Development of the Duckweed Holobiont Resource Values towards Thailand BCG Economy

Japanese side: **Hokkaido U**, Tohoku U, U Yamanashi, Kyoto U, Osaka U, National Institute for Environmental Studies (NIES), Saraya Co. Ltd.

Thai side: **Kasetsart U**, Mahidol U, Khon Kaen U, Chulalongkorn U, Nakhon Pathom Rajabhat U, Ramkhamhaeng U, NBT, BIOTEC, NANOTEC, NSTDA, ADGreen

Period of Project: October 2021 - September 2026 (5-year)

Be-HoBiD

Previous Achievement (2022)

Be-HoBiD

Research Grant: 2021-2022 6,559,100 THB, 400,000 JPY

Publications:

1. Saimee et al. 2021. **IJSEM**, 71 (11): 005106.
2. Yoksan et al. 2022. **Int J Biol Macromol** 203: 369–378.
3. Duangjarus et al. 2022. **Foods**, 11, 2348.

Conference:

1. The 14th Botanical Conference of Thailand, Khon Kaen University, 11-12 June 2022
2. International Conference of Genetics Society of Thaland (iGST2022), 21-22 June 2022.
3. Proceeding of the 11th International Conference on Environmental Engineering, Science and Management, Environmental Engineering Association of Thailand, 12 May 2022
4. The Proceedings of the 59th KU Annual Conference, 2002. 655-662

Project Monitoring Sheet I (2023)

(Annex 1-1, 1-2 Form 3-2)

(Annex 1-1, 1-2 Form 3-2)

Narrative Summary	Objectively Verifiable Indicators	Means of Verification	Achievement
Overall Goal			
Research activities at the Duckweed Holobiont Resource & Research Center (DHbRC) are continued and further developed, and the research activities will be applied to biological resources other than duckweed, so that the project's contribution to the Bio-Circular-Green (BCG) 2 economy will be recognized.	1. Number of cases where DHbRC provided host organisms, associated microorganisms (groups), DNA sequence data, and related information (at least 10 cases related to duckweed) (at least 5 cases other than duckweed)	>DHbRC and related organizations' materials >Interviews with DHbRC and related organizations	
	2. Number of technologies and cases applied socially by DHbRC and related organizations (at least 3)		
	3. Amount of R&D funding (budget) and project funding (budget) acquired by DHbRC and related organizations (3M THB)		2022 = 4,559,100 THB (KURDI), 400,000 JPY (Kurita Water and Environment Fund); 2023 = 300,000 THB (KURDI)

(Annex 1-1, 1-2 Form 3-2)

Narrative Summary	Objectively Verifiable Indicators	Means of Verification	Achievement
Project Purpose			
A research development base is established for the development of duckweed industrial technology and its practical use which contributes to Thailand BCG economy.	1. Number of human resources trained (at least 20)	>Project report >Monitoring report >Interview, survey and materials from related entities	Training in Japan Long term: G3:4pp Short term: G1:2pp, G2:1pp, G3:3pp, G4-2:2pp, G4-3:1pp, G4-4:1pp, G5:1pp, G6:1pp
	2. Number of valuables developed using duckweed holobiont resources (at least 3)		
	3. Number of entities (universities, government agencies, companies) and a number of individual farmers for which DHbRC provided duckweed, associated microorganisms, DNA sequence data, and related information (at least XX entities, at least 3 individuals).		
	~~4. Number of technical manuals and proposals to promote the duckweed industry (at least XX)~~		Deleted OVI.4 in the PDM version 1.2

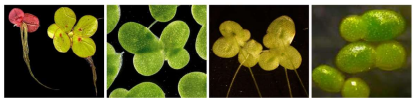
(Annex 1-1, 1-2 Form 3-2)

Narrative Summary	Objectively Verifiable Indicators	Means of Verification	Achievement
Outputs			
1. Duckweed Holobiont Resource & Research Center (DHbRC) is established at Kasetsart University.	1. Establishment of DHbRC	>Project report >Established DHbRC >DHbRC's homepage >Constructed duckweed plant factory in DHbRC >Interviews with DHbRC and research groups	DHbRC laboratory and office are established. JICA 1st batch equipment were delivered and operational (22 items). Procurement of JICA 2nd batch equipment is underway.
	2. Construction of a duckweed plant factory in DHbRC		
	3. Quantity of produced duckweed holobiont biomass to supply to the research groups (adequate amount for research requirement)		
	4. Establishment of functions and services of DHbRC as a common laboratory		

(Annex 1-1, 1-2 Form 3-2)

Narrative Summary	Objectively Verifiable Indicators	Means of Verification	Achievement
2. Duckweed holobiont collection is created	1. Number of preserved individual duckweeds, associated microorganisms, associated microbial communities, and their DNA sequence data (at least 20 plant specimens, 400 microbial strains, 20 microbial communities, 400 DNA sequence data)	>Project report >Created catalog >Published academic papers related to the project	
	2. Creation of a catalog of preserved organisms and relevant information		
	3. Number of academic papers (including peer-reviewed conference proceedings) published (at least 5)		1 Publication (AIMS Microbiol.), 2 Manuscript (in prep)

G2 Biodiversity of Thai Duckweed Species

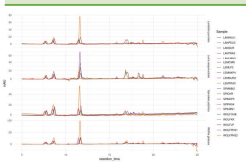


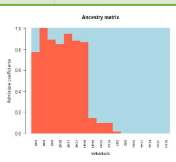
2020-2023 Output

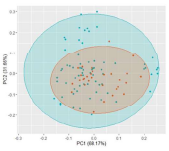
- Funding KURDI FF(KU)4.64, 65
- Data
  - 126+ DNA sequences
  - Ecological data from 10 sites
  - Morphology from 42 plants
  - HPLC profiles for 4 species
  - LC MS/MS QTOF data for 4 species
- Research
  - 2 prepared MS
  - 2 Bachelor's Thesis
  - 1 PhD Student, 1 MS Student
- Awards/Talks
  - 1 National Conference Award
  - 2 National Conference Talks
  - 1 International Internship
  - 1 International Conference

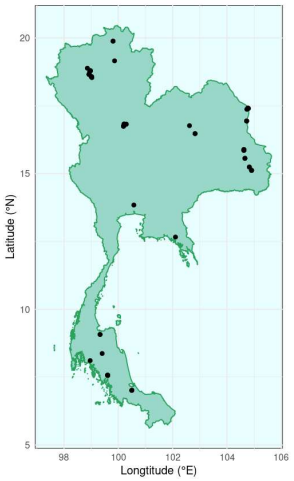
Research Plan

Topic	2020		2021		2022		2023	
Collection	x	x	x	x	x	x	x	x
Morphology		x	x	x	x			
Ecology		x	x	x				
Genetics	x	x	x	x	x			
Phytochemicals						x	x	x









Ekaphan Kraichak
Group PI

Athita Senayai
PhD Student

Siwaporn Jansantia
MS Student

G2-2 Biodiversity of duckweed associated microbes


Assoc. Prof. Dr. Kannika Duangmal
(PI; Actinobacteria)
Dept. Microbiology, Fac. Science, KU


Assist. Prof. Dr. Chanita Boonmak
(Bacteria)
Dept. Microbiology, Fac. Science, KU


Assoc. Prof. Dr. Nantana Srisuk
(Yeast)
Dept. Microbiology, Fac. Science, KU


Assist. Prof. Dr. Pannida Khunnamwong
(Yeast)
Dept. Microbiology, Fac. Science, KU

Microbes	no. of isolates in collection	Species identification	PGP abilities
Bacteria	880	249	46
Actinobacteria	573	151	573
Yeast	252	252	252
Total	**1,705**	**652**	**871**

Y1 → Y2 → Y3 → Y4 → Y5

Culture of duckweed-associated microbiota
Living microbial bioresources

Database of microbial community
Species identification and classification

PGP traits data
Characterization of PGP abilities to enhance duckweeds biomass production, starch/protein production

Database of duckweed associated microbes
Ecology and taxonomy

Library of duckweed-microbe holobionts
Co-cultivation data for high-yield production of starch-rich and protein-rich duckweed biomass

The world first biobank of duckweed holobionts

Basement to establish duckweed-based BCG economy in Thailand

Current output 2023
Publication : 1
Submitted manuscript : 1
Manuscript : 1
Master students : 3

Output 2021-2022
KU Graduate School Scholarship, 2022
Fundamental Fund, KURDI, 2022
Publication: 1
Master students : 3

(Annex 1-1, 1-2 Form 3-2)

Narrative Summary	Objectively Verifiable Indicators	Means of Verification	Achievement
3. Technology base is developed for function enhancement of the duckweed holobiont.	1. Number of potential duckweed holobionts for function enhancement and wastewater treatment (at least 10)	>Project report >Published academic papers related to the project	
	2. Number of omics 6 databases of duckweed and associated microorganisms at DHbRC (at least 5)		1 duckweed genome data with long-read and short-read data
	3. Number of analyses of duckweed and associated microorganisms' interaction (at least 2)		
	4. Number of technologies developed for improvement of duckweed holobionts for growth/stress tolerance (at least 2)		
	5. Number of active substances discovered/identified (at least 5)		
	6. Number of academic papers (including peer-reviewed conference proceedings) published (at least 10)		1 Publication (Plants), 3 Manuscript (in prep)

G3-1: Duckweed-Microbe Interaction

PI
Prof. Dr. Arinthip Thamchaipenet
Genetics, Science, KU

Research Team
Peerapat R, Passorn W, Chanita B, Waraporn A, Mayura V, Roypim T, Kantinan L, Nattika S

Be-HoBiD

Duckweed collection
- Natural water, WW

Duckweed Microbiomes
- Metagenome analysis

Duckweed genome analysis

Isolation and characterization of duckweed associated microbes from WW

Short-read/ Long-read sequencing

Selection of duckweed-microbe interaction for WW treatment

Transcriptome/metabolome analyses towards growth, nutrition, stress, and WW treatment by duckweed-microbe interaction

plants MDPI

Article

Dynamic Alteration of Microbial Communities of Duckweeds from Nature to Nutrient-Deficient Condition

Chakrit Bunyoo [1,2,3], Peerapat Roongsattham [2,3], Sirikorn Khumwan [2,3], Juthaporn Phonmakham [2,3], Passorn Wonnapinij [2,3,4] and Arinthip Thamchaipenet [2,3,4,*]

4 Manuscripts in prep

1 Post-Doc
1 PhD
1 MS
1 RA

Faculty of SCIENCE

G3-2 Active Substances Team


Witcha Imaram (PI)


Pakorn Wattana-Amorn


Pitak Chuawong


Wanchai Pluempanupat

2022 → 2023 → 2024 → 2025 → 2026

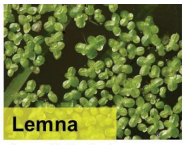
To compare metabolic profiles of duckweeds using NMR and MS-based approaches

Outputs
- Two M.Sc. and one Ph.D. Students
- Fundamental Fund, KURDI, 2022
- KU Graduate School Scholarships, 2021 &2023.

To determine active substances from duckweed holobionts actions and metabolomics

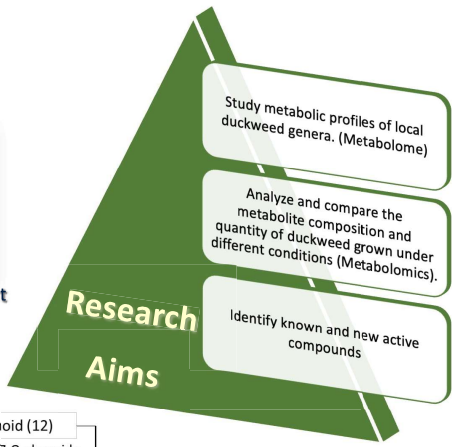
To investigate duckweed holobionts as bioremediation for pesticide degradation


Landoltia
Source : Asit K Gosh


Lemna
Source : Markku Savela


Spirodela
Source : Etsy


Wolffia
Source : NC state UNIVERSITY



Identified Active Compounds

Flavonoid (12)
Pratensein-7-O-glucoside
Glucosylvitexin
Homoorientin
Tectoridin
Puerarin
Luteoloside
Vitexin
Apigenin
Genistin
Orientin
Luteolin
Diosmetin

Terpenoid (5)
Campesterol
Sclareol
Resibufogenin
Blinin
Asiatic acid


Spirodela polyrhiza

Phenolic (9)
3-Hydroxybenzaldehyde
2-(2-Hydroxyethoxy)phenol
3-Coumaric acid
Pinoresinol-glucoside
Neochlorogenic acid
p-Coumaric acid
Protocatechuic acid
Cryptochlorogenic acid
α-Mangostin

Alkaloid (4)
Coniine
Piperine
Neferine
Adenine

(Annex 1-1, 1-2 Form 3-2)

Narrative Summary	Objectively Verifiable Indicators	Means of Verification	Achievement
4. Technology base is developed for manufacturing valuables using duckweed as a raw material.	1. Number of technologies developed for manufacturing valuables using duckweed as a raw material (at least 3)	>Project report >Published academic journals related to the project	2 Thai petty patents
	2. Number of products of verified selected valuables at the laboratory level or bench plant scale (at least 3)		
	3. Number of academic papers (including peer-reviewed conference proceedings) published (at least 5)		4 Manuscript (in prep)

G4-1 BioFUEL : methane

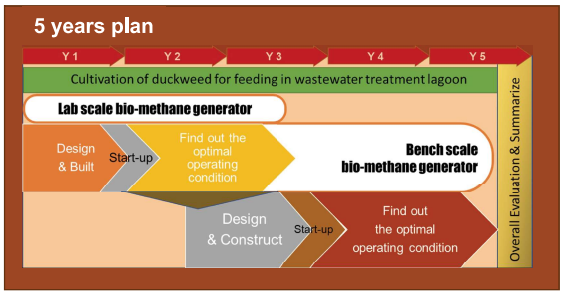

Assoc. Prof. Pairaya Choeisai, D. Eng.
Principal Investigator


Thanapat Thepubon, M. Eng.
Research Assistant


Zhafirah Meuthia Ardhana, M.Eng
Master degree student (graduated)

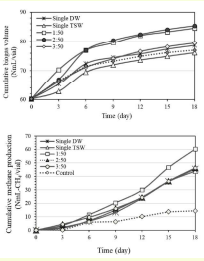

Sunisa Srisopa, B.Eng
Master degree student

Group Target : Bio-fuel (bio-methane) production from Thai duckweed cultivated by wastewater



https://www.jica.go.jp/Resource/project/english/thailand/044/index.html

Output during October 2022 –September 2023



1) Established duckweed supply system at KKU (harvesting >200 g DW/week)

2) Set up Laboratory-scale reactors (ready for experiments)

3) Started-up the reactors (finished and continuing the experiments for the steady-state)

4) Obtaining the data of DW methane fermentation under different operation conditions

5) Thesis

- Ardhana, M. Z. (2023). Evaluation of Methane Production Potential from Duckweed(Spirodela Polyrhiza) and Tapioca Starch Factory Wastewater as Co-Substrates [Master's Thesis, Khon Kaen University]

6) Manuscript

- Choeisai P, Ardhana, M. Z., Thepubon T., Kubota K., 2023. Duckweed as a Co-Substrate for Methane Production from Tapioca Starch Factory Wastewater. (in prep)

7) Graduate students and scholarships for students

- **Ms. Zhafirah Meuthia Ardhana** : scholarship student from Indonesia AY 2021-2022 graduated master degree in time of 2 years, supported scholarship by Khon Kaen University (KKU) scholarship for ASEAN & GMS Countries' Personnel for Master student, 2021-2022 = 228,000 THB (2y), Supported research grant for master degree student 15,000 THB (2y)**Graduated**
- **Ms. Sunisa Srisopa** : scholarship for enhance productivity of Master degree student from Faculty of Engineering, KKU, 2023-2024 = 120,000 THB (2y) and Teaching Assistance Scholarship from Graduate School, KKU year 2023 = 30,000 THB (1y), **Studying**

G4-2: Bioplastics from duckweed biomass

PACKAGING & MATERIALS TECHNOLOGY AGRO-INDUSTRY

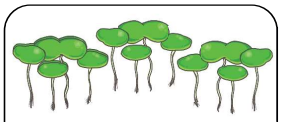
GOALS:
1. To add the value and expand the applications in bioplastics of duckweed (DW) biomass
2. To reduce the cost of bioplastics by replacing with renewable low-cost DW materials which has little impact on the food chain

Year 1 | Year 2 | Year 3 | Year 4 | Year 5

Basic research — *Technology development*

Research to feasibility (proof of concept) — *Prototype development*

1 Fabrication of DW-based bioplastics with improved performances



Duckweed biomass (DW)
- Municipal and agricultural wastewater stream-treated DW
- Low cost cultivation DW

Renewable and sustainable feedstock for bioplastics

2 Investigation of the relationship between the composition and properties of the obtained DW-based bioplastics

+ Other components

Technologies:
- Direct plasticization
- Blending with other bioplastics and/or commodity plastics

DW-based bioplastic resins/pellets

Possible plastic converting processes
- Injection molding
- Compression molding
- Sheet extrusion & thermoforming

3 Preparation of product prototype of DW-based bioplastics

DW-based bioplastic prototypes/ products

4 Evaluation of preliminary cost of DW-based bioplastics

PI:
Assoc. Prof. Rangrong Yoksan
Department of Packaging and Materials Technology, Faculty of Agro-Industry, Kasetsart University

RA:
Dr. Dang Minh Khanh
(Post-doc)

RA:
Miss Apinya Boontanimitr
(Post-master)

Outputs:
1. Publication: Yoksan R, Boontanimitr A, Klompong N, Phothongsurakun T. 2022. Poly(lactic acid)/ thermoplastic cassava starch blends filled with duckweed biomass. Int J Biol Macromol 203: 369–378.
2. Prototypes from DW-based bioplastic

Group: G4-3 Animal feed

Researcher team

Asst. Prof. Dr. Chanwit Kaewtapee
Department of Animal Science, Faculty of Agriculture, Kasetsart University, Bangkok

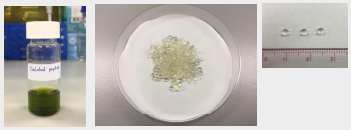
Asst. Prof. Dr. Sirinapa Chungopast
Department of Soil Science, Faculty of Agriculture, Kasetsart University, Nakhon Pathom

Ms. Hathaipat Thongthung
(Master Degree Student in Animal Nutrition)
Department of Animal Science, Faculty of Agriculture, Kasetsart University, Bangkok

Dr. Nattika Saengkrit
National Nanotechnology Center National Science and Technology Development Agency

Dr. Kantinan Leetanasaksakul
National Center for Genetic Engineering and Biotechnology
National Science and Technology Development Agency

Research plan and out put

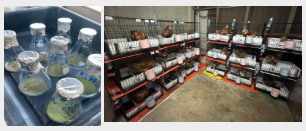


To isolate protein and encapsulate it release at lower GI-tract.

To study gut microbiome.

5

4



To study *In vitro* / *In vivo* digestibility

3

To study effect of duckweed on production performance and egg quality

2

1

To analysis nutrient compositions

Asst. Prof. Dr. Suvimol Charoensiddhi
(Dept. Food Science and Technology, Fac. Agro-industry, KU)- **PI**

Assoc. Prof. Dr. Massalin Nakphaichit
(Dept. Biotechnology, Fac. Agro-Industry, KU)- **Member**

Assoc. Prof. Dr. Wanwipa Vongsangnak
(Dept. Zoology, Fac. Science, KU)- **Member**

Asst. Prof. Narissara Suratannon, M.D.
(Dept. Pediatrics, Fac. Medicine, CU)- **Member**



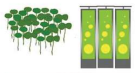

KU KASETSART UNIVERSITY

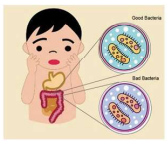
G4-4 Functional food

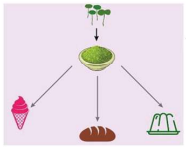
Aims & Plan:

1. Active-enriched components from duckweed leading to health benefits is developed.
2. Functional food applications are produced from duckweed active-enriched components.

Y1	Y2	Y3	Y4	Y5
1.1 **Collection and preparation** of duckweed **raw materials** 1.2 Development of **production processes** for duckweed active-enriched components	1.3 Investigation of **digestibility** of active-enriched components in simulated human digestive system 1.4 Assessment of **health benefits** 1.5 **Characterization** of major compositions	1.4 & 1.5 Continue 2.1 Development of **up-scale production process** for active-enriched components 2.2 Study of **physicochemical and functional properties** in food model	2.2 Continue 2.3 Assessment of **acute and subchronic toxicity** of active-enriched components in an *in vivo* model	2.4 Development of **functional food applications**





Key output: **Digestibility and health benefits (anti-microbial activity and gut microbiome modulation) of duckweed and its protein and polysaccharide extracts. 2 Manuscripts, 1 oral presentation, and 1 Master student.**

(Annex 1-1, 1-2 Form 3-2)

Narrative Summary	Objectively Verifiable Indicators	Means of Verification	Achievement
5. Low-carbon effect of the water purification system using duckweed holobiont is verified.	1. Energy saving rate of the entire system (Energy consumption lower than the Business-As-Usual (BAU))	>Project report >Created database/handbook >Published academic journals related to the project	
	2. Amount of green-house-gas (GHG) emission reduction (GHG emission lower than the BAU)		
	3. Database/handbook for design and operation management of duckweed holobiont water purification system		
	4. Number of academic papers (including peer-reviewed conference proceedings) published (at least 5)		1 Book Chapter (in prep), 1 Manuscript (in prep), 2 Proceedings

G5: Duckweed-based wastewater treatment

PI: Chart Chiemchaisri, *Dept. Environmental Eng. Faculty of Eng*
Team: Wilai Chiemchaisri, 3 Post-doctoral researcher, 2 graduate students (1 Ph.D., 1 master)



2021	2022	2023	2024	2025	2026
Preparation	Evaluate duckweed base WWT performance at laboratory scale using livestock farm & food processing WW		Practical water purification of duckweed based WWT at bench or field scale operation at targeted WW source		Database & guidelines of technology
			Dissemination of research results		

Main findings (Oct22-Sep23)

- Appropriate duckweed species: *Spirodela sp.* for farm WW, *Lemna sp.* for food factory WW.
- Appropriate duckweed growth condition. 25-50% influent, 100% effluent, HRT 4-7 days, 75% initial duckweed coverage, 2-3 times/week harvesting
- WWT performance: Organic removal 60-90%, TN removals 30-60%
- Duckweed adaptation to survive higher WW conditions after appropriate microbial cultivation.

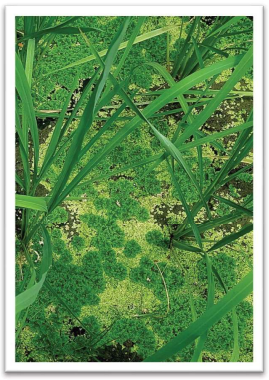
Research output (up to Sep 23)

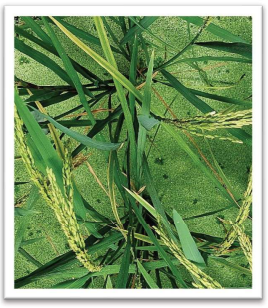
- Book chapter: C. Chiemchaisri, W. Chiemchasri, L. Saksukol, C. Chandaravithoon, C. Witthayaphirom, V. Boonyaroj, T. Toyama, K. Mori, M. Morikawa, Duckweed-based waste stabilization ponds for wastewater treatment, In: Low-cost Water and Wastewater Treatment Systems, Elsevier (in press)
- Int. journal: W. Chiemchaisri, C. Chiemchaisri, L. Saksukol, T. Chanhaworn, K. Chuanprakop, T. Toyama, K. Mori, M. Morikawa Duckweed growth and pollutant removals in influent and effluent of condiments processing wastewater treatment system, Agriculture and Natural Resources journal (submitted)
- 2 conference proceeding disseminated at National Environmental Conference (May 2023)

(Annex 1-1, 1-2 Form 3-2)

Narrative Summary	Objectively Verifiable Indicators	Means of Verification	Achievement
6. Support for duckweed production in farms and practical application of technology using duckweed are promoted.	1. Number of publication/dissemination/public relations activities of results from each research group (at least 3)	>Project report	
	2. Number of support activities for duckweed production (at least 3)	>Dissemination and public relations activity reports >Created technical manuals and proposals	
	3. Number of created technical manuals and proposals of technology using duckweed (at least 3)		

Duckweed cultivation for farmers at Suphanburi





Be-HoBiD Output 2023

(Annex 2)

Publications:

1. Bunyoo C, Roongsattham P, Khumwan S, Phonmakham J, Wonnapinij P, **Thamchaipenet A.** 2022. Microbial communities of duckweeds in nature and in nutrient deficient condition. **Plants**. 11, 2915.
2. Kajadpai N, Angchuan J, Khunnamwong P, **Srisuk N**. 2023. Diversity of duckweed (Lemnaceae) associated yeasts and their plant growth promoting characteristics. **AIMS Microbiology.** 9(3): 486-517.

Manuscript (in prep):

1. Senayai, A., **Kraichak, E**. 2023. Species-specific chemical profiles of some duckweed species in Thailand, using HPLC and LC-QTOF-MS techniques. Phytochemistry (in prep).
2. Senayai, A. **Kraichak, E**. 2023. Genetic and morphological variation among populations of duckweed species found in Thailand. Plants. (in prep.).
3. Saimee, Y., **Boonmak, C**. and **Duangmal, K.** 2023 *Actinomycetospora lemnae* sp. nov., a novel actinobacterium isolated from *Lemna aequinoctialis* able to enhance duckweed growth. **Current Microbiology**. (in revision)
4. Duckweed associated bacteria as plant growth-promotor to enhance growth of *Spirodela polyrhiza* in wastewater effluent from a poultry farm (in prep)
5. Bunyoo C, Phonmakham J, **Thamchaipenet A**. 2023. High resolution profiling of microbial communities associated with duckweed, *Landoltia punctata* using full-length 16S rRNA sequencing. Phytobiomes J. (in prep).

Be-HoBiD Output 2023

(Annex 2)

Manuscript (in prep):

6. Bunyoo C, Thananusak R, Phonmakham J, **Thamchaipenet A**. 2023. Characterization of plastome sequences of the tiniest duckweed, *Wolffia globosa,* using long-read technology. BMC Genomics (in prep)

7. **Roongsattham P**, Khumwan S, **Boonmak C, Thamchaipenet A**. 2023. Plant growth promoting bacteria for promoting *Lemna aequinoctialis* growth (in prep)

8. Narsing Rao, MP, Thananusak, R, Bunyoo, C, Phonmakham, J, **Morikawa, M, Thamchaipenet, A** 2023. Microbial partnerships in duckweed ecosystems: A comprehensive review. Molecular Plant-Microbe Interaction (in prep).

9. Wacharakorn, P., **Peerapat, R., Imaram, W**. 2023. Metabolomic study of the effect of sucrose on *Spirodela polyrhiza* chemical profile (in prep)

10. **Choeisai P**, Ardhana, M. Z., Thepubon T., **Kubota K**. 2023. Duckweed as a co-substrate for methane production from tapioca starch factory wastewater (in prep)

11. **Yoksan R**, Boontanimitr A 2023. Effect of calcium carbonate on the performance of poly(butylene adipate-co-terephthalate) filled with duckweed biomassEffect of calcium carbonate and titanium dioxide on properties of biodegradable polyesters filled with duckweed biomass. **Indust Crop Prod** (in revision)

12. Khanh DM, **Yoksan R, Matsumoto K, Morikawa M**. 2023. Duckweed biomass as alternative to cassava starch in manufacturing of TPS/PHBV/PBAT ternary blend (in prep).

Be-HoBiD Output 2023

(Annex 2)

Manuscript (in prep):

13. Thongthung, H., Chungopast, S., **Kaewtapee, C.** 2023. Chemical composition and In vitro protein digestibility of duckweed and feed ingredients. (in prep)

14. Dhamaratana S., Methacanon P., **Charoensiddhi S.** 2023. Chemical composition and in vitro digestibility of duckweed (*Wolffia globosa*) and its polysaccharide and protein fractions. Plant Foods for Human Nutrition (in prep)

15. **Charoensiddhi S.**, Natchaya D., Weerachai C., Chitsiri R., Roytrakul S. 2023. Synthesis and characterization of peptides derived from duckweed (*Wolffia globosa*) for enhancing antimicrobial properties. Food Control (in prep)

16. **Chiemchaisri C, Chiemchaisri W**, Saksukol L, Chandaravithoon C, Witthayaphirom C, Boonyaroj ., 2022. Duckweed based waste stabilization ponds for wastewater treatment. In “Low Cost Water and Wastewater Treatment Systems: Conventional and Recent Advances”, Elsevier (in prep).

17. Saksukol L, **Chiemchaisri W, Chiemchaisri C.** 2023. Duckweed growth and pollutant removals in influent and effluent of food processing wastewater treatment. Thai Environmental Engineering Journal (in prep)

Be-HoBiD

(Annex 2)

Be-HoBiD Output 2022 (Annex 3)

Conference:

1. Bunyoo C, **Roongsattham P**, Khumwan S, Phonmakham J, **Thamchaipenet A** 2023. Exploration of bacterial communities associated with duckweeds using short- and long-read metagenomics. **The 5th ICoBio2023, Bogor, Indonesia** (Oral presentation).
2. Thongthung H, Chungopast S, **Kaewtapee C**. 2022. Chemical composition and in vitro protein digestibility of duckweed. **The 11th National Animal Science Conference of Thailand**.
3. Development of functional ingredients from duckweed *Wolffia globosa* for gut microbiome modulation. **"International Joint Seminar 2022" between Sejong University-Shinshu University-Kasetsart University**.
4. Chandaravithoon C, Sutthasil N, **Chiemchaisri W, Chiemchaisri C.** 2023. Effect of organic pollutant concentrations on duckweed growth during piggery wastewater treatment using duckweed holobiont. **Proceeding of the 12th International Conference on Environmental Engineering, Science and Management**, 17-18 May 2023, Pattaya, Thailand.
5. Saksukol L, **Chiemchaisri W, Chiemchaisri C.** 2023. Duckweed growth and organic removals in influent and effluent of activated sludge wastewater treatment plant of food processing industry. **Proceeding of the 12th International Conference on Environmental Engineering, Science and Management**, 17-18 May 2023, Pattaya, Thailand.

No. of postgrad students & RA: 12 MS, 5 PhD, 5 Post-doc, 4 RA

(Annex 2)

Be-HoBiD Output 2023

Research grant:

1. Fundamental Fund, KURDI, KU 2022 = **4,574,100** THB
2. SRU, KU 2022 = **300,000** THB
3. Kurita Water and Environment Fund 2022 = **400,000** JPY
4. Research Grant for New Scholar, KURDI, KU 2023 = **300,000** THB

Scholarship:

1. Canada-ASEAN scholarships and Educational Exchange for Development (SEED), EduCanada (Ph.D)
2. Post-Doc Scholarship, KU Reinventing U 2022 = **590,000** THB (1y)
3. KU Graduate School Scholarship 2021-2024 = **800,000** THB (2y) (4x)
4. KU Graduate School Scholarship 2022 = **300,000** THB (3y)
5. Post-Doc Fellowship, KU 2022 = **480,000** THB (1y)
6. Doctoral Scholarship from Fac. Engineering, KU 2022 = **786,000** THB (3y)
7. KKU scholarship for ASEAN & GMS Countries 2021 = **228,000** THB (2y)
8. Scholarship from Fac. Engineering, KKU 2023 = **120,000** THB (2y)
9. TA Scholarship, KKU 2023 = **30,000** THB (1y)

Awards: Good level academic oral presentation award, **The 11th National Animal Science Conference of Thailand (2022)**

Awards : The 11 national animal science conference of Thailand 2023

Good level academic oral presentation award