals like Diatock.

This shows that the distance corresponds to a discriminative criterion because it intervenes in the variation of the morphology of the species, as well as the climatic conditions (Gbaguidi *et al*., 2015). Apart from this semblance of homogeneity, Khay is revealed as the most homogeneous population while Diatock is the most heterogeneous. This could lead us to consider the Niayes area as the focus of the infestation (Han et al., 2007).

The results with the hierarchical ascending classification show that:

On the lemon tree we can distinguish 4 groups with the group 1 which consists essentially of the populations of Diatock and Oussouye, group 2 in which we find all the populations (Diatock, Oussouye, Santhie and Khay). In groups 3 and 4 we find respectively populations of Oussouye and Diatock. As the populations of Diatock and Oussouye are almost found in all groups, we can consider that the individuals from Casamance (Diatock and Oussouye) are more heterogeneous than those from the Niayes (Khay and Santhie).

With the orange tree, the ascending hierarchical classification also allows to have 4 groups with group 1 where we find only the populations of Diatock, the group 2 in which we meet all the populations (Oussouye, Diatock, Khay and Santhie), in group 3 we find only the Santhie populations and in group 4 we find all the populations except that of Khay. These results confirm the heterogeneity of the Diatock population whose individuals appear in all groups. The populations of Oussouye and Santhie are not very heterogeneous because of the 4 groups they are present only on both. Only the population of Khay is homogeneous because it is present only in group 2.

However, greater similarity between Khay and Oussouye individuals is noted, but also between Diatock individuals and others who seem even closer.

According to these two agro-ecological zones, we can consider that the individuals are more homogeneous in Thies than in Casamance. The morphological homogeneity of intragroup individuals in the Niayes biotype is explained by the fact that the plants in this zone constitute the primary speculation of *R. invadens* (FALL *et al*., 2017).

5.CONCLUSION

The study of the morphometric characterization of Rastrococcus invadens populations made it possible to acquire additional information on the biology of this phytophage. It revealed morphometric groups more under less distinct especially between the zone of niayes and low Casamance. All of its results should be taken into account when developing IPM techniques against this pest in citrus orchards in Senegal.

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Genetic structuration of *Rastrococcus invadens* populations in Senegal (Casamance and Thies)

Amadou Fall, Fawrou Seye, Tofféne Diome, Mamour Toure, Raymond Demba Ndione and Mady Ndiaye

Abstract

Rastrococcus invadens (Homoptera, Pseudococcidae) or cochineal is an insect pest of mango trees and several other fruit trees including citrus. It belongs to the branch of Arthropods, class of insects, to the order of orthoptera, to the super family of Coccoidea and to the family Pseudococcidae. The cochineal is native to Southeast Asia and was first identified in Dakar (Senegal) in 1995. Since then it has been widely used throughout the country and more particularly in the two most fruit-producing regions: Casamance and Thies. To study the genetic structure of the populations of *Rastrococcus invadens*, we have chosen the three species of host plants most attacked, namely the mango tree, the lemon tree and the orange tree. On each foot, we randomly harvested 10 insects. This allows us to have a total of 60 individuals, including 30 in the Casamance natural region and 30 in the Thies region. Samples are coded according to the area and type of plant in which they were collected using the first letter of the genus name, the first letter of the region of origin and the first letter of the host plant. The same individuals stored in 70% alcohol were used for extractions, PCR (Chain Reaction Polymerase) and sequencing. The analysis is done by several software in order to output the different parameters of the study.The results obtained in genetic diversity show six groups of individuals according to host plants and study areas which confirm those of morphometry. However, since these groups have very small genetic distances, they constitute a single species of *Rastrococcus invadens*.

Keywords: *Rastrococcus invadens*, host plants, study area, genetic diversity, morphometric characterization, pest

1. Introduction

Scale insects (Hemiptera: Pseudococcidae) are a large family of insects with around 2,000 species described in more than 270 genera [1]. The family Pseudococcidae has a worldwide distribution, but it is more common in the subtropical and tropical regions [2]. Their name derives from a white, waxy secretion found on the bodies of adult females and nymphs of most species. Many members of this family are pests of a wide variety of crops in tropical, subtropical and temperate regions. Certain species cause a very significant negative impact on the yield and quality of production. Losses in economic crops due to large populations of mealybugs and excessive production of honeydew which serves as a substrate for mold growth [3] or the transmission of viruses which can radically reduce crop yields [4]. The taxonomy of mealybugs has generally been based on the morphology of the characters of adult females [5], and on few studies that have focused on adult males. This is likely due to the ephemeral nature of adult males and the difficulty in capturing them. In addition, some mealybug species are parthenogenic [5], thus eliminating the possibility of using males to identify these species and create inconsistencies in phylogenetic studies. Because of these factors, the use of adult females remains the standard for taxonomy, phylogenetic analysis and description of species in the Pseudococcidae family. Recently, advances in genetics have made DNA barcodes a practical means of classifying individuals of Pseudococcidae and comparing them morphologically. Several studies on the molecular variation of individuals of Pseudococcidae have been made [6]. But it is only recently that phylogenetic studies have been integrated morphological data with DNA sequences [7]. Faced with this numerous damages, several control techniques have been developed, going from chemical struggles with their consequences on the environment, to physical struggles (felling and incineration of trees) which constitute a real shortfall for farmers. Therefore, a better knowledge of the bio-ecology of the insect and its genetic structure in Senegal in the two most fruit-producing areas (Casamance and Thies) is necessary to be able to adopt an adequate control.

The objective of this study is therefore to determine the genetic diversity of the different populations of *Rastrococcus invadens* and their structures according to the agro-ecological zones and the host plants most affected.

2. Materials and methods

2.1 Sampling

The study areas were chosen according to the importance of fruit production and the degree of infestation. Sampling was carried out at two sites in Senegal, namely Diatock in the Casamance natural region and Khay in the Thies region.

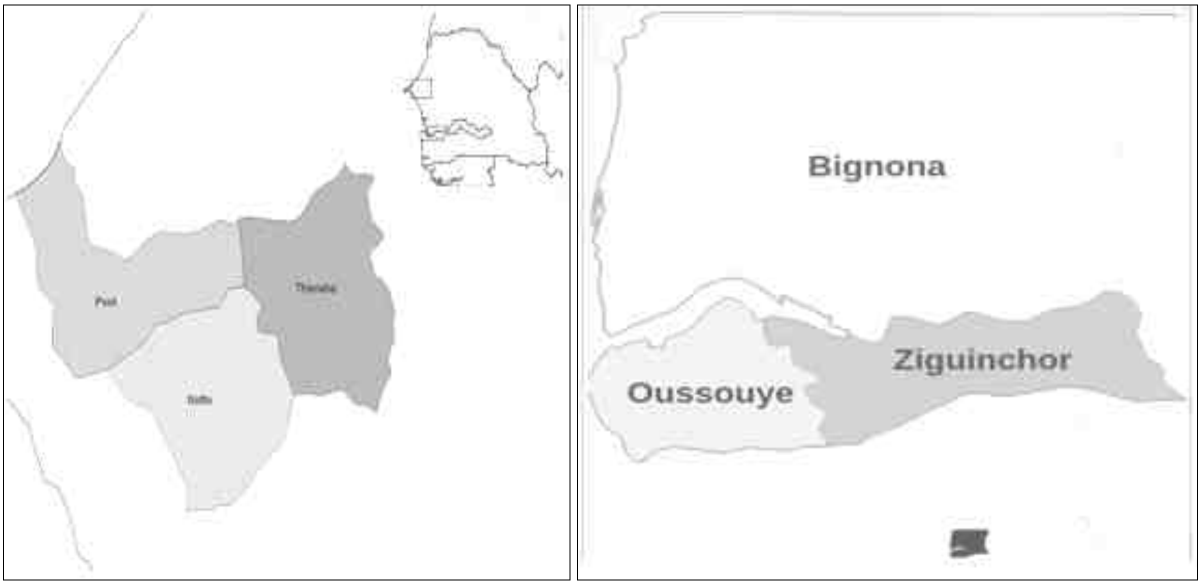

Fig 1: Agro-ecological zones sampled

In our sampling strategy, we chose the three most attacked host plant species, namely the mango, lemon and orange trees. On each foot, we randomly harvested 10 insects. This allows us to have a total of 60 individuals, including 30 in the Casamance natural region and 30 in the Thies region. Samples were coded according to the area and type of plant in which they were collected using the first letter of the genus name, the first letter of the region of origin and the first letter of the host plant. The data is described in table 1 below. Insect pests (*R. invadens*) were then collected in the laboratory and stored in 96% alcohol for the PCR-Sequencing technique.

Table 1: Summary table of the sampling

Study area	Locations	Host plants	Number of individuals	Codes
Casamance	Diatock	Mango	10	RCM
		Lemon	10	RCC
		Orange	10	RCO
Thies	Khay	Mango	10	RTM
		Lemon	10	RTC
		Orange	10	RTO

2.2 Genetic study

2.2.1 DNA extraction

The Qiagen DNeasy Tissue kit method was used for DNA extraction from insects. For this, the insect was dissected, only the thorax, the head and the legs were used for the extraction by placing them in a 1.5 ml tube in which 180 µl of ATL buffer were added for dissociation of the tissues and an individualization of the cells then 20 µl of proteinase K to degrade all the proteins after an incubation at 55 ° C. for 3 hours overnight.

2.2.2 Cytochrome b PCR

It was based on selective *in vitro* amplification of a particular template DNA sequence by extension of two primers by a DNA polymerase, in the presence of deoxyribonucleotides (dNTP) and Mg2 + ions. The amplification was carried out in a reaction volume of 25 µl containing 18.525 µl of ultrapure water, 2.5 µl of non-colored buffer (10x), 1 µl of Mgcl2 (25mM), 0.175 µl of each primer (100 µM), 0.125 µl Taq (5U / µl) and 2 µl DNA extract.

2.2.3 Cytochrome b sequencing

Sequencing was a technique that involves determining the nucleotide succession of a DNA fragment. It was produced in South Korea. Thus, it makes it possible to highlight point mutations, by comparing the sequences of the same gene in different individuals. This is done thanks to a specific PCR reaction, using in addition to the usual compounds (DNA-matrix, polymerase, primers, dNTPs, Mg2 +), modified nucleotides, such as didesoxyribonucleotides (ddNTPs).

2.3 Genetic analyzes

The sequences were analyzed by several software programs in order to extract several parameters from the study. Thus, the sequences were aligned, checked and corrected by BioEdit software version 7.0.5.3 2005. To determine the number of haplotypes, conserved, variable and informative sites sparingly, it is the software dnasp.5.10.01 from Rozas *et al*., 2010 [9] which has been used. Haplotypes designate a group of individuals with the same sequence. To this was added the use of Harlequin software version 3.1 from Excoffier *et al*., 2005

[10] to be able to study genetic differentiation, molecular variance within populations and between populations. For the implementation of haplotype networks, the sequences were first transformed by dnasp.5.10.1 from Rozas *et al*., 2010 [9] in phylip format then analyzed by TCS1.21 from Clément *et al*., 2005 [11] in order to visualize the number of mutational steps. The parameters of demographic evolution of populations such as the D of Tajima and the FS of Fu are determined by harlequin version 3.1 of Excoffier *et al*., 2005 [10]. The phylogenetic reconstructions of the trees by the Neighbor-Joining method, the maximum parsimony and the maximum likelihood, were implemented by the MEGA5.05 software from Tamura *et al*., 2011 [12]. However, the elaboration of trees by the Bayesian inference method was carried out by Mrbaye software version 3.1.2 of Huelsenbeck and Ronquist, 2001 [13] by first transforming the sequences into phylil format.

3. Results

3.1 Polymorphism and genetic diversity

3.1.1 Polymorphism

The H1 haplotype contains 14 individuals, H2: 10 individuals, H3: 12 individuals, H4 and H5 each contain 16 individuals and H6: 11 individuals.

3.1.2 Haplotypic and nucleotide diversity of *R. invadens* populations in agro-ecological zones

We can clearly see that the nucleotide diversity is zero (0) in the different agro-ecological zones studied and according to the plants, with the exception of the Casamance mango tree (RMC: 0.15385) and the lemon tree of Thies (0.11765) (table 2).

Table 2: Genetic diversity of *R. invadens* populations in the study areas

	RCC	ROC	RMC	RCT	ROT	RMT
N	13	10	13	17	11	15
H	1	1	2	2	1	1
S	0	0	3	15	0	0
Hd	0	0	0.15385	0.11765	0	0
Pi	0	0	0.00062	0.00235	0	0

N: number of individuals, H: number of haplotypes, Hd: haplotypic diversity Pi: nucleotide diversity, S: segregation site

RCC: *Rastrococcus* from the Casamance lemon tree, ROC: *Rastrococcus* from the Casamance orange tree, RMC: *Rastrococcus* from the Casamance mango tree, RCT: *Rastrococcus* from the Thies lemon tree, ROT: *Rastrococcus* from the Thies orange tree, RMT: *Rastrococcus* from the Thies mango tree.

3.1.3 Genetic differentiation of *R. invadens* populations between study areas and host plants

It is noted that the values of Fst obtained between the different populations studied are everywhere strong with, however, values substantially equal to 1 (Table 3).

Table 3: Genetic differentiation (Fst of *R. invadens* populations between study areas and host plants

Fs de Fu	D de Tajima	R2
0.37613	-0.05157	0.09578
12.54340	12.48809	8.26505

3.1.4 Demographic evolution of *R. invadens* populations in the two areas studied

Considering the total population, we obtain a negative Tajima D (-0.05157) and a positive Fs (0.37133) but are not significant. The value of R2 (0.09578) is also not significant and the values of p-values almost everywhere equal to 1 with the exception of individuals from the Casamance and Thies mango trees where the value is substantially zero (Table 4).

Table 4: Demographic parameters of the total population of *R. invadens*

	RCC	ROC	RMC	RCT	ROT	RMT
RCC	0					
ROC	1	0				
RMC	1.000	0.967	0			
RCT	0.917	0.907	0,911	0		
ROT	1	1	0,972	0.902	0	
RMT	1	1	0,969	0.933	1	0

The values of D of Tajima (DT) are not significant in each agro-ecological zone, the p-value (P) are all greater than 0.05 and those of Fu (Fs) significant in populations from the Casamance mango tree (0.97596) and very significant in populations from the Thies lemon tree (4.54061) (table 5).

Table 5: The indices of neutrality of the populations of *R. invadens* encountered in different areas

	RCC	ROC	RMC	RCT	ROT	RMT
DT	0	0	-1.65231	-2.31940	0	0
P-value	1	1	0.02700	0	1	1
Fs	0	0	0.97596	4.54061	0	0
P-value	N.A.	N.A.	0.59800	0.96100	N.A.	N.A.

The irregularity index (rg) is significant only in populations from the Casamance mango tree (0.76331) and the Thies lemon tree (0.80623). However, it is zero for all other populations.

This same result is observed on all the other parameters with zero P-value for all populations except those from the mango tree from Casamance (0.1200) and the lemon tree from Thies (0.0900). The SSD value is also zero for all populations except that from the Casamance mango tree (0.03430) and the Thies lemon tree (0.02032) (Table 6).

Table 6: Demographic parameters for each population of *R. invadens*

	RCC	ROC	RMC	RCT	ROT	RMT
R2	0.16419	0.16241	0.16254	0.16125	0.16191	0.16252
P -value	0.5	0.507	0.523	0.518	0.513	0.499
SSD	0	0	0.03430	0.02032	0	0
P -value	0	0	0.12000	0.09000	0	0
rg	0	0	0.76331	0.80623	0	0
P-value	0	0	0.64000	0.77000	0	0

The "mismatch distribution" curves where the distribution of the number of differences between the haplotypes taken two by two are multimodal (Figure 2).

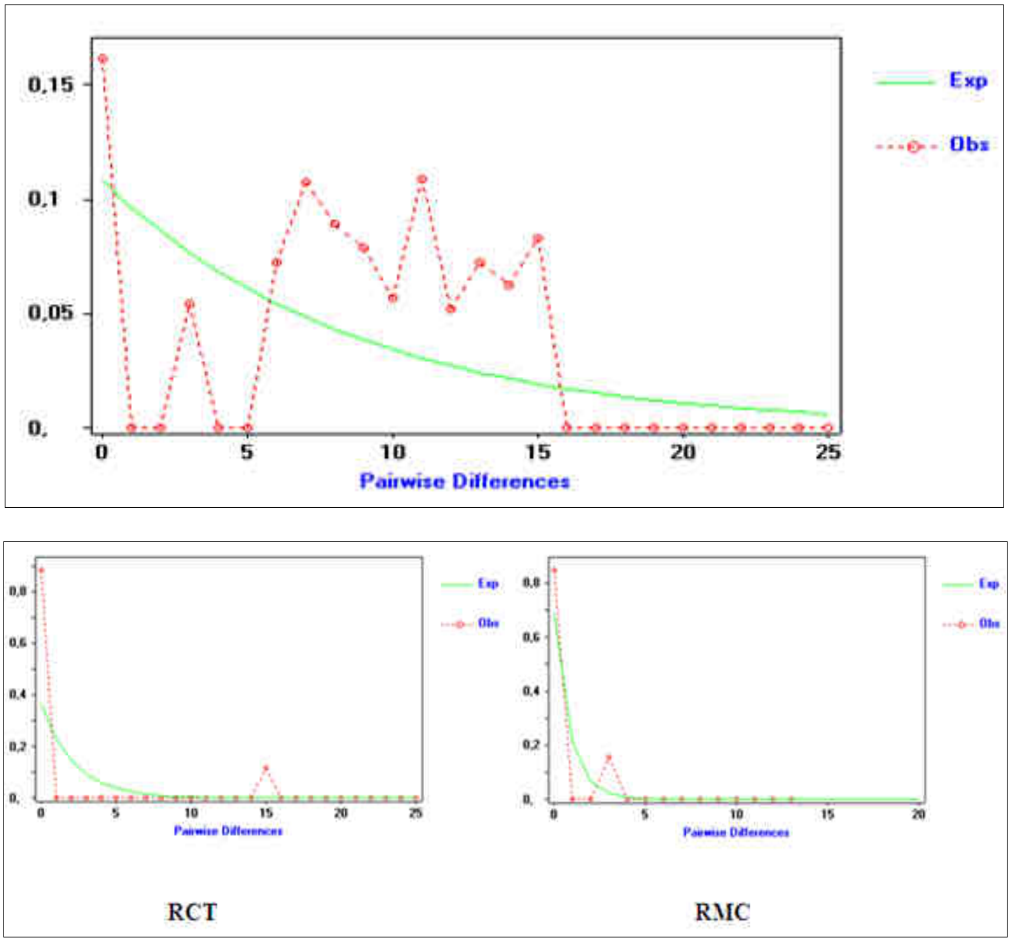

Fig 2: Distribution of the number of differences between haplotypes taken two by two (mismatch distribution) for the populations of *R. invadens* subservient in the different agro-ecological zones

3.2 Genetic distance of *R. invadens* populations between study areas

The genetic differentiation between the populations of the Casamance zone and those of This on the one hand and that between the host plants on the other hand is weak and not significant (table 7).

Table 7: Genetic distance between populations

Species 1	Species 1	Dist	Std. Err
RCC-	ROC-	0.009	0.003
RCC-	RMC-	0.003	0.002
ROC-	RMC-	0.010	0.003
RCC-	ROT-	0.011	0.003
ROC-	ROT-	0.012	0.004
RMC-	ROT-	0.012	0.004
RCC-	RMT-	0.008	0.003
ROC-	RMT-	0.015	0.004
RMC-	RMT-	0.009	0.003
ROT-	RMT-	0.013	0.004

3.2.1 Phylogenetic haplotype networks and reconstructions

3.2.1.1 Haplotype network and distribution of *R. invadens* haplotypes

Haplotype networks allow us to see the genetic differences and the links between different haplotypes. Each disc corresponds to a haplotype, and their size is proportional to the number of individuals corresponding to the haplotype. The white circle separates two mutational steps between haplotypes. The majority haplotype (16 individuals) is found in the population from the Thies mango tree. Likewise, the average haplotype (13 individuals) is found in the population from the Thies lemon tree. In the first, it is the population from the Thies lemon tree which is more represented and in the second haplotype, it is the population from the Casamance lemon tree which is the majority. However, there are neither individual haplotypes nor private haplotypes. Six (6) haplotypes were encountered in the two agro-ecological zones studied (H1, H2, H3, H4, H5 and H6) with three haplotypes in Thies (one on mango tree, one on lemon tree and one on orange tree) and three in the Natural Casamance (one on mango tree, one on lemon tree and one on orange tree).

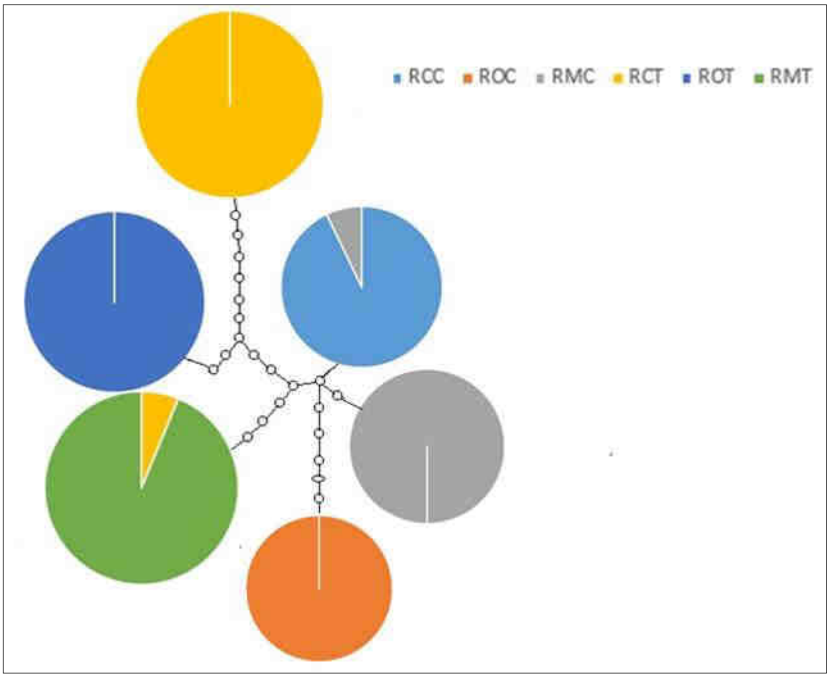

Fig 3: Cyt b haplotype network of *R. invadens* populations encountered in the study areas

3.2.1.2 Phylogenetic reconstructions

The phylogenetic trees were constructed by the Neighbor Joining method, maximum parsimony, maximum likelihood and by the Bayesian interference method. The phylogenetic trees of the *R. invadens* populations were rooted by an individual of a Bactrocera species. The most resolving trees were obtained by the Bayesian inference method. In *R. invadens*, the phylogenetic tree of Cyt individuals. b presents six very distinct groups. However in different trees, the result is almost the same.

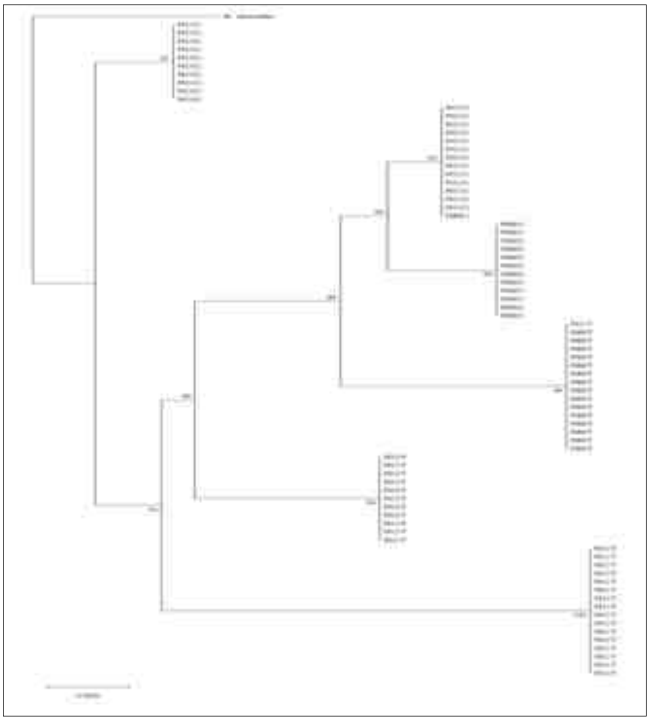

Fig 4: Phylogram of individuals of *R. invadens* from Senegal using the Neighbor-Joining method

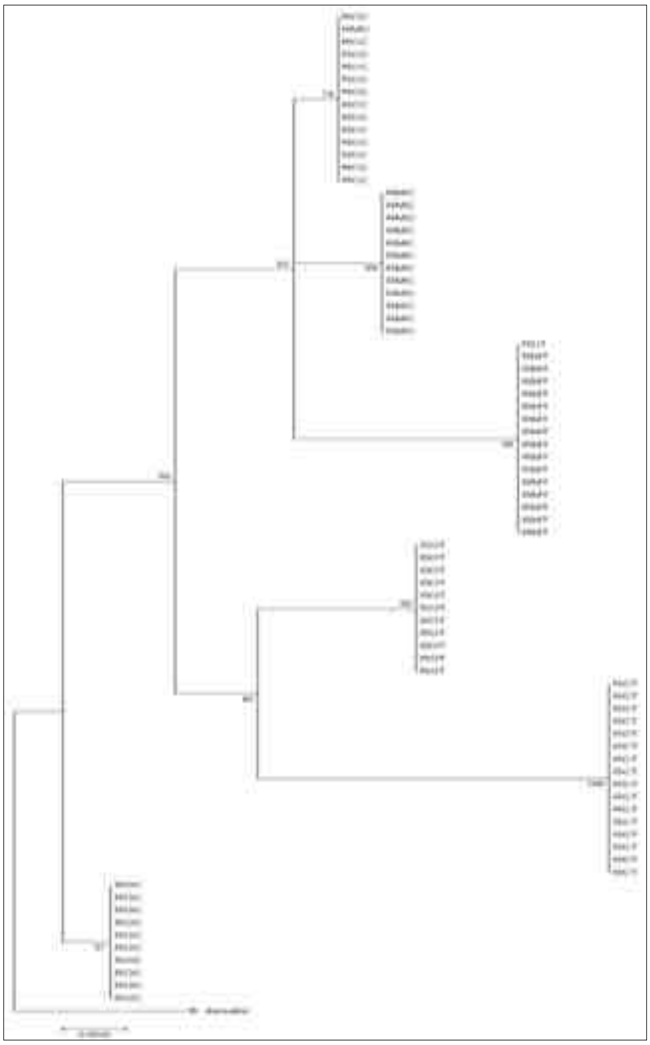

Fig 5: Tree of maximum parsimony of *R. invadens* individuals

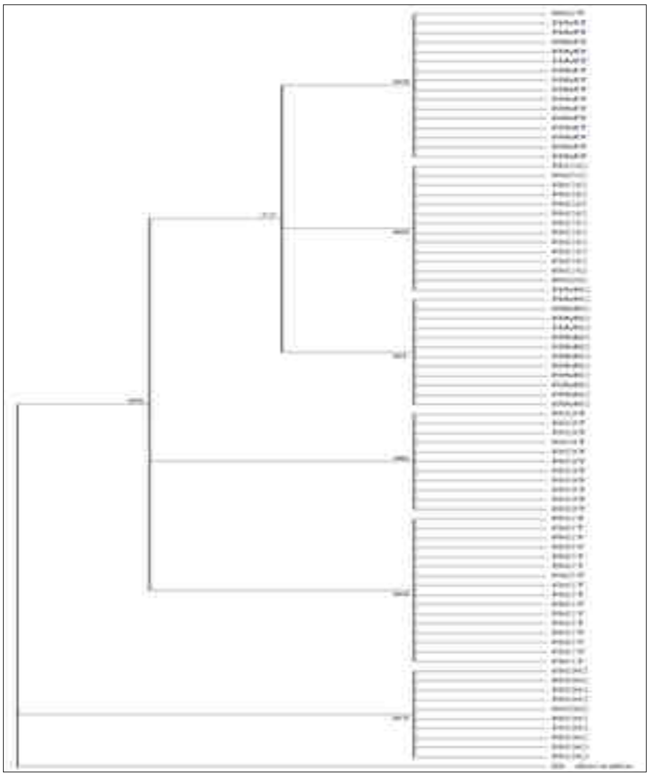

Fig 6: Maximum likelihood tree of *R. invadens* individuals

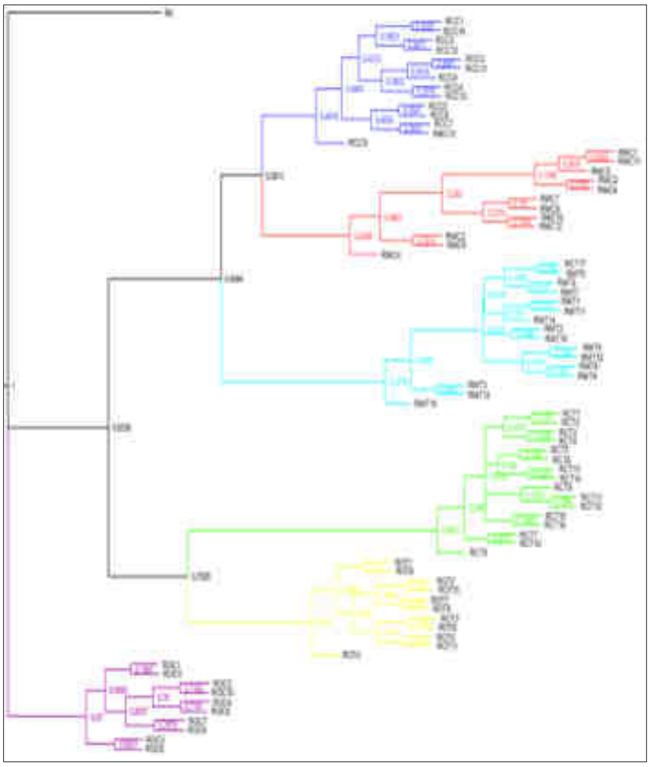

Fig 7: Bayesian tree of *R. invadens* populations using the Bayesian interference method

4. Discussion

The objective of this study is to determine the diversity and genetic structure of *R. invadens* according to the study areas (Thies and natural region of Casamance) and host plants. This study is necessary for a better fight because the mealybugs (Hemiptera: Pseudococcidae) are real very polyphagous pests. The results obtained with the mitochondrial cytochrome b gene show that the populations of *R. invadens* encountered in Senegal contain different haplotypes. At least 6 haplotypes of *R. invadens* circulate in the different host plants and the agro-ecological zones sampled. In agro-ecological zones, the strong haplotypic and nucleotide diversities observed would testify either to the stability of these populations with large effective size, or to an admixture of both. The same assumptions are noted for the population of host plants. A strong genetic diversity is noted in Thies. This could lead us to consider that Thies would be the home of the infestation because the insect was observed for the first time in Senegal in the Niayes area [14]. The difference that exists for the evolution of these populations at the molecular level could be explained by the variable nature of Cyt. b. According to a report by GERAD, 2006 [15], in most cases the insect can be transported on plant material, by travelers ...,Indeed, in all the localities studied, mango and citrus fruits have become commercial crops. This could lead to a large gene flow by the introduction of new individuals from border areas and a rapid multiplication of the species by the availability of food throughout the year. Indeed, there is a significant human displacement in Senegal thus facilitating the transport of plant material (fruits, vegetables from one zone to another). The widening of the study of the genetic structuring of the different populations of *R. invadens*, shows at the level of Cyt. b high haplotypic and nucleotide diversity, resulting in a large genetic flow between populations. Since the mango and citrus fruits do not have the same period of fruit production and the insect was first discovered on mango [16], it can be considered that citrus and other host plants are refusal plants for *R. invadens*. The study of genetic differentiation revealed that between the populations of *R. invadens* from Thies and Casamance, there is little genetic differentiation. This genetic differentiation is also noted between populations from different host plants. This observed genetic differentiation can be considered as the genetic differentiation that exists between the different localities, because each is encountered in a specific agro-ecological zone and according to the host plants which do not have the same organoleptic taste. Therefore, we can assume that there is a structure of *R. invadens* within these different localities, as in the case of *Tribolium castaneum* [17]. The haplotype study shows that *R. invadens* has 6 haplotypes in all of the study areas, with H4 and H5 as the majority haplotypes (16 individuals each). The establishment of the *R. invadens* haplotype network shows that some haplotypes have the H4 haplotype as their common ancestor. The latter is not only the majority haplotype, but can be considered to be regional, as it is present in Thies and Casamance. In this network, the link between the H4 and H6 haplotype on the one hand and H1 and H3 on the other hand is very remarkable. In H2, we only find populations from the Casamance orange tree and in H5 we only find populations from the Thiès orange tree. The particularity of the Cyt haplotype network. b is that haplotypes H1 (RCC), H2 (ROC) and H3 (RMC), all of Casamance origin, would come from haplotypes H4 (RCT), H5 (ROT) and H6 (RMT) which come from Thies. Consequently the individuals of Casamance would come from individuals of Thies which could be considered as the ancestral haplotype. Based on the values of D from Tajima and FS from Fu du Cyt. b, the populations of *R. invadens* from Thiès and from Casamance show excesses of rare variant and are the target of natural selection favoring genetic diversity. By considering each host plant and each agro-ecological zone, we see that the value of D of Tajima is zero or even negative; which probably indicates a random evolution of the populations of *R. invadens* in these different host plants and agro-ecological zones. Indeed, according to Excoffier, 2005 [10], a negative Tajima D could correspond to a demographic expansion. In the populations from the Casamance mango tree from the Thies lemon tree, the values of D from Tajima (RMC: -1.65231; RCT: -2.31940), (-0.00864) are negative but not significant. This shows that these populations are in demographic balance. The multimodal curves observed would indicate stable populations across the entire Cyt gene. b. This stability would be due to an adaptation of *R. invadens* to their environment by the presence perhaps of endocytobiota which according to Hubert C., 1997 [18] plays an important role in the accommodation of the host in relation to the variations of the environment. In general, the populations of *R. invadens* are almost genetically identical and stable. This is confirmed by the table 7 and the mismatch distribution curves at the level of the Cyt gene. b. *R. invadens* would present a structure at the level of certain agro-ecological zones. However, the development of the tree of individuals of *R. invadens* shows that the grouping is done not only according to the zones but also according to the host plants.

5. Conclusion

At the end of this study, only one species of the genus *Invadens* was identified in the different agro-ecological zones. Its evolution is that of a stable population with large effective size. This stability is due to an adaptation of *R. invadens* to its environment. So new strategies to control these crop pests must be considered. In populations of the same species, the Cyt gene. b has different trends. The genetic differentiation between agro-ecological zones as well as between host plants is sometimes different at the level of the *R. invadens* gene where we have identified a large number of populations. From the analysis of the results, a structure of *R. invadens* between certain host plants is noted. According to the molecular variance and the correlation between geographic distance and genetic differentiation, *R. invadens* shows a genetic structure according to agro-ecological zones and host plants. On the other hand, the development of the haplotype tree presents groupings of haplotypes according to agro-ecological zones and host plants.

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