

## Table of contents

List of tables .....	vii
List of figures .....	ix
List of appendices.....	xi
I. INTRODUCTION .....	1
1.1 Background.....	1
1.2 Statement of Problems.....	2
1.3 General objectives.....	3
1.4 Expected outcomes.....	3
1.5 Originality .....	3
II. LITERATURE REVIEW AND THEORETICAL BASIS.....	4
2.1 Literature review.....	4
2.1.1 Diaphorina citri.....	4
2.1.2 Distribution of Diaphorina citri .....	6
2.1.3 Citrus mandarin (Keprok) and tangerine (Siam) in Indonesia.....	7
2.1.4 Huanglongbing disease on citrus.....	8
2.1.5 Yellow sticky trap as a control method of ACP.....	9
2.1.6 Yellow 3D printed trap as a control method of ACP .....	11
2.1.7 Attractant for ACP.....	12
2.1.8 Modelling distribution using Maximum Entropy (MaxEnt).....	12
2.2 Theoretical basis .....	14
2.3 Hypothesis .....	15
III. TOPIC 1: INSECT STICKY TRAPPING WITH VARIOUS LURES.....	16
3.2.1. Introduction.....	16
3.2.1. Materials and equipment .....	17
3.2.2. Time and location .....	19
3.2.3. Research Design.....	19
3.2.5. Data collection for insect sticky trapping.....	23
3.3. Results and Discussion .....	23
3.4. Conclusion .....	37
IV. TOPIC 2: MONITORING AND SURVEY OF ACP .....	39
5.1 Introduction .....	39
5.2 Materials and methods .....	40
4.2.1 Time and location .....	40
4.2.2 Direct manual inspection .....	41
4.2.3 Yellow Sticky Trap .....	42

4. 2. 4	Yellow Cylinder Trap.....	43
4. 2. 5	Sucking Trap .....	44
4. 2. 6	Sites and Data Collection.....	45
5. 3	Results and discussion.....	46
4.3. 1	Direct manual inspection .....	48
4.3. 2	Yellow Sticky Trap .....	48
4.3. 3	Yellow Cylinder Trap.....	49
4.3. 4	Sucking Trap .....	50
4.3. 5	ACP Population status and environmental factor .....	51
5. 4	Conclusion .....	57
V.	TOPIC 3: MODELLING DISTRIBUTION OF ACP POPULATION BASED ON MAXIMUM ENTROPY (MaxEnt).....	58
5. 2	Materials and methods .....	59
5.2. 1	Time and location .....	59
5.2. 2	Materials and equipment .....	59
5.2. 3	MaxEnt model creation sequence and process.....	59
5.2. 4	Location data selection .....	62
5.2. 1	Environmental data selection .....	62
5.2. 1	Data collection .....	63
5. 3. 1	Environmental factor affecting ACP population distribution .....	63
5. 3. 2	Training data for the global occurrence of <i>Diaphorina citri</i> in the world 64	
5. 3. 3	Modelling based on Indonesian environment from the past 30 years to the current climate scenario .....	68
	MaxEnt models can provide adequate support for ACP management and citrus policy in Indonesia. ....	71
	Environmental variables influential in predicting ACP distribution using MaxEnt in Indonesian contexts .....	72
5. 4	Conclusion .....	73
VI.	GENERAL DISCUSSION.....	74
VII.	CONCLUSION AND RECOMMENDATION .....	82
VI.	FURTHER RESEARCH AND APPLICATION TO INDUSTRIES .....	84
VII.	REFERENCES.....	85
	APPENDIX .....	99

## List of tables

Table 2. 1 Countries list of <i>D.citri</i> distribution in the world (2006) .....	6
Table 2. 2 Indonesia Citrus production in tonnes during 2017,2018, and 2019 (Hakim & Wahyuningsih, 2020) .....	7
Table 3. 1 Materials and equipment for the experiment .....	18
Table 3. 2 Activities and kinds of collected data .....	24
Table 3. 3 The average number of adult ACP captured in YST with various lure treatments under controlled conditions for six weeks during October 25th - November 9, 2023.....	25
Table 3. 4 The average number of adult ACP captured in YST with various lure treatments under semi-field conditions during September 19 - November 8, 2023.....	26
Table 3. 5 The average number of adult ACP captured in YST with various lure treatments under field conditions with population scenario. ....	27
Table 3. 6 Correlation value between climate and number of ACP trapped in natural high population ACP conditions.....	29
Table 3. 7 Average number of ACP trapped weekly with YST under various treatment lures in high population of ACP (BenIV.TOPIC 2: MONITORING AND OCTO	
Table 3. 8 Average number of ACP trapped in each location with YST under various treatment lures in high population of ACP (Bengkulu) during September 15 - October 18, 2024. ....	31
Table 3. 9 The comparison of the average number of adult ACP captured in YST with various lure treatments under field conditions with natural population ACP in Low Population Banyuwangi and High Population Bengkulu from September 15, 2024 to January 6th 2.....	32
Table 3. 10 Correlation value between climate and number of ACP trapped in high population ACP conditions at Banyuwangi during November 25th, 2024 - January 6th, 2025.....	32
Table 3. 11 Average number of ACP trapped weekly with YST under various treatment lures in low population of ACP during November 25th, 2024 to January 6th, 2025, in Banyuwangi, East Java. ....	33
Table 3. 12 Average number of ACP trapped in each location with YST under various treatment lures in high population of ACP during November 25th, 2024 to January 6th, 2025, in Banyuwangi, East Java.....	33
Table 3. 13 The effectiveness of acid-based pheromones, including acetic acid, formic acid, propionic acid, and a commercial product (alpha scents), in capturing adult ACP through lime yellow sticky traps (YST) under various research conditions.....	36
Table 4. 1 Materials and equipment for experiment survey and monitoring population of ACP in Indonesia 2022-2023.....	40
Table 4. 2 Activities and kinds of collected data .....	47
Table 4. 3 Summary record result surveillance of <i>Diaphorina citri</i> population status in Indonesia 2022-2023.....	47
Table 4. 4 Number of <i>Diaphorina citri</i> counted by manual direct inspection (DMI) in 206 locations.....	48
Table 4. 5 Number of <i>Diaphorina citri</i> counted by yellows sticky trap (YST) in 24 locations.....	49
Table 4. 6 Number of <i>Diaphorina citri</i> counted by Cylinder yellow trap (CYT) in 9 locations.....	50



Table 4. 7 Number of <i>Diaphorina citri</i> counted by Sucking trap (CYT) in 11 locations.....	50
Table 4. 8 Confirmed Sites of <i>Diaphorina citri</i> distribution in Indonesia. ....	52
Table 5. 1 Materials and equipment for the experiment .....	59
Table 5. 2 Activities and kinds of collected data .....	64
Table 5. 3 Listed environmental variables affecting species distribution by Woldclim 2.0 (2022).....	64
Table 6. 1 The possible role of interaction between the Yellow lime colour trap and the acid-based attractant during trapping ACP. ....	76
Table 6. 2 The relevance of acid-based attractants, surveillance, and MaxEnt in controlling ACP in Indonesia. ....	79

### List of figures

Figure 2. 1 Life cycle of <i>D.citri</i> in citrus from egg, nymph to adult (Oke et al., 2020) .6	
Figure 2. 2 Symptom HLB on citrus trees and Clas, (A) trees with leaves do not expand but straighten upwards, (B) figure Clas inside plant tissue (yellow arrow) (Chen et al., 2022), and (C) leaves indicate HLB with green vein symptom. .... 10	
Figure 2. 3 Commercial product of YST from Alpha Scent (Table 2. 2 Indon,esia Citrus production in tonnes during 2017,2018, and 2019 (Hakim & Wahyuningsih, 2020).....8r 545nm	11
Figure 2. 4 Cylinder Yellow Trap (CYT) for ACP monitoring, (A) head funnel design by Snyder et.al, 2022 and (B) ready used CYT including printed funnel, dome and cylinder tube..... 12	
Figure 2. 5 Maxent main page, (A) Input layer and (B) output model in MaxEnt model (S. Phillips, 2010). .... 15	
Figure 3. 1 Rearing ACP with <i>Muraya paniculata</i> , (A) plastic tube covered with new shot infested with ACP, (B) situation of ACP rearing in green house during experiment..... 19	
Figure 3. 2 Design model for trapping under controlled conditions. 20	
Figure 3. 3 Experimental design of ACP sticky trapping under semi-field conditions. 22	
Figure 3 4 Number of adult ACPs were trapped in Yellow Sticky Trapping with various lures under field conditions in a high population scenario, control(C), alpha scents (AS), acetic acid (AA), formic acid (FA), and propionic acid (PA) from November 27, 2023 to 14th January 2024. 26	
Figure 3. 5 Average number of adult ACPs were trapped in Yellow Sticky Trapping with various lures under field conditions in a low population scenario, control(C), alpha scents(AS), acetid acid (AA), formic acid (FA), and propionic acid (PA) during November 27th 22023 to 14 <sup>th</sup> January 2024. 26	
Figure 3. 6 Number of adult ACPs were trapped in Yellow Sticky Trapping with various lures under field conditions in high population of ACP during September 15 - October 18, 2024, control(C), alpha scents (AS), acetic acid (AA), formic acid (FA), propionic acid (PA), magnesium oxide (UV) and magnesium oxide with alpha scents (AS+UV). .... 29	
Figure 3. 7 Number of adult ACPs were trapped in Yellow Sticky Trapping with various lures under field conditions in low population of ACP November 25th, 2024 - January 6th, 2025, in Banyuwangi, East Java. Control (C), alpha scents(AS), acetic acid (AA), formic acid (FA), propionic acid (PA), magnesium oxide (UV) and magnesium oxide with alpha scents (AS+UV).31	
Figure 4. 1 Layout direction for the manual inspection method of the surveillance of <i>Diaphorina citri</i> in the citrus tree.....42	
Figure 4. 2 Yellow Sticky Trap (YST) installed in a citrus tree during the survey. ....43	
Figure 4. 3 Yellow Cylinder trap in the field during surveillance.....44	
Figure 4. 4 Procedure of sucking trap method during surveillance. ....45	
Figure 4. 5 A map of the total of 206 sites for the monitoring of <i>Diaphorina citri</i> in Indonesia in the years 2022-2023. ....46	
Figure 4. 6 Map of 35 sites confirming <i>Diaphorina citri</i> distribution in Indonesia.....51	



Figure 4. 7 Indonesia monthly average of minimum surface temperature, average mean surface air temperature, average maximum surface air and precipitation during 1991-2022.....	52
Figure 5. 1 Percent contribution of the environmental variables to the MaxEnt model of <i>Diaphorina citri</i> .....	65
Figure 5. 2 Analysis of omission/commission of the MaxEnt model of <i>Diaphorina Citri</i> .....	67
TABLE 5. 3 LISTED ENVIRONMENTAL VARIABLES AFFECTING SPECIES DISTRIBUTION BY WOLDCLIM 2.0 (2022).....	65
Figure 5. 5 Analysis of ROC and AUC <i>D.citri</i> in Indonesia during last past 30 years the under MaxEnt model.....	68
Figure 5. 6 Analysis of omission/commission <i>D.citri</i> in Indonesia during last past 30 years the under MaxEnt model. ....	68
Figure 6. 1 Key points regarding ACP and HLB management in Indonesian citrus production.....	77
Figure 6. 2 Interrelationship and Practical Workflow of acid-based attractants, surveillance, and MaxEnt Modeling in ACP & HLB Management.....	80