UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF GINGER ESSENTIAL OILS-NANOBACTERICIDES FOR CONTROLLING BACTERIAL LEAF BLIGHT DISEASE OF RICE CAUSED BY Xanthomonas oryzae pv. oryzae

ADAMU ABDULLAHI

FP 2022 31

DEVELOPMENT OF GINGER ESSENTIAL OILS-NANOBACTERICIDES FOR CONTROLLING BACTERIAL LEAF BLIGHT DISEASE OF RICE CAUSED BY *Xanthomonas oryzae* pv. *oryzae*

By

ADAMU ABDULLAHI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

June 2022

DEDICATION

This thesis is dedicated to my parents, Alh. (Mal) Abdullahi Muhammad Gada and Mlm. Fatima Abubakar Gada, as well as my entire family.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement of the degree of Doctor of Philosophy

DEVELOPMENT OF GINGER ESSENTIAL OILS-NANOBACTERICIDES FOR CONTROLLING BACTERIAL LEAF BLIGHT DISEASE OF RICE CAUSED BY *Xanthomonas oryzae* pv. *oryzae*

By

ADAMU ABDULLAHI

June 2022

Chairman : Associate Professor Khairulmazmi bin Ahmad, PhD
Faculty : Agriculture

The bacterial leaf blight (BLB) caused by *Xanthomonas oryzae* pv. *oryzae* (Xoo) have been found to be the major rice disease that causes significant loss of yield upon infection. The susceptible plants can result in the production losses of up to 50%. Scientists and farmers are increasingly paying more attention to the development of plant-based nanobactericides for disease management in order to lessen overdependence on chemical pesticides. A series of laboratory experiments were conducted in order to promote this development. These experiments concentrated on the extraction and characterization of the phytochemical compounds found in ginger essential oils (EOs), the suppression of the development of Xoo biofilm, and microscopic examinations. It was followed by nanobactericide evaluation of the antibacterial activity of *Xoo*. Three blocks were made for each treatment and three plants per replicate in a completely randomized block design. The essential oils (EOs) were extracted from fresh ginger rhizomes using a modified Clevenger-type apparatus by hydro-distillation, which were purchased from local producers in Bentong, Pahang. The chemical compositions of the EOs were then discovered and profiled using the analytical techniques of gas chromatography-mass spectroscopy (GCMS) and headspace procedures. Chemical compounds present in the EOs were monoterpenes such as trans-caryophyllene, camphene, geranial, eucalyptol, and neral, as well as sesquiterpene hydrocarbons mainly α-zingiberene, ar-curcumene, β-bisabolene, β-sesquiphellandrene which differ in their composition and concentrations. Food poisoned and disc diffusion techniques were applied on the tested pathogens to determine the percentage inhibition of fungal mycelial and bacterial growth inhibition, respectively. The EOs produced mycelial growth inhibition in all the test fungal pathogens which include (*Fusarium oxysporum, Pyricularia oryzae*, *Colletotrichum falcatum*, *Ganoderma boninense*, and *Rigidoporus microporus Fusarium oxysporum, Pyricularia oryzae*, *Colletotrichum falcatum*, *Ganoderma boninense*, and *Rigidoporus microporus*) after five days of incubation. The minimum inhibitory concentrations (MIC) and minimum fungicidal concentrations (MFC) of the EOs on the tested fungi were in the range of 1- 3 µL/mL and 5-6 µL/mL, respectively. The bacterial growth of all the tested isolates (*Xanthomonas oryzae* pv.

oryzae- strain A, *X. oryzae* pv. *oryzae*- strain B, *Ralstonia solanacearum*, *Bacillus* sp. and *Klebsiella* sp.) was also affected by EOs at 100-500 µL/mL, from weak to strong antibacterial activity. The inhibition zone of positive control (streptomycin) at 15 µg/disc was 25.00 mm and appeared to be efficient. The MIC values of the EOs were in the range of 100 µL/mL to 200 µL/mL. The LC50 value resulting from exposure to the EOs varied among fungal and bacterial pathogens. Metabolomics analysis to concurrently quantify variability among multiple compounds in the data sets and identify such compounds responsible for the *Xoo* inhibition were determined. The cross validated PLS model has shown a strong correlation between ginger EOs and bioactivity. The action of ginger EOs on the cell structure of *Xoo* was fully identified using scanning electron microscope (SEM), transmission electron microscope (TEM) and confocal laser scanning microscope (CLSM) as well as biofilm formation. It was done by observing the changes in morphology and integrity of *Xoo* cells. The Dimethyl sulfoxide (DMSO) treatment (control) showed a normal rod shape cell, while treatment with the ginger EOs showed irregular shape with sunken surfaces, and treatment with antibiotics display abnormal growth of the cells. The ginger EOs display a wide range of activity against the pathogen. The biofilm of the *Xoo* strain has been formed. The EOs showed different optical density values measured due to the formation of *Xoo* biofilms and the inhibition percentage of *Xoo* biofilm. The results showed that the control (broth containing untreated *Xoo* cells) had the highest mean optical density value with a strong biofilm formation (2.459 O.D), followed by 31.25 µL/mL treatment. The inhibition percentage showed that the maximum inhibition was 76.33% at a concentration of 500 µL/mL. When the concentration of EOs was decreased, the *Xoo* biofilm inhibition declined. Problems of volatility, solubility, and stability of EOs lead to the use nanotechnology via nanoemulsions approach. The preparation of nano-emulsion of ginger EOs have prepared. A ternary phase diagram (TPD) was developed using a low-energy method based on nonionic surfactant Tween 20, water, and EOs as the active ingredient. Four formulations of nanobactericides coded as A1, A2, A3 and A4 were chosen from the single-phase ternary phase diagram for preliminary screening after constructing TPD. They were tested for their stability and thermostability over time at 54°C and 28°C. Finally, A4- is the best formulation that displays a single, low viscous and watery phase that is stable following physiochemical property measures. Usage of the developed nanobactericides have been applied both *in- vitro* and *in-vivo* to evaluate its efficiency to the pathogens. The in-vitro antibacterial activity of the nanobactericides was measured by the presence or absence of inhibition zones. The growth of the tested pathogens was affected by the different concentration of the formulation ranging from 50-125 µL/mL. The findings showed significant antibacterial activity against *Xoo, Bulkholderia glumae Ralstonia solanacearum,* and least effective against *Erwinia chrysanthemi* at higher concentrations. Glasshouse application showed that the disease symptoms decrease more gradually to nanobactericides due to its phytoconstituents. Three concentrations of formulation were tested containing 75, 100, and 125 µL/mL. Findings of research revealed that treatment 125 µL/mL was the best treatment based on suppression of disease severity index, area under the disease progress curve (AUDPC) value as well as plant height, physiological and yield parameters when compared to the positive control. In conclusion, developed nanobactericides could be used as a new antimicrobial agent in suppressing the growth of *Xoo in-vitro* and suppress disease severity index of bacterial leaf blight disease *in-vivo* trials and as a promising new alternative to synthetic bactericides.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN MINYAK PATI HALIA-NANOBAKTERISID UNTUK MENGAWAL PENYAKIT HAWAR DAUN BAKTERIA PADI YANG DISEBABKAN OLEH *Xanthomonas oryzae* pv. *oryzae*

Oleh

ADAMU ABDULLAHI

Jun 2022

Pengerusi : Profesor Madya Khairulmazmi bin Ahmad, PhD
Fakulti : Pertanian

Penyakit hawar daun bakteria (BLB) yang disebabkan oleh *Xanthomonas oryzae* pv. *oryzae* (*Xoo*) merupakan penyakit padi utama yang mengakibatkan kehilangan hasil yang ketara. Pada masa ini, pembangunan nanobakterisid-berasaskan tumbuhan telah mendapat perhatian daripada para saintis dan petani untuk mengawal penyakit ini dan seterusnya mengurangkan kebergantungan kepada racun kimia. Untuk merangsang perkembangan ini, satu siri eksperimen makmal telah dijalankan. Penekanan diberikan kepada pengekstrakan dan pencirian sebatian fitokimia yang terdapat dalam minyak pati halia, diikuti dengan penindasan pembentukan biofilm *Xoo* dan pemeriksaan mikroskopik, pembangunan nanobakterisid dan penilaian aktiviti antibakteria patogen tumbuhan. Minyak pati halia adalah cecair volatil berminyak dengan banyak juzuk dan mempunyai aktiviti antimikrob yang ketara. Minyak pati diekstrak menggunakan peralatan jenis *Clevenger* yang diubahsuai oleh *hydro-distillation* kemudian diikuti dengan kaedah analisis *gas chromatography-mass spectroscopy* (GCMS) dan prosedur *headspace* untuk mengesan dan menentukan profil dan komposisi fitokimia. Fitokimia yang terdapat dalam minyak pati adalah *monoterpenes* seperti *trans-caryophyllene, camphene, geranial, eucalyptol,* dan *neral*, serta hidrokarbon *sesquiterpene* terutama *α-zingiberene, ar-curcumene, β- bisabolene dan β-sesquiphellandrene* yang berbeza komposisi dan kepekatan. Teknik media beracun dan difusi cakera digunakan terhadap fitopatogen yang diuji untuk menentukan peratusan perencatan miselium kulat dan perencatan pertumbuhan bakteria. Minyak pati menghasilkan perencatan pertumbuhan miselium bagi kesemua patogen kulat yang diuji selepas lima hari inkubasi. Nilai MIC dan MFC pada kulat yang diuji adalah dalam julat 1->3 µL/mL dan 5-6 µL/mL. Pertumbuhan bakteria untuk semua isolate fitopatogen yang diuji juga berkesan pada 100-500 µL/mL, daripada lemah kepada aktiviti antibakteria yang kuat. Minyak pati berupaya mengawal *Xoo*-strain-A pada kepekatan yang rendah kepada lebih tinggi masing-masing pada 400-500 µL/mL dengan purata perencatan masing-masing 20.66 mm dan 22.66 mm. Zon perencatan kawalan positif (streptomycin) pada 15 µg/cakera adalah 25.00 mm dan kelihatan sangat berkesan. Nilai-nilai MIC adalah dalam julat 100-> 200 µL/mL. Nilai LC_{50} yang terhasil daripada pendedahan kepada minyak pati berbeza

di kalangan patogen kulat dan bakteria. Analisis metabolomik untuk mengukur kepelbagaian di kalangan sebatian dalam set data dan mengenalpasti sebatian yang bertanggungjawab untuk perencatan *Xoo* telah ditentukan. Model PLS yang telah divalidasi silang telah menunjukkan hubungkait yang kuat antara minyak pati halia dan bioaktiviti. Tindakan minyak pati halia pada struktur sel *Xoo* telah dikenalpasti sepenuhnya menggunakan *scanning electron microscope* (SEM), *transmission electron microscope* (TEM) dan *confocal laser scanning microscope* (CLSM) serta pembentukan biofilm. Ia dilakukan dengan memerhatikan perubahan morfologi dan integriti sel *Xoo*. Rawatan DMSO (kawalan) menunjukkan sel berbentuk rod normal, manakala rawatan dengan minyak pati halia menunjukkan bentuk yang tidak teratur dengan permukaan tenggelam, dan rawatan dengan antibiotik pula memaparkan pertumbuhan sel-sel yang tidak normal. Minyak pati halia memaparkan pelbagai aktiviti terhadap patogen. Biofilm *Xoo* telah terbentuk. Minyak pati memberi nilai ketumpatan optik yang berbeza disebabkan pembentukan biofilm *Xoo* dan peratusan perencatan biofilm *Xoo*. Keputusan menunjukkan kawalan (larutan yang mengandungi sel-sel *Xoo* yang tidak dirawat) mempunyai nilai kepadatan optik tertinggi dengan pembentukan biofilm yang kuat (2.459), diikuti oleh rawatan 31.25 µL/mL. Peratusan perencatan menunjukkan bahawa perencatan maksimum adalah 76.33% pada kepekatan 500 µL/mL. Apabila kepekatan minyak pati berkurangan, perencatan biofilm *Xoo* juga merosot. Masalah turun naik, kebolehlaksanaan, dan kestabilan minyak pati membawa kepada penggunaan nanoteknologi melalui pendekatan nano-emulsi. Penyediaan nano-emulsi minyak pati halia telah disediakan. Gambar rajah fasa ternary (TPD) dibangunkan menggunakan kaedah tenaga rendah berdasarkan gabungan Tween-20, air, dan minyak pati bukan ionik sebagai bahan aktif. Empat rumusan nanobakterisid yang dikodkan sebagai A1, A2, A3 dan A4 dipilih daripada gambar rajah fasa *single-phase ternary* untuk saringan awal selepas membina TPD. Ia diuji dari segi kestabilan dan ketegakan dari masa ke semasa pada 54°C dan 28°C. Rumusan A2 dan A3 bertukar menjadi *milky solution* manakala baki dua formulasi, A1 dan A4 mengekalkan kestabilan sebagai cecair yang jernih telah dipilih untuk meneruskan ciri-ciri fisiokimia. Akhirnya, A4- adalah formulasi terbaik yang memaparkan fasa tunggal, likat rendah dan berpasir yang stabil berikutan langkah-langkah harta fisiokimia, termasuk kelikatan (19.0±0.2), pH (4.2±0.4), saiz zarah (73±0.8), potensi zeta (-43.43.42±0.38), pdi (0.21±0.30), ketegangan permukaan (30.90±0.5) dan struktur/morfologi zarah. Penggunaan racun bakteria-nano yang dibangunkan telah digunakan dalam *in-vitro* dan *in-vivo* untuk menilai kecekapannya kepada patogen. Aktiviti antibakteria *in-vitro* bakteria-nano diukur dengan kehadiran atau ketiadaan zon perencatan. Pertumbuhan patogen yang diuji terjejas oleh kepekatan formulasi yang berbeza antara 50-125 µL/mL. Penemuan ini menunjukkan aktiviti antibakteria yang ketara terhadap *Xoo*, *Bulkholderia glumae Ralstonia solanacearum*, dan paling kurang berkesan terhadap *Erwinia chrysanthemi* pada kepekatan yang lebih tinggi. Aplikasi rumah kaca menunjukkan gejala penyakit berkurangan dengan lebih beransur-ansur kepada bakteria-nano kerana campuran kompleks tersebut. Tiga kepekatan rumusan telah diuji mengandungi 75, 100, dan 125 µL/mL. Hasil penyelidikan mendedahkan rawatan 125 µL/mL adalah rawatan terbaik berdasarkan penindasan indeks keterukan penyakit, nilai AUDPC serta pertumbuhan, parameter fisiologi dan hasil jika dibandingkan dengan kawalan positif. Kesimpulannya, pembangunan bakteria-nano boleh digunakan sebagai agen antimikrob baru dalam menindas pertumbuhan *Xoo in-vitro* dan menyekat indeks keterukan penyakit hawar daun bakteria dalam percubaan *in-vivo* dan sebagai alternatif baru kepada bakteria sintetik.

ACKNOWLEDGEMENT

Alhamdulillah, praise be to Allah, the most merciful and beneficent. I praise Almighty Allah for his constant guidance and for providing me with the courage, patience, and determination to complete the program.

This study is the result of many people's tireless efforts and the sponsorship of a variety of organizations, to whom I would like to express my gratitude. First and foremost, I want to thank my chairman of the supervisory committee, Assoc. Prof. Dr. Khairulmazmi Ahmad, for his commitment, guidance, hospitality, support, scientific training, and exceptional position as he never failed to mentor me during my studies. I'd also like to express my gratitude to my co-supervisors. Dr. Norhayu Asib for her unwavering encouragement, advice, tenacious assistance, and patience. I'm also grateful to Assoc. Prof. Dr. Intan Safinar Ismail, my co-supervisor, for her scholarly guidance in this task. Their scientific intuition has influenced and enriched my development as a researcher and a student. Words alone are inadequate to show my gratitude for what they have done for me. May Allah, the Almighty, bless and reward them abundantly. I am looking forward to work with you in the future.

I am also grateful to the staff of Institut Biosains (IBS) GC-MS and Biodiversity units for their suggestions and assistance. My special thanks go to the staff of Bacteriology Laboratory, Molecular Laboratory viz: Mr. Muhammad Nazri, Mrs. Asmalina, and Mr. Johari for their valuable help and support during the conduct of my research.

My gratitude also goes to the Nigerian government's Tertiary Education Trust Fund (TETFund) and the management of Sokoto State University, Sokoto, for providing me with a research fellowship that enabled me to complete my studies comfortably and successfully. I appreciate their support and prompt acceptance of all of my financial requests during the course of my study. During my study, I have a number of excellent friends and colleagues (PhD students in UPM), but just to mention few that include Dr. Buhari Muhammad, M. Bello Sani Haliru sokoto, Osamah Zaid, Abdulaziz Bashir Kutawa, Abubakar A. Ismail, Wael Sultan, Imam Hussain, Zia-Rahman.

To my family, I would like to express my gratitude to my parents, especially Alh. (Mal) Abdullahi Muhammad Gada and Mlm. Fatima Abubakar Gada, as well as my lovely wife (Aisha) and children (Hafsat, Fatima, Abdussalam, and Muhammad) for their unwavering support, devotion in prayers, love, and unbending confidence in me. I also want to express my gratitude to my friends at home, Aminu Umar Gada and Bashar Muhammad Gada, Bashiru Aliyu Gada, Umar Muhammad Dodoru and Ibrahim Abdullahi Dukamaje, Muhammad Musa Tanko and all staffs of biological sciences, SSU for their support and prayers. Finally, I want to express my gratitude to everyone who helped me finish this study, and I apologize for not mentioning everyone here.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Khairulmazmi bin Ahmad, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

Intan Safinar binti Ismail, PhD
Associate Professor ChM.
Faculty of Science
Universiti Putra Malaysia
(Member)

Norhayu binti Asib, PhD
Senior Lecturer, Ts.
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

____
ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 13 October 2022

Declaration by Members of Supervisory Committee

This is to confirm that:

- The research conducted and the writing of this thesis was under our supervision
- Supervision responsibilities as stated in Rules 41 in Rules 2003 (Revision 2012-2013) were adhered to.

Signature: ____
Name of Chairman of supervisor Committee: Associate Professor Dr. Khairulmazmi bin Ahmad

Signature: ____
Name of Member of supervisor Committee: Associate Professor Dr. Intan Safina binti Ismail

Signature: ____
Name of Member of supervisor Committee: Ts. Dr. Norhayu binti Asib

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

%	Percent
&	And
±SD	Standard deviation of means
°	Degree
°C	Celsius
µL	microliter
ABI	Agro Biotechnology Institute
AI	active ingredient
ANOVA	Analysis of variance
AUDPC	Area under Disease Progress Curve BLB Bacterial leaf Blight
Cm	Centimeter
CRD	Complete Randomize Design
Conc.	Concentrations
CLSM	Confocal Laser Scanning Microscopy
CW	Control with water
DAI	Days After Inoculation
DAS	Days After Sowing
DMT	Domestic
DMSO	Dimethyl sulfoxide
DSI	Disease Severity Index
EOS	Essential oils
et al.	*et alli,* and others
FAO	Food and Agricultural

GC-MS	Gas Chromatography-Mass Spectrophotometry
i.e	*example gratia*, for example
IBS	Institute of Bioscience
MHA	Mueller Hinton Agar
MHB	Mueller Hinton Broth
mg	milligram
Mins	Minutes
ML	Milliliters
Mm	millimeters
mN/m	millinewtons per meter
mPas	Millipascal-second
NA	Nutrient Agar
NB	Nutrient Broth
NFO-AI	Nanoformulation- Active ingredients nm Nanometer
NIBM	National Institutes of Biotechnology Malaysia No. Number
O/W	Oil-in-water
PBD	Potato Dextrose Broth
PDA	Potato dextrose agar
PDI	Polydispersity Index
pH	Logarithm of hydrogen ion activity
PIRG	Percentage Inhibition Radial Growth
PSGI	Percentage Spore Germination Inhibition
pv	Pathovar
PEO	Pure essential oils
Rpm	Revolution per minute

RCBD	Randomized Complete Block Design RT Retention Times
SEM	Scanning Electron Microscopy
SI	Similarity Index
SIMCA	Sugud Islands Marine Conservation Area spp species
TC	Treatment control 1
TD	Treatment control 2
TE	Treatment control 3
TF	Treatment control with antibiotics
TA	Treatment control with pathogen
TEM	Transmission Electron Microscopy
Tw	Tween 20
UPM	Universiti Putra Malaysia
v/v	volume per volume
Ver.	Version
Viz	*videlicet*, that is, namely
Vol.	Volume
w/v	weight/volume
w/w	weight/weight
WLD	Wild
Xoo	*Xanthomonas oryzae*

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Rice (*Oryza sativa*) is the staple food crop globally and major important foodstuff of Asia (Kagale *et al.,* 2004) including Malaysia (Vaghefi *et al.,* 2011). Pathogenic microbes in plants are the major cause of plant diseases which lead to huge crop losses, especially in tropical regions. Fungal diseases of rice like sheath blight and bacterial blight caused by *Rhizoctonia solani* and *Xanthomonas oryzae* pv. *oryzae,* respectively poses a serious problem which significantly affects rice productions and food security. The safety in food production play a very vital role, being food production not only to feed the growing world population but also one of the primary drivers of economy (Ali *et al.,* 2016; Son *et al.,* 2020).

Bacterial blight disease is the most important disease that affects the cultivation/production of rice in Malaysia. The BLB infections of susceptible plants can result in severe production losses of up to 50%. However, at the greatest tillering stage, yield losses are reduced by 20–40%, whereas early infection stage losses are seen at about 50%, thus, it led to crop losses (Chompa *et al.,* 2022). It is challenging to control this plant disease despite recent agricultural advancements. This is because readily available synthetic chemicals have a very limited ability to treat diseases without causing significant side effects. (Shaheen and Issa, 2020). These synthetic chemicals are attributed to the negative effects on the environment such as significant soil and water pollutions, long periods of degradation, residual accumulation in the food chain and less control efficacy against pathogenic microbes with long-term usage (Ghormade *et al.,* 2011; Nega, 2014; Bhavaniramya *et al.,* 2019). The existing antibiotics and copper-based fungicides are actually prohibited for agricultural practices in many countries of the world due to their adverse effects including severe or extreme pathogens resistance, higher cost of production, prolonged cycles of chemicals degradation, and environmental pollutions (Hajano *et al.,* 2012; Sundin *et al.,* 2016; Buttimer *et al.,* 2017). Moreover, Streptomycin was the primary antibiotic used in the management of plant diseases. It is sprayed on plants at a concentration of 0.5 g/L. Although it is only advised as an emergency measure for blight under the integrated disease and pest management schedule (IDIPM), farmers frequently use this antibiotic carelessly to prevent the occurrence of bacterial blight (Sharma *et al.,* 2022). But, later, the phytopathogens resistant to Streptomycin emerged and developed (Xu *et al.,* 2010). Therefore, these limitations heavily affected the control efficiency of plant diseases in the agriculture production system (Juroszek and Von Tiedemann, 2011; Dara, 2019). Nevertheless, the disease management systems are of the major concern with a strong need to look for the novel and potential natural antimicrobial agents or biopesticides that can be effective, non-toxic, and ecologically safe to control plant diseases. Research into alternative pesticides and antimicrobials, including natural plant products such as ginger essential oils, has tripled recognition. The introduction of new generation/innovation of biopesticides could provide solutions for the pathogenic microbes that have developed resistance to the available synthetic chemicals (Saha *et al.,* 2016).

It became evident from nowadays researches that these natural products have the ability to influence the modern agrochemical solutions for their biological and antimicrobial activities (Abdel-Kader *et al.,* 2015) as well as economic viability and low toxicity (Brusotti *et al.,* 2014). They are also well known for their antibacterial, antiviral, antifungal activities and as an insect repellent (Venkateshwarlu, 2014; Sendanayake *et al.,* 2017; Azhari *et al.,* 2017), biodegradable and generally embraced by many societies. Thus, it is a new solution in the plant protection sector (Lim *et al.,* 2012; Lanzotti *et al.,* 2013). Ginger essential oils (EOs) have demonstrated excellent antimicrobial activity against pathogenic microorganisms as it was well documented (Debbarma *et al.,* 2013; Nikolic *et al.,* 2014; Wonni *et al.,* 2016; Mostafa, 2018). However, because of their low water solubility and high sensitivity to oxygen, moisture, heat, and light make their uses very limited. Advancement in science and technology have emerged as solutions to these emerging challenges to improve their stability, water-solubility, and protect it from UV light degradation. The ginger EOs nano-based delivery systems such as nanoemulsions is one of the models for enclosure of these natural bioactive compounds to enhance antimicrobial activity. Thus, it can bring active compounds to the desired site, shield them from adverse environmental factors and increase their effectiveness (Donsi and Ferrari, 2016). Recently, nanoemulsions have become increasingly important as potential vehicles for the controlled delivery and optimized dispersion of active ingredients, particularly the ginger EOs. The penetration of the active ingredient is increased due to the small droplet with its high surface area, which allows the active to be efficiently transported to the desired parts of the plant (Ostrosky *et al.,* 2015). It is one of the promising delivery systems used in many field of researches such as plant protection in agricultural sector (Ram *et al.,* 2014) with a great advantages over typical emulsions in which droplets are smaller in sizes (Lee *et al.,*2016). The system resulted in displaying greater spreadability, superior mechanical stability, and wettability (Nair *et al.,* 2010., Diaz-Blancas *et al.,* 2016).

Studies have been performed and solutions have been found on plant disease control, yet various diseases have been persisted, invariably incurring crop loss annually. In Malaysia, bacterial and fungal species had been isolated from various crops, but there is need to subject them for antimicrobial testing using ginger EOs as an alternative way that is eco-friendly for the management of rice diseases. Therefore, the recent effort is directed towards extraction and characterization of ginger EOs as well as control efficacy of developed nanobactericides in controlling *X. oryzae* pv. *oryzae* and this may serve as one of the new tools for controlling the BLB disease of rice. This is considered an interesting alternative to synthetic chemical control and to explore hidden potentiality of the herbs for its antimicrobial activity against the phytopathogenic bacteria.

1.2 Objectives of Studies

The main objective of this study is to develop nanobactericides through nanoelmulsion approach to control *X. oryzae* pv. *oryzae* towards sustainable disease management.

The specific objectives are:

1. To extract essential oils, profile its chemical components, and determine the antibacterial efficacy against important phytopathogens from domestic and wild gingers.

2. To determine the mechanism of action of ginger EOs against *X. oryzae* pv. *oryzae.*

3. To develop and characterize nanobactericides formulated from ginger EOs

4. To evaluate the disease control efficacy of the developed nanobactericides both *in vitro* and *in-vivo* trials.

REFERENCES

Abdel-Kader, M. M., Shaban, A. M. H., and El-Mougy, N. S. (2015). Biological and Chemical Resistance Inducers as Seed priming for Controlling Faba Bean Root rot Disease under Field Conditions. *International Journal of Engineering and Innovative Technology*, *4*(11), 300–305.

Agarwal, M., Walia, S., Dhingra, S., and Khambay, B. P. S. (2001). Insect growth inhibition, antifeedant and antifungal activity of compounds isolated/ derived from Zingiber officinale Roscoe (ginger) rhizomes. *Pest Management Science*, *57*(3), 289–300.

Aghazadeh, M., Bialvaei, A. Z., Aghazadeh, M., Kabiri, F., Saliani, N., Yousefi, M., Eslami, H., and Kafil, H. S. (2016). Survey of the antibiofilm and antimicrobial effects of Zingiber officinale (In vitro study). *Jundishapur Journal of Microbiology*, *9*(2), 1–6.

Agrios, G. N. (2005). *Plant pathology* (5th ed.). Elsevier Academic press.

Ahmad, S., Wong, C., Fook, K., and Vadamalai, G. (2020). Molecular characterization of Fusarium oxysporum f . sp . cubense Tropical Race 4 (Foc-TR4) isolates from Malaysian banana using secreted in Xylem (SIX) effector genes. *Archives of Phytopathology and Plant Protection*, 1–16.

Akhlaghi, M., Tarighi, S., and Taheri, P. (2020). Effects of plant essential oils on growth and virulence factors of Erwinia amylovora. *Journal of Plant Pathology*, *102*(2), 409–419.

Akhtar, M. S., Swamy, M. K., and Sinniah, U. R. (2019). *Natural Bio-active Compounds* (Vol. 1). Springer Nature Singapore Pte Ltd.

Akthar, M. S., Degaga, B., and Azam, T. (2014). Antimicrobial activity of essential oils extracted from medicinal plants against the pathogenic microorganisms : A review. *Issues in Biological Sciences and Pharmaceutical Research*, *2*(January), 1–7.

Al-Hetar, M. Y., Zainal Abidin, M. A., Sariah, M., and Wong, M. Y. (2011). Antifungal activity of chitosan against Fusarium oxysporum f. sp. cubense. *Journal of Applied Polymer Science*, *120*(4), 2434–2439.

Ali, H., Abbasi, F. M., and Ahmad, H. (2016). Bacterial Blight , a serious threat to productivity of rice (Oryza Sativa L .), an overview. *International Journal of Biosciences*, *6655*, 154–169.

Alzoreky, N. S., and Nakahara, K. (2003). Antibacterial activity of extracts from some edible plants commonly consumed in Asia. *International Journal of Food Microbiology*, *80*(3), 223–230.

Amadioha, A. C. (2000). Controlling rice blast in vitro and in vivo with extracts of Azadirachta indica. *Crop Protection*, *19*(5), 287–290.

Aman, M., and VR, R. (2015). Antifungal activity of fungicides and plant extracts against yellow sigatoka disease causing Mycosphaerella musicola. *Current Reasearch in Environmental and Applied Mycology*, *5*(March), 277–284.

Arifullah, M., Vikram, P., Chiruvella, K. K., Shaik, M. M., and Abdullah Ripain, I. H. (2014). A Review on Malaysian Plants Used for Screening of Antimicrobial Activity. *Annual Research and Review in Biology*, *4*(13), 2088–2132.

Asbahani, A. El, Miladi, K., Badri, W., Sala, M., Addi, E. H. A., Casabianca, H., Mousadik, A. El, Hartmann, D., Jilale, A., Renaud, F. N. R., and Elaissari, A. (2015). Essential oils: From extraction to encapsulation. *International Journal of Pharmaceutics*, *483*(1–2), 220–243.

Aswathanarayan, J. B., and Vittal, R. R. (2019). Nanoemulsions and Their Potential Applications in Food Industry. *Frontiers in Sustainable Food Systems*, *3*(November), 1–21.

Awla, H. K., Kadir, J., Othman, R., Rashid, T. S., and Wong, M. (2016). Bioactive Compounds Produced by Streptomyces sp . Isolate UPMRS4 and Antifungal Activity against Pyricularia oryzae. *American Journal of Plant Sciences*, *7*, 1077–1085.

Azhari, H., Sook, S., and Nour, A. (2017). Extraction And Chemical Compositions of Ginger (Zingiber Officinale Roscoe) Essential Oils As Cockroaches Repellent. *Australian Journal of Basic and Applied Sciences*, *11*(3), 1–8.

Aziza, A. E., and Okiy, S. (2018). Extraction and Characterization of Essential Oil Ginger from Ginger Rhizome. *American Journal of Engineering Research (AJER)*, *7*(2), 266–270.

Azman, N. A., Sijam, K., Hata, E. M., Othman, R., and Saud, H. M. (2017). Screening of Bacteria as Antagonist against Xanthomonas oryzae pv. oryzae, the Causal Agent of Bacterial Leaf Blight of Paddy and as Plant Growth Promoter. *Journal of Experimental Agriculture International*, *16*(4), 1–15.

Bajerski, L., Michels, L. R., Colomé, L. M., Bender, E. A., Freddo, R. J., Bruxel, F., and Haas, S. E. (2016). The use of Brazilian vegetable oils in nanoemulsions: An update on preparation and biological applications. *Brazilian Journal of Pharmaceutical Sciences*, *52*(3), 347–363.

Bajpai, V. K., Kang, S., Xu, H., Lee, S. G., Baek, K. H., and Kang, S. C. (2011). Potential roles of essential oils on controlling plant pathogenic bacteria Xanthomonas species: A review. *Plant Pathology Journal*, *27*(3), 207–224.

Barzegar, H., Mehrnia, M. A., Nasehi, B., and Alipour, M. (2018). Fabrication of peppermint essential oil nanoemulsions by spontaneous method: Effect of preparing conditions on droplet size. *Flavour and Fragrance Journal*, *33*(5), 351–356.

Bazargani, M. M., and Rohloff, J. (2016). Antibiofilm activity of essential oils and plant extracts against Staphylococcus aureus and Escherichia coli biofilms. *Food Control*, *61*, 156–164.

Ben Jemaa, M., Falleh, H., and Ksouri, R. (2019). Encapsulation of Natural Bioactive Compounds: Nanoemulsion Formulation to Enhance Essential Oils Activities. *Microencapsulation - Processes, Technologies and Industrial Applications*.

Berahim, Z., Dorairaj, D., Saud, H. M., Omar, M. H., Yaapar, N., and Ismail, M. R. (2018). Water Stress Affects Growth, Biomass Partitioning, Grain Filling and Productivity Of Mr219, A High Yielding Rice Variety Of Malaysia. *International Journal of Agriculture, Environment and Bioresearch*, *03*(04), 410–426.

Bernardi, D. S., Pereira, T. A., Maciel, N. R., Bortoloto, J., Viera, G. S., Oliveira, G. C., and Rocha-Filho, P. A. (2011). Formation and stability of oil-in-water nanoemulsions containing rice bran oil: In vitro and in vivo assessments. *Journal of Nanobiotechnology*, *9*(1), 44.

Bhattarai, K., Pokharel, B., Maharjan, S., and Adhikari, S. (2018). Chemical Constituents and Biological Activities of Ginger Rhizomes from Three Different Regions of Nepal. *Journal of Nutritional Dietetics and Probiotics*, *1*(1), 1–12.

Bhavaniramya, S., Vishnupriya, S., Al-Aboody, M. S., Vijayakumar, R., and Baskaran, D. (2019). Role of essential oils in food safety: Antimicrobial and antioxidant applications. *Grain and Oil Science and Technology*, *2*(2), 49–55.

Bohme, K., Barros-velazquez, J., Calo-mata, P., and Aubourg, S. P. (2014). Antibacterial , Antiviral and Antifungal Activity of Essential Oils : Mechanisms and Applications. In *Antimicrobial Compounds* (pp. 51–81).

Brusotti, G., Cesari, I., Dentamaro, A., Caccialanza, G., and Massolini, G. (2014). Isolation and characterization of bioactive compounds from plant resources: The role of analysis in the ethnopharmacological approach. *Journal of Pharmaceutical and Biomedical Analysis*, *87*, 218–228.

Buttimer, C., McAuliffe, O., Ross, R. P., Hill, C., O'Mahony, J., and Coffey, A. (2017). Bacteriophages and bacterial plant diseases. *Frontiers in Microbiology*, *8*(JAN), 1–15.

Chandrasekaran, N., Sugumar, S., and Mukherjee, A. (2015). Nanoemulsion formation and characterization by spontaneous emulsification: Investigation of its antibacterial effects on Listeria monocytogenes. *Asian Journal of Pharmaceutics*, *9*(1), 23.

Chang, T. (1976). The Origin, Evolution, Dissemination, Cultivation, and Diversification of Asian and African Rices. *Euphytica*, *25*, 425–441.

Chibuike, C. S., Y, R. M., Izan, R. S., Izera, I. S., Yussuf, O., Emmanuel, O., Godwin, O., Emeka, U., Lynda, E., Senesie, S., and Momodu, J. (2019). Marker-assisted selection and gene pyramiding for resistance to bacterial leaf blight disease of rice (Oryza sativa L .). *Biotechnology and Biotechnological Equipment*, 1–16.

Chikte, R. G., Paknikar, K. M., Rajwade, J. M., and Sharma, J. (2019). Nanomaterials for the control of bacterial blight disease in pomegranate: quo vadis? *Applied Microbiology and Biotechnology*, *103*(11), 4605–4621.

Chompa, S. S., Akter, A., and Sadeq, B. M. (2022). An Overview of Major Bacterial Diseases of Rice and Management Strategies for Their Control in Malaysia. *Global Scientific Journals*, *10*(April), 1074–1102.

Chouhan, S., Sharma, K., and Guleria, S. (2017). Antimicrobial Activity of Some Essential Oils—Present Status and Future Perspectives. *Medicines*, *4*(3), 58.

Chua, L. S. (2013). A review on plant-based rutin extraction methods and its pharmacological activities. *Journal of Ethnopharmacology*, *150*(3), 805–817.

Chuacharoen, T., Prasongsuk, S., and Sabliov, C. M. (2019). Effect of surfactant concentrations on physicochemical properties and functionality of curcumin nanoemulsions under conditions relevant to commercial utilization. *Molecules*, *24*(15), 1–12.

Corral, R., Leach, J. E., Verdier, V., and Cruz, C. V. (2013). Recovery Plan for Xanthomonas oryzae Causing Bacterial Blight and Bacterial Leaf Streak of Rice. *Xanthomonas Oryzae Recovery Plan*, 1–22.

Cristani, M., D'Arrigo, M., Mandalari, G., Castelli, F., Sarpietro, M. G., Micieli, D., Venuti, V., Bisignano, G., Saija, A., and Trombetta, D. (2007). Interaction of four monoterpenes contained in essential oils with model membranes: Implications for their antibacterial activity. *Journal of Agricultural and Food Chemistry*, *55*(15), 6300–6308.

Dara, S. K. (2019). The New Integrated Pest Management Paradigm for the Modern Age. *Journal of Integrated Pest Management*, *10*(1), 1–9.

Das, A., Kasoju, N., Bora, U., and Rangan, L. (2013). Chemico-biological investigation of rhizome essential oil of Zingiber moran—native to Northeast India. *Medicinal Chemistry Research*, *22*(9), 4308–4315.

De Azevedo Ribeiro, R. C., Barreto, S. M. A. G., Ostrosky, E. A., Da Rocha-Filho, P. A., Veríssimo, L. M., and Ferrari, M. (2015). Production and characterization of cosmetic nanoemulsions containing Opuntia ficus-indica (L.) Mill extract as moisturizing agent. *Molecules*, *20*(2), 2492–2509.

de Melo, G. A. N., Grespan, R., Fonseca, J. P., Farinha, T. O., da Silva, E. L., Romero, A. L., Bersani-Amado, C. A., and Cuman, R. K. N. (2011). Inhibitory effects of ginger (Zingiber officinale Roscoe) essential oil on leukocyte migration in vivo and in vitro. *Journal of Natural Medicines*, *65*(1), 241–246.

de Oliveira, A. G., Murate, L. S., Spago, F. R., Lopes, L. de P., Beranger, J. P. de O., Martin, J. A. B. S., Nogueira, M. A., Mello, J. C. P. de, Andrade, C. G. T. de J., and Andrade, G. (2011). Evaluation of the antibiotic activity of extracellular compounds produced by the Pseudomonas strain against the Xanthomonas citri pv. citri 306 strain. *Biological Control*, *56*(2), 125–131.

Debbarma, J., Kishore, P., Nayak, B. B., Kannuchamy, N., and Gudipati, V. (2013). Antibacterial activity of ginger, eucalyptus and sweet orange peel essential oils on fish-borne bacteria. *Journal of Food Processing and Preservation*, *37*(5), 1022–1030.

Devi, M. P., Chakrabarty, S., and Ghosh, S. K. (2015). Essential Oil: Its Economic Aspect, Extraction, Importance, Uses, Hazards and Quality. In *Value Addition of Horticultural Crops: Recent Trends and Future Directions* (pp. 269–278).

Dhanik, J., Arya, N., and Nand, V. (2017). A Review on Zingiber officinale. *Journal of Pharmacognosy and Phytochemistry JPP*, *174*(63), 174–184.

Dhifi, W., Bellili, S., Jazi, S., Bahloul, N., and Mnif, W. (2016a). Essential Oils' Chemical Characterization and Investigation of Some Biological Activities: A Critical Review. *Medicines*, *3*(4), 25.

Dhifi, W., Bellili, S., Jazi, S., Bahloul, N., and Mnif, W. (2016b). Essential Oils ' Chemical Characterization and Investigation of Some Biological Activities : A Critical Review. *Medicines*, *3*(25), 16.

Diaz-Blancas, V., Medina, D. I., Padilla-Ortega, E., Bortolini-Zavala, R., Olvera-Romero, M., and Luna-Barcenas, G. (2016). Nanoemulsion formulations of fungicide tebuconazole for agricultural applications. *Molecules*, *21*(10), 1–12.

Donsi, F., and Ferrari, G. (2016). Essential oil nanoemulsions as antimicrobial agents in food. *Journal of Biotechnology*, *233*, 106–120.

Dorman, H. J. D., and Deans, S. G. (2000). Antimicrobial agents from plants: Antibacterial activity of plant volatile oils. *Journal of Applied Microbiology*, *88*(2), 308–316.

Echeverria, J., and Albuquerque, R. (2019). Nanoemulsions of Essential Oils: New Tool for Control of Vector-Borne Diseases and In Vitro Effects on Some Parasitic Agents. *Medicines*, *6*(2), 42.

El-baky, H. H. A., Farag, R. S., and Saleh, M. a. (2010). Characterization of antioxidant and antimicrobial compounds of cinnamon and ginger essential oils. *African Journal of Biochemistry Research*, *4*(6), 167–174.

El-Baroty, G. S., El-Baky, H. H. A., Farag, R. S., and Saleh, M. A. (2010). Characterization of antioxidant and antimicrobial compounds of cinnamon and ginger essential oils. *African Journal of Biochemistry Research*, *4*(6), 167–174.

Espitia, P. J. P., Fuenmayor, C. A., and Oton, C. G. (2019). Nanoemulsions : Synthesis , Characterization , and Application in Bio-Based Active Food Packaging. *ComprehensiveReviews in Food Science and FoodSafety*, *18*.

Fitriady, M. A., Sulaswatty, A., Agustian, E., Salahuddin, and Aditama, D. P. F. (2017). Steam distillation extraction of ginger essential oil: Study of the effect of steam flow rate and time process. *International Symposium on Applied Chemistry (ISAC)*, *1803*.

Gakuubi, M. M., Maina, A. W., and Wagacha, J. M. (2017). Antifungal Activity of Essential Oil of Eucalyptus camaldulensis Dehnh. against Selected Fusarium spp. *International Journal of Microbiology*, 1–8.

Gani, S. S. A., Kamairudin, N., Razalli, R. L., and Basri, M. (2015). Phase behaviour study of pitaya seed oil: Jojoba oil with non-ionic surfactants in emulsion system. *Asian Journal of Chemistry*, *27*(9), 3452–3456.

Ghormade, V., Deshpande, M. V., and Paknikar, K. M. (2011). Perspectives for nano-biotechnology enabled protection and nutrition of plants. *Biotechnology Advances*, *29*(6), 792–803.

Ghosh, V., Mukherjee, A., and Chandrasekaran, N. (2013). Formulation and characterization of plant essential oil based nanoemulsion: Evaluation of its larvicidal activity against Aedes aegypti. *Asian Journal of Chemistry*, *25*(SUPPL).

Gnanamanickam, S. S., Brindha Priyadarisini, V., Narayanan, N. N., Vasudevan, P., and Kavitha, S. (1999). An overview of bacterial blight disease of rice and strategies for its management. *Current Science*, *77*(11), 1435–1444.

Gnanamanickam, Samuel S. (2009). *biological control of rice diseases* (Issue November). Texas AandM University 17360 Coit Road, Dallas, TX 75252 United States.

Gupta, A., Eral, H. B., Hattona, T. A., and Doyle, P. S. (2016). Nanoemulsions: formation, properties and applications. *Soft Matter*, *12*(11), 2826–2841.

Gurjar, M. S., Ali, S., Akhtar, M., and Singh, K. S. (2012). Efficacy of plant extracts in plant disease management. *Agricultural Sciences*, *03*(03), 425–433.

Gurpreet, K., and Singh, S. K. (2018). Review of nanoemulsion formulation and characterization techniques. *Indian Journal of Pharmaceutical Sciences*, *80*(5), 781–789.

Hajano, J. U. D., Lodhi, A. M., Pathan, M. A., Khanzada, M. A., and Shah, G. S. (2012). In-vitro evaluation of fungicides, plant extracts and bio-controlagents against rice blast pathogen Magnaporthe Oryzae couch. *Pakistan Journal of Botany*, *44*(5), 1775–1778.

Ham, Y., and Kim, T.-J. (2018). Nitrogen Sources Inhibit Biofilm Formation of Xanthomonas oryzae pv. oryzae. *Journal of Microbiology and Biotechnology*, *28*(12), 2071–2078. https://doi.org/10.4014/jmb.1808.08025

Hoferl, M., Stoilova, I., Wanner, J., Schmidt, E., Jirovetz, L., Trifonova, D., Stanchev, V., and Krastanov, A. (2015). Composition and Comprehensive Antioxidant Activity of Ginger (Zingiber officinale) Essential Oil from Ecuador. *Natural Product Communications*, *10*(6), 1085–1090.

Hossain, I., Ahmad, K., Siddiqui, Y., Saad, N., Rahman, Z., Haruna, A. O., and Bejo, S. K. (2020). Current and Prospective Strategies on Detecting and Managing Colletotrichum falcatum Causing Red Rot of Sugarcane. *Agronomy 2020*, *10*(9), 1–19.

Howard, R. J. (2009). Cultural control of plant diseases: a historical perspective. *Canadian Jounal of Plant Pathology*, *2012*, 37–41.

Hu, J., Qian, W., and He, C. (2007). Xanthomonas oryzae. *FEMS Microbiology Letters*, *40*(10), 2193–2199.

Ingle, K. P., Deshmukh, A. G., Padole, D. A., Dudhare, M. S., Moharil, M. P., and Vaibhav, K. C. (2017). Phytochemicals: Extraction methods, identification and detection of bioactive compounds from plant extracts. *Journal of Pharmacognosy and Phytochemistry JPP*, *6*(61), 32–36.

Inkson, B. J. (2016). Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) for Materials Characterization. In *Materials Characterization Using Nondestructive Evaluation (NDE) Methods* (1st ed., pp. 17–43). Elsevier Ltd.

Jabeen, R. (2011). Medicinal Plants - a Potent Antibacterial Source Against Bacterial Leaf Blight (Blb) of Rice. *Pakistan Journal of Botany*, *43*(Xoo 105), 111–118.

Jaiswal, M., Dudhe, R., and Sharma, P. K. (2015). Nanoemulsion: an advanced mode of drug delivery system. *3 Biotech*, *5*(2), 123–127.

Jakribettu, R. P., Boloor, R., Bhat, H. P., Thaliath, A., Haniadka, R., Rai, M. P., George, T., and Baliga, M. S. (2016). Ginger (Zingiber officinale Rosc.) oils. *Essential Oils in Food Preservation, Flavor and Safety*, *December*, 447–454.

Jeger, M., Candresse, T., Chatzivassiliou, E., Dehnen-Schmutz, K., Gilioli, G., Gregoire, J., Jaques Miret, J. A., MacLeod, A., Navajas Navarro, M., Niere, B., Parnell, S., Potting, R., Rafoss, T., Rossi, V., Urek, G., Van Bruggen, A., Van der Werf, W., West, J., Winter, S., … Caffier, D. (2018). Pest categorisation of Xanthomonas oryzae pathovars oryzae and oryzicola. *EFSA Journal*, *16*(1), 1–25.

Juroszek, P., and Von Tiedemann, A. (2011). Potential strategies and future requirements for plant disease management under a changing climate. *Plant Pathology*, *60*(1), 100–112.

K.N, C., Manivannan, S., Chandrashekara, C., and Chakravarthi, M. (2012). Biological Control of Plant Diseases. In *Biological Control of Plant Diseases* (Issue June 2014).

Kagale, S., Marimuthu, T., Thayumanavan, B., Nandakumar, R., and Samiyappan, R. (2004). Antimicrobial activity and induction of systemic resistance in rice by leaf extract of Datura metel against Rhizoctonia solani and Xanthomonas oryzae pv. oryzae. *Physiological and Molecular Plant Pathology*, *65*(2), 91–100.

Kala, A., Soosairaj, S., Mathiyazhagan, S., and Raja, P. (2015). *Isolation and Identification of Xanthomonas oryzae pv . oryzae the causal agent of rice bacterial leaf blight and its activities against of six medicinal plants*. *5*(6), 80–83.

Kaur, A., Sharma, S., Singh, M., Kaushik, P., and Jain, U. K. (2018). Nano-Emulsion: a Review About General Introduction, Preparation Methods, Evaluation and Some Marketed Nanoemulsion Formulations. *International Research Journal of Pharmacy*, *9*(1), 16–18.

Kaushal, M. (2018). Nanobiotechnology Applications in Plant Protection. In *Nanotechnology in the Life Sciences* (Issue August, pp. 111–135). Springer International Publishing AG, part of Springer Nature 2018.

Kebede, M., Ayalew, A., and Yesuf, M. (2013). *Efficacy of plant extracts, traditional materials and antibacterial chemicals against Xanthomonas campestris pv. vesicatoria on tomato seed*. *7*(20), 2395–2400.

Khan, J. A., Siddiq, R., Arshad, H. M. I., Anwar, H. S., Saleem, K., and Jamil, F. F. (2012). Chemical control of bacterial leaf blight of rice caused by xanthomonas oryzae pv. oryzae. *Pak. J. Phytopathol*, *24*(2), 97–100.

Khayyat, S. A., and Roselin, L. S. (2018). Recent progress in photochemical reaction on main components of some essential oils. *Journal of Saudi Chemical Society*, *22*(7), 855–875.

Khoshkdaman, M., Ebadi, A. A., and Kahrizi, D. (2012). Evaluation of pathogencity and race classification of Xanthomonas oryzae pv. oryzae in guilan province-Iran. *Agricultural Sciences*, *03*(04), 557–561. https://doi.org/10.4236/as.2012.34066

Khot, L. R., Sankaran, S., Maja, J. M., Ehsani, R., and Schuster, E. W. (2012). Applications of nanomaterials in agricultural production and crop protection: A review. *Crop Protection*, *35*, 64–70.

Koch, W., Kukula-Koch, W., Marzec, Z., Kasperek, E., Wyszogrodzka-Koma, L., Szwerc, W., and Asakawa, Y. (2017). Application of chromatographic and spectroscopic methods towards the quality assessment of ginger (Zingiber officinale) rhizomes from ecological plantations. *International Journal of Molecular Sciences*, *18*(2), 1–15.

Komaiko, J., and McClements, D. J. (2015). Low-energy formation of edible nanoemulsions by spontaneous emulsification: Factors influencing particle size. *Journal of Food Engineering*, *146*(February), 122–128.

Kotta, S., Khan, A. W., Ansari, S. H., Sharma, R. K., and Ali, J. (2015). Formulation of nanoemulsion: A comparison between phase inversion composition method and high-pressure homogenization method. *Drug Delivery*, *22*(4), 455–466.

Kumar Sharma, P., Singh, V., and Ali, M. (2016). Chemical Composition and Antimicrobial Activity of Fresh Rhizome Essential Oil of Zingiber Officinale Roscoe. *Pharmacognosy Journal*, *8*(3), 185–190.

Kumari, S., Kumaraswamy, R. V., Choudhary, R. C., Sharma, S. S., Pal, A., Raliya, R., Biswas, P., and Saharan, V. (2018). Thymol nanoemulsion exhibits potential antibacterial activity against bacterial pustule disease and growth promotory effect on soybean. *Scientific Reports*, *8*(1), 1–12.

Lambert, R. J. W., Skandamis, P. N., Coote, P. J., and Nychas, G. (2001). A study of the minimum inhibitory concentration and mode of action of oregano essential oil, thymol and carvacrol. *Journal of Applied Microbiology*, *91*(3), 453–462.

Lanzotti, V., Bonanomi, G., and Scala, F. (2013). What makes Allium species effective against pathogenic microbes? *Phytochemistry Reviews*, *12*(4), 751–772.

Lee, J., Jung, M., Lee, S., Huh, M., Seo, S., and Park, I.-K. (2020). Antibacterial mode of action of trans -cinnamaldehyde derived from cinnamon bark (Cinnamomum verum) essential oil against Agrobacterium tumefaciens. *Pesticide Biochemistry and Physiology*, *165*, 1045–1046.

Lee, K. W., Omar, D., Abdan, K., and Wong, M. Y. (2016). Physiochemical characterization of nanoemulsion formulation of phenazine and their antifungal efficacy against Ganoderma boninense PER71 in vitro. *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, *7*(6), 3056–3066.

Li, J., Xie, S., Ahmed, S., Wang, F., Gu, Y., Zhang, C., Chai, X., Wu, Y., Cai, J., and Cheng, G. (2017). Antimicrobial activity and resistance: Influencing factors. *Frontiers in Pharmacology*, *8*(JUN), 1–11.

Li, Y. xin, Zhang, C., Pan, S., Chen, L., Liu, M., Yang, K., Zeng, X., and Tian, J. (2020). Analysis of chemical components and biological activities of essential oils from black and white pepper (Piper nigrum L.) in five provinces of southern China. *Food Science and Technology*, *117*(April 2019), 108644.

Lim, C. J., Basri, M., Omar, D., Abdul Rahman, M. B., Salleh, A. B., and Raja Abdul Rahman, R. N. Z. (2012). Physicochemical characterization and formation of glyphosate-laden nano-emulsion for herbicide formulation. *Industrial Crops and Products*, *36*(1), 607–613.

Liu, Q., Meng, X., Li, Y., Zhao, C. N., Tang, G. Y., and Li, H. Bin. (2017). Antibacterial and antifungal activities of spices. *International Journal of Molecular Sciences*, *18*(6).

Lopez, E. I. C., Balcazar, M. F. H., Mendoza, J. M. R., Ortiz, A. D. R., Melo, M. T. O., Parrales, R. S., and Delgado, T. H. (2017). Antimicrobial Activity of Essential Oil of Zingiber officinale Roscoe (Zingiberaceae). *American Journal of Plant Sciences*, *08*(07), 1511–1524.

Lu, W. C., Huang, D. W., Wang, C. C. R., Yeh, C. H., Tsai, J. C., Huang, Y. T., and Li, P. H. (2018). Preparation, characterization, and antimicrobial activity of nanoemulsions incorporating citral essential oil. *Journal of Food and Drug Analysis*, *26*(1), 82–89.

Lucas, G. C., Alves, E., Pereira, R. B., Perina, F. J., and de Souza, R. M. (2012). Antibacterial activity of essential oils on Xanthomonas vesicatoria and control of bacterial spot in tomato. *Pesquisa Agropecuaria Brasileira*, *47*(3), 351–359.

M., T. I. H., and El-Sharkawy, R. I. (2011). Xanthomonas oryzae PV . oryzae in Egypt: Virulence of Isolates and cultivars reaction. *J. Plant Prot. and Path., Mansoura Univ*, *2*(11), 931–946.

Mahdavi, V., Rafiee-Dastjerdi, H., Asadi, A., Razmjou, J., and Achachlouei, B. F. (2018). Synthesis of Zingiber officinale essential oil-loaded nanofiber and its evaluation on the potato tuber moth, Phthorimaea operculella (Lepidoptera: Gelechiidae). *Journal of Crop Protection*, *7*(1), 39–49.

Manful, J. T. T., and Graham-Acquaah, S. (2016). African Rice (Oryza glaberrima): A Brief History and Its Growing Importance in Current Rice Breeding Efforts. In *Reference Module in Food Science* (2nd ed., Vols. 1–4). Elsevier Ltd.

Marriott, P. J., Shellie, R., and Cornwell, C. (2001). Gas chromatographic technologies for the analysis of essential oils. *Journal of Chromatography A*, *936*(1–2), 1–22.

Marwat, S. K., Shoaib, M., Khan, E. A., Fazal-ur-Rehman, and Ullah, H. (2015). Phytochemistry and bioactivities of quranic plant, Zanjabil-Ginger (Zingiber officinale Roscoe): a review. *American-Eurasian Journal of Agricultural and Environmental Sciences*, *15*(5), 707–713.

Marzuki, N. H. C., Wahab, R. A., and Hamid, M. A. (2019). An overview of nanoemulsion: Concepts of development and cosmeceutical applications. *Biotechnology and Biotechnological Equipment*, *33*(1), 779–797.

Mathew, S. (2014). An Evaluation of the Antimicrobial Activity of Various Concentrations of Ocimum sanctum Against Various Species of Bacteria : an Invitro Study. *International Journal of Advances in Applied Sciences (IJAAS)*, *3*(1), 33–36.

Mesomo, M. C., Corazza, M. L., Ndiaye, P. M., Dalla, O. R., Cardozo, L., and Paula, A. De. (2013). Supercritical CO 2 extracts and essential oil of ginger (Zingiber officinale R .): Chemical composition and antibacterial activity. *The Journal of Supercritical Fluids*, *80*, 44–49.

Mesomo, M. C., Corazza, M. L., Ndiaye, P. M., Dalla Santa, O. R., Cardozo, L., and de Paula Scheer, A. (2013). Supercritical CO_2 extracts and essential oil of ginger (Zingiber officinale R.): Chemical composition and antibacterial activity. *The Journal of Supercritical Fluids*, *80*, 44–49.

Mishra, S., Yang, X., Ray, S., Fraceto, L. F., and Singh, H. B. (2020). Antibacterial and biofilm inhibition activity of biofabricated silver nanoparticles against Xanthomonas oryzae pv. oryzae causing blight disease of rice instigates disease suppression. *World Journal of Microbiology and Biotechnology*, *36*(4), 1–10.

Moradi, S., and Barati, A. (2019). Essential oils nanoemulsions: Preparation, characterization and study of antibacterial activity against Escherichia Coli. *International Journal of Nanoscience and Nanotechnology*, *15*(3), 199–210.

Morishima, H., Hinata, K., and Oka, H.-I. (1963). Comparison of Modes of Evolution of Cultivated Forms from Two Wild Rice Species, Oryza breviligulata and O. perennis. *Evolution*, *17*(2), 170.

Mosie, T. (2019). A Review on Influence of Growth Regulator and Culture Condition on Micro- Propagation of Ginger (Zingiber officinale). *International Journal of Food Science and Agriculture*, *3*(3), 200–204.

Mostafa, N. M. (2018). Antibacterial Activity of Ginger (Zingiber officinale) Leaves Essential Oil Nanoemulsion against the Cariogenic Streptococcus mutans. *Journal of Applied Pharmaceutical Science*, *8*(09), 34–41.

Nair, R., Varghese, S. H., Nair, B. G., Maekawa, T., Yoshida, Y., and Kumar, D. S. (2010). Nanoparticulate material delivery to plants. *Plant Science*, *179*(3), 154–163.

Nayar, N. M. (2014a). Rice in the World. In *Origin and Phylogeny of Rices* (pp. 1–14).

Nayar, N. M. (2014b). The Origin of Asian Rice. *Origin and Phylogeny of Rices*, *May*, 169–253.

Nazzaro, F., Fratianni, F., Coppola, R., and Feo, V. De. (2017). Essential Oils and Antifungal Activity. *Pharmaceuticals*, *10*(86), 1–20.

Nazzaro, F., Fratianni, F., Martino, L. De, Coppola, R., and Feo, V. De. (2013). Effect of Essential Oils on Pathogenic Bacteria. *Pharmaceuticals*, *6*, 1451–1474.

Nega, A. (2014). Review on Concepts in Biological Control of Plant Pathogens. *Journal of Biology, Agriculture and Healthcare*, *4*(27), 33–55.

Nejad, M. S., Bonjar, G. H. S., Khatami, M., Amini, A., Aghighi, S., Soltani Nejad, M., Bonjar, G. H. S., Khatami, M., Amini, A., and Aghighi, S. (2017). In vitro and in vivo antifungal properties of silver nanoparticles against Rhizoctonia solani, a common agent of rice sheath blight disease. *IET Nanobiotechnology*, *11*(3), 236–240.

Nikolic, M., Vasic, S., Djurdjevic, J., Stefanovic, O., and Comic, L. (2014). Antibacterial and anti-biofilm activity of ginger (Zingiber officinale (Roscoe)) ethanolic extract. *Kragujevac Journal of Science*, *36*(36), 129–136.

Nino-Liu, D. O., Ronald, P. C., and Bogdanove, A. J. (2006). Xanthomonas oryzae pathovars: Model pathogens of a model crop. *Molecular Plant Pathology*, *7*(5), 303–324.

Nirmala M, J., and R, N. (2017). Recent Research Trends in Fabrication and Applications of Plant Essential Oil Based Nanoemulsions. *Journal of Nanomedicine and Nanotechnology*, *08*(02), 1–10.

Ostrosky, E. A., Rocha-filho, P. A., and Veríssimo, L. M. (2015). Production and Characterization of Cosmetic Nanoemulsions Containing Opuntia ficus-indica (L.) Mill Extract as Moisturizing Agent. *Molecules*, 2492–2509.

Pal, K. K. and B. M. G., and Gardener, B. M. (2006). Biological control of plant pathogens. *The Plant Health Instructor*, 1–25. https://doi.org/10.1094/PHI-A-2006-1117-02.Biological

Pandey, S., Giri, K., Kumar, R., and Mishra, G. (2016). Nanopesticides : Opportunities in Crop Protection and Associated Environmental Risks. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*, *2*, 1–16.

Patil, M., and Devanna, P. (2016). Isolation and Characterization of Bacterial Leaf Blight of Rice (Xanthomonas Isolation and Characterization of Bacterial Leaf Blight of Rice (Xanthomonas oryzae pv . oryzae) Isolates from Southern India. *Advances in Life Sciences*, *5*(14).

Pavoni, L., Perinelli, D. R., Bonacucina, G., Cespi, M., and Palmieri, G. F. (2020). An overview of micro-and nanoemulsions as vehicles for essential oils: Formulation, preparation and stability. *Nanomaterials*, *10*(1).

Perez-de-Luque, A. (2017). Interaction of nanomaterials with plants: What do we need for real applications in agriculture? *Frontiers in Environmental Science*, *5*(APR), 1–7.

Qin, F.-F., and Xu, H.-L. (2008). Active Compounds in Gingers and Their Therapeutic Use in Complimentary Medication. *Medicinal and Aromatic Plant Science and Biotechnology*, 72–77.

Rahman, N., Mahmood, R., Rahman, H., and Haris, M. (2014). Spectrophotometric Screening of Potent Bactericidal Property of Thevetia Peruviana Schum. Leaf and Fruit Rind Extracts on Clinical and Plant Pathogens. *International Journal of Applied Sciences and Biotechnology*, *2*(4), 451–459.

Rai, M., and Ingle, A. (2012). Role of nanotechnology in agriculture with special reference to management of insect pests. *Applied Microbiology and Biotechnology*, *94*(2), 287–293.

Rajip., Sumiya K. V., Dhanya S., R. K. and N. M. C. (2016). Inhibitory Effect of Plant Extracts and Plant Oils on Xanthomonas Oryzae Pv Oryzae, the Bacterial Blight Pathogen of Rice. *International Journal of Applied and Natural Sciences (IJANS)*, *5*(2), 71–76.

Rakib, M. R. M., Bong, C. F. J., Khairulmazmi, A., Idris, A. S., Jalloh, M. B., and Wahida, N. H. (2017). Ganoderma species of basal and upper stem rots in oil palm (Elaeis Guineensis) in Sarawak, Malysia. *Journal of Academia UiTM Negeri Sembilan*, *5*(December), 27–35.

Ram, P., Vivek, K., and Kumar, S. P. (2014). Nanotechnology in sustainable agriculture: Present concerns and future aspects. *African Journal of Biotechnology*, *13*(6), 705–713.

Recupido, F., Toscano, G., Tatè, R., Petala, M., Caserta, S., Karapantsios, T. D., and Guido, S. (2020). The role of flow in bacterial biofilm morphology and wetting properties. *Colloids and Surfaces B: Biointerfaces*, *192*(December 2019), 111047.

Rocha-Filho, P. A., Ferrari, M., Maruno, M., Souza, O., and Gumiero, V. (2017). In vitro and in vivo evaluation of nanoemulsion containing vegetable extracts. *Cosmetics*, *4*(3), 32. https://doi.org/10.3390/cosmetics4030032

Sa-nguanpuag, K., Kanlayanarat, S., and Tanprasert, K. (2008). Applications of Volatiles in Ginger Essential Oil Can Reduce Microorganisms in Shredded Green Papaya. *Acta Horticulturae*, *804*, 439–444.

Saad, A., and Habibuddin, H. (2010). Pathotypes and virulence of Xanthomonas oryzae causing bacterial blight disease of rice in Peninsular Malaysia. *J. Trop. Agric. and Fd. Sc.*, *38*(2), 257–266.

Sabulal, B. (2016). Chemical composition and antimicrobial properties of essential oils from India. In L. Valgimigli (Ed.), *Essential Oils as Natural Food Additives* (ISBN 978-1, Issue January 2012). Nova Science Publishers, Inc.

Saha, S., Garg, R., Biswas, A., and Rai, A. B. (2016). Bacterial diseases of rice : An overview Bacterial Diseases of Rice : An Overview. *Journal of Pure and Appliied Microbiology*, *9*(1), 725–736.

Sahu, S. K., Zheng, P., and Yao, N. (2018). Niclosamide blocks rice leaf blight by inhibiting biofilm formation of xanthomonas oryzae. *Frontiers in Plant Science*, *9*(March), 1–16.

Saleha, R., Maria, K., and Kazi Alvina, G. (2015). Nanobiotechnology in Agricultural Development. *PlantOmics: The Omics of Plant Science*, 1–825.

Sarla, N., and Swamy, B. P. M. (2005). Oryza glaberrima: A source for the improvement of Oryza sativa. *Current Science*, *89*(6), 955–963.

Sasidharan, I., and Menon, A. N. (2010). Comparative chemical composition and antimicrobial activity fresh and dry ginger oils (Zingiber officinale Roscoe). *International Journal of Current Pharmaceutical Research*, *2*(4), 40–43.

Sasidharan, I., Venugopal, V. V., and Menon, A. N. (2012). Essential oil composition of two unique ginger (Zingiber officinale Roscoe) cultivars from Sikkim. *Natural Product Research*, *26*(19), 1759–1764.

Saxena, S., Banerjee, G., Garg, R., and Singh, M. (2014). Comparative study of biofilm formation in pseudomonas aeruginosa isolates from patients of lower respiratory tract infection. *Journal of Clinical and Diagnostic Research*, *8*(5), 9–11.

Sendanayake, L. R., Sylvester, T. P., De Silva, U. H. A. J., Dissanayake, D. R. R. P., Daundasekera, D. M. K. C., and Sooriyapathirana, S. D. S. S. (2017). Consumer preference, antibacterial activity and genetic diversity of ginger (Zingiber officinale Roscoe) cultivars grown in Sri Lanka. *Journal of Agricultural Sciences*, *12*(3), 207–221.

Shafiei, S. N. S., Ahmad, K., Ikhsan, N. F. M., Ismail, S. I., and Sijam, K. (2020). Suppression of Xanthomonas oryzae pv. oryzae biofilm formation by Acacia mangium methanol leaf extract. *Brazilian Journal of Biology*, *6984*, 1–7.

Shaheen, H. A., and Issa, M. Y. (2020). In vitro and in vivo activity of Peganum harmala L. alkaloids against phytopathogenic bacteria. *Scientia Horticulturae*, *264*, 108940.

Shankara, K., Patil, M. B., Pramesh, D., Sunkad, G., Yenjerappa, S. T., Ibrahim, M., L., R. N., and Chikkannaswamy. (2017). *Characterization of Xanthomonas oryzae pv . oryzae Isolates from Rice Growing Regions of Southern India*. *5*(4), 452–461.

Sharifi-Rad, J., Sureda, A., Tenore, G. C., Daglia, M., Sharifi-Rad, M., Valussi, M., Tundis, R., Sharifi-Rad, M., Loizzo, M. R., Oluwaseun Ademiluyi, A., Sharifi-Rad, R., Ayatollahi, S. A., and Iriti, M. (2017). Biological activities of essential oils: From plant chemoecology to traditional healing systems. *Molecules*, *22*(1), 1–55.

Sharifi-Rad, M., Varoni, E. M., Salehi, B., Sharifi-Rad, J., Matthews, K. R., Ayatollahi, S. A., Kobarfard, F., Ibrahim, S. A., Mnayer, D., Zakaria, Z. A., Sharifi-Rad, M., Yousaf, Z., Iriti, M., Basile, A., and Rigano, D. (2017). Plants of the genus zingiber as a source of bioactive phytochemicals: From tradition to pharmacy. *Molecules*, *22*(12), 1–23.

Sharma, J., Manjunatha, N., Pokhare, S. S., Patil, P. G., Agarrwal, R., Chakranarayan, M. G., Aralimar, A., Devagire, P., and Marathe, R. A. (2022). Genetic Diversity and Streptomycin Sensitivity in Xanthomonas axonopodis pv. punicae Causing Oily Spot Disease in Pomegranates. *Horticulturae*, *8*(5), 441.

Singh, A., Gupta, R., Tandon, S., and Pandey, R. (2017). Thyme Oil reduces biofilm formation and impairs virulence of xanthomonas oryzae. *Frontiers in Microbiology*, *8*(JUN), 1–16. https://doi.org/10.3389/fmicb.2017.01074

Singh, A., Gupta, R., Tandon, S., Prateeksha, and Pandey, R. (2018). Anti-biofilm and anti-virulence potential of 3,7-dimethyloct-6-enal derived from Citrus hystrix against bacterial blight of rice caused by Xanthomonas oryzae pv. oryzae. *Microbial Pathogenesis*, *115*(December 2017), 264–271.

Singh, R. A., Das, B., Ahmed, K. M., and Pal, V. (1980). Chemical control of bacterial leaf blight of rice. *Tropical Pest Management*, *26*(1), 21–25.

Singh Sekhon, B. (2014). Nanotechnology in agri-food production: An overview. *Nanotechnology, Science and Applications*, *7*(2), 31–53.

Son, S., An, H. K., Seol, Y. J., Park, S. R., and Im, J. H. (2020). Rice transcription factor WRKY114 directly regulates the expression of OsPR1a and Chitinase to enhance resistance against Xanthomonas oryzae pv. oryzae. *Biochemical and Biophysical Research Communications*, *533*(4), 1262–1268.

Soylu, E. M., Soylu, S., and Kurt, S. (2006). Antimicrobial activities of the essential oils of various plants against tomato late blight disease agent Phytophthora infestans. *Mycopathologia*, *161*(2), 119–128.

Subudhi, P. K., Sasaki, T., and Khush, G. S. (2006). *Rice* (Vol. 1). Genome Mapping and Molecular Breeding in Plants.

Sunder, S., Singh, R., and Agarwal, R. (2014). Brown spot of rice : an overview. *Indian Phytopath*, *67*(3), 201–215.

Sundin, G. W., Castiblanco, L. F., Yuan, X., Zeng, Q., and Yang, C. (2016a). Review Bacterial disease management : challenges , experience , innovation and future prospects Challenges in Bacterial Molecular Plant Pathology. *Molecular Plant Pathology*, *7*(20 16), 1506–1518.

Sundin, G. W., Castiblanco, L. F., Yuan, X., Zeng, Q., and Yang, C. H. (2016b). Bacterial disease management: Challenges, experience, innovation and future prospects: Challenges in bacterial molecular plant pathology. *Molecular Plant Pathology*, *17*(9), 1506–1518.

Suresh, S. R., Yenjerappa, S. T., Naik, M. K., Mallesh, S. B., and Kalibavi, C. M. (2013). Studies on cultural and physiological characters of Xanthomonas oryzae pv . oryzae causing bacterial blight of rice *. *Karnataka Journal of Agricultural Sciences*, *26*(2), 214–216.

Suryadi, Y., Susilowati, D. N., Kadir, T. S., and Ruskandar, A. (2012). Seed-Dipping Application of Local Endophytic Bacterial Consortium Against Bacterial Leaf Blight of Rice. *Jurnal Agrotropika*, *17*(1), 7–13.

Sweeney, M., and McCouch, S. (2007). The complex history of the domestication of rice. *Annals of Botany*, *100*(5), 951–957.

Syed-Ab-Rahman, S. F., Carvalhais, L. C., and Omar, D. (2020). Development of plant-based emulsion formulations to control bacterial leaf blight and sheath brown rot of rice. *Heliyon*, *6*(1).

Tabassum, N., and Vidyasagar, G. M. (2013). Antifungal investigations on plant essential oils. A review. *International Journal of Pharmacy and Pharmaceutical Sciences*, *5*(2), 19–28.

Talibi, I., Askarne, L., Boubaker, H., Boudyach, E. H., Msanda, F., Saadi, B., and Ait Ben Aoumar, A. (2012). Antifungal activity of some Moroccan plants against Geotrichum candidum, the causal agent of postharvest citrus sour rot. *Crop Protection*, *35*, 41–46.

Tao, C., Wang, Y., Zhang, X., Li, L., Wu, Y., Han, X., Jiang, X., and Lv, Z. (2019). Mechanism of action of essential oils extracted from bamboo (Phyllostachys heterocycla cv. pubescens) leaves: Chemical composition and antimicrobial activity against four food-related microorganisms. *Bioresources*, *14*(1), 1419–1434.

Teixeira, P. C., Leite, G. M., Domingues, R. J., Silva, J., Gibbs, P. A., and Ferreira, J. P. (2007). Antimicrobial effects of a microemulsion and a nanoemulsion on enteric and other pathogens and biofilms. *International Journal of Food Microbiology*, *118*(1), 15–19.

Trimanto, and Hapsari, L. (2018). Short communication: A new record of Etlingera megalocheilos (Griff.) A.D. Poulsen (Zingiberaceae) in Sulawesi, Indonesia. *Biodiversitas*, *19*(4), 1227–1235.

Tripathi, K. ., Warrier, R., Govila, O. ., and Ahuja, V. (2011). *Biology of Oryza sativa (Rice)* (pp. 1–577). Government of India.

Vaghefi, N., Nasir Shamsudin, M., Makmom, A., and Bagheri, M. (2011). The economic impacts of climate change on the rice production in Malaysia. *International Journal of Agricultural Research*, *6*(1), 67–74.

Vairappan, C. S., Nagappan, T., and Palaniveloo, K. (2012). Essential oil composition, cytotoxic and antibacterial activities of five Elingera species from Borneo. *Natural Product Communications*, *7*(2), 239–242.

Valentim, D. S. S., Duarte, J. L., Oliveira, A. E. M. F. M., Cruz, R. A. S., Carvalho, J. C. T., Conceição, E. C., Fernandes, C. P., and Tavares-Dias, M. (2018). Nanoemulsion from essential oil of Pterodon emarginatus (Fabaceae) shows in vitro efficacy against monogeneans of Colossoma macropomum (Pisces: Serrasalmidae). *Journal of Fish Diseases*, *41*(3), 443–449.

Vasireddy, L., Bingle, L. E. H., and Davies, M. S. (2018). Antimicrobial activity of essential oils against multidrug-resistant clinical isolates of the burkholderia cepacia complex. *PLOS ONE*, *13*(8), 1–26.

Venkateshwarlu G, J. K. A. (2014). Effect of Essential Oil and Aqueous Extract of Ginger (Zingiber Officinale) on Oxidative Stability of Fish oil-in-Water Emulsion. *Journal of Food Processing and Technology*, *06*(01), 1–5.

Villa, T. G., and Veiga-Crespo, P. (2014). Antimicrobial compounds: Current strategies and new alternatives. In *Antimicrobial Compounds: Current Strategies and New Alternatives* (Vol. 9783642404).

Wei, E., Chan, C., Lim, Y. Y., Azah, N., and Ali, M. (2010). Composition and Antibacterial Activity of Essential Oils from Leaves of Etlingera species (Zingiberaceae). *INTERNATIONAL JOURNAL FOR THE ADVANCEMENT OF SCIENCE and ARTS*, *1*(2).

Wong, C. K. F., Zulperi, D., Vadamalai, G., and Saidi, N. B. (2019). Phylogenetic Analysis of Fusarium oxysporum f . sp . cubense Associated with Fusarium Wilt of Bananas from Peninsular Malaysia. *Sains Malaysiana*, *48*(October), 1593–1600.

Wonni, I., Ouedraogo, S. L., Ouedraogo, I., and Sanogo, L. (2016). Antibacterial activity of extracts of three aromatic plants from Burkina Faso against rice pathogen, Xanthomanas oryzae. *African Journal of Microbiology Research*, *10*(20), 681–686.

Wu, K., Lin, Y., Chai, X., Duan, X., Zhao, X., and Chun, C. (2019). Mechanisms of vapor-phase antibacterial action of essential oil from Cinnamomum camphora var. linaloofera Fujita against Escherichia coli. *Food Science and Nutrition*, *7*(8), 2546–2555.

Xu, Y., Zhu, X. F., Zhou, M. G., Kuang, J., Zhang, Y., Shang, Y., and Wang, J. X. (2010). Status of streptomycin resistance development in xanthomonas oryzae pv. oryzae and xanthomonas oryzae pv. oryzicola in China and their resistance characters. *Journal of Phytopathology*, *158*(9), 601–608.

Yang, C., Powell, C. A., Duan, Y., Shatters, R., and Zhang, M. (2015). Antimicrobial nanoemulsion formulation with improved penetration of foliar spray through citrus leaf cuticles to control citrus huanglongbing. *PLoS ONE*, *10*(7), 1–14.

Yang, Z., Yang, W., Peng, Q., He, Q., and Feng, Y. (2009). *Volatile phytochemical composition of rhizome of ginger after extraction by headspace solid-phase microextraction , petroleum ether extraction and steam distillation extraction*. 136–143.