DUCKWEED - AQUATIC MONOCOT CROP - A POTENTIAL SOLUTION TO THE PROBLEM OF GLOBAL POPULATION EXPLOSION

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Abstract

The worldwide population explosion (estimated 9.7 billion people in 2050) has caused humans to face enormous challenges of environmental pollution (soil, water and air), depletion of natural resources and fossil fuels as well as food security issues. Moreover, global climate changes also make problems more serious. The area of arable land is shrinking while the food demand for livestock and humans is increasing. Research, discovery and use of new plant varieties, especially aquatic plants, to reduce pressure on the need for arable land is the attention of scientists towards a green, clean and sustainable agriculture. Since the beginning of the 21st century, duckweed has been attracting the attention of scientists around the world due to its unique biological characteristics such as being a floating plant; has the fastest growth rate among flowering plants (the biomass could be doubled within 16-24 hours); high ability of N, P and heavy metal absorption, producing large biomass, high nutritional content,..... In this article, current applied advances in duckweed have been compiled as well as the achievements of Vietnamese biologists in general and our research group in particular in international effort.

Keywords: biofuel, duckweed, animal feed, water treatment.

1. INTRODUCTION

Duckweed is a monocotyledonous plant, small in size but has the fastest growth rate among flowering plants. Along with high biomass growth rate, biomass from duckweed contains high protein content and is an important food source for livestock. In particular, duckweed grown on ponds and lakes has become a component of the garden-pond-barn model without affecting the area of land for growing traditional food crops. In addition, duckweed is also a popular aquatic plant used to clean wastewater sources. Because of its unique characteristics compared to other crops, duckweed is increasingly receiving research attention from scientists in many countries around the world. The research not only focuses on decoding the genome but also addresses many other issues such as studying the nature of the process of forming turions, the ability to respond to adverse conditions and the more important is their role in biofuel production, human food, animal feed, wastewater treatment...

On the other hand, since the 18th century, the world population has seen a rapid increase; population growth will continue for decades, to 9.7 billion in 2050 and 11.2 billion in 2100. With the rapid population growth, mankind faces environmental and social problems such as shortages of all resources,starvation, pollution, etc... Due to its special biological characteristics (as mentioned above), duckweed can contribute to alleviating some of the most important problems facing mankind such as to supply good quality and quantity protein for feed and food, to clean wastewater, and to produce renewable energy in a sustainable way.

Even though the potential application of duckweed was investigated all over the world, in Vietnam, the research on this topic is still limited. Therefore, this article will update some research directions on duckweed in the world as well as the potential for research and application in Vietnam.

2. BIOLOGICAL CHARACTERISTICS OF DUCKWEED

Duckweed is a group of aquatic monocotyledonous plants with a very wide distribution, fast growth rate, high economic potential and is of interest in basic research. Currently, the subfamily Lemnoideae has 36 species belonging to 5 genera: Spirodela, Landoltia, Lemna, Wolffia and Wolffia (Bog et al., 2020).

The genome size of the species is very different (from about 150 Mbp in Spirodela polyrhiza to 1881 Mbp in Wolffia arrhiza) (Fig. 1). Duckweed has an extremely simple body structure consisting of leaves, a poorly differentiated stem and roots (Spirodela, Landoltia and Lemna) or no roots (Wolffia and Wolffia) (Cao et al., 2015). In addition to differences in genome size, the number of the chromosome sets of duckweed species is also very variable. However, most species have a chromosome set of 2n = 40 (the number of chromosomes of species ranges from 20-126 (Hoang et al., 2022; Landolt, 1987; Wang et al., 2011).

Fig. 1. Representative species of 5 duckweed genera with corresponding genome sizes (Hoang et al., 2019)
The geographical distribution of duckweed is shown by Landolt's research results in 1986 (Fig. 2). It's easy to see that, 30 years ago, scientists discovered the presence of duckweed on all continents, except the poles. That trait demonstrates the ability of duckweed to adapt to different climates, from the Siberian tundra to the Amazon rainforest, without significant phenotypic differences (Lam et al., 2014).

Duckweed is distributed throughout the world but is most common and diverse in tropical and subtropical areas. In temperate and cold regions, they mainly thrive in the summer months. Duckweed often appears in areas with stagnant water or slow currents. Rapid growth is often recorded in small ponds and swamps because these are areas with abundant nutrients. Especially in areas where crocodiles live, the growth rate of duckweed is maximum. Some species also exist in saline water (maximum 2.5% NaCl for *Lemna minor*), however they do not accumulate Na+ ions during growth (FAO, 1999).

Under optimal growing conditions (water temperature, pH, lighting, nutrient source), duckweed can double its biomass within 16-24 hours, therefore with an initial amount of only 10 cm², duckweed can cover 1 hectare after only 50 days and up to 32 hectares after 60 days (FAO, 1999). Several researches were performed to investigate the effect of water depth, coverage rate and harvest regime on the performance of a duckweed-based pilot-scale system; to obtain preferable conditions for high-protein duckweed production and wastewater treatment. The main advantages of duckweed over other aquatic plants used in effluent treatment are the high growth rate, easy harvesting, high protein and high starch content of the biomass (Zhao et al., 2014b).

**Fig. 2.** Distributions of several duckweed species worldwide with *Spirodela polyrhiza*, *Lemnoides aequinoctialis* and *Wolffia globosa* were found in Vietnam. (Redrawn from Landolt, 1986 (Cao et al., 2020))

3. THE ROLE OF DUCKWEED IN PLANT BIOLOGY STUDIES

"Darwinian Demon" is a term used to refer to creatures that are able to reproduce almost immediately after birth, have the healthiest physiological state and are considered eternal. Using quantitative analysis methods to study *S. polyrhiza*, scientists have proven that duckweed is the angiosperm species with the fastest growth rate compared to body ratio. Therefore, duckweed is used to illustrate the concept of "Darwinian Demon" (Kutscher and Niklas, 2015).

Since the 1960s, William Hillman had convincing commentary on the use of duckweed - a plant belonging to the Lemnaceae family - as a model plant for research on plant biology. Fast growth cycle, small body size, simple structure and easy radioactive labeling of the entire body are the outstanding advantages of duckweed compared to other plants. Therefore, based on Hillman's arguments, duckweed has been widely used in plant biology research and has helped scientists discover the auxin biosynthesis process as well as the sulfur assimilation pathway from the 60s to the 80s of the twentieth century (Lam et al., 2014).

Despite the fact that duckweed was one of the first subject to be cloned, the difficulties in establishing studies on the entire genetic information as well as the unclear correlation between duckweed and other traditional agricultural species are the main reason for decreasing interest of researchers and other funding sources in this species. Therefore, in the past 30 years, new model plants such as Arabidopsis, maize and rice have been widely used in plant research, while duckweed has only been used in a few studies on environment effects (Lam et al., 2014).

However, in the past decade, sustainable agricultural development has become an urgent requirement to limit the impacts of climate change as well as provide new sources of animal feed. And once again, duckweed is of interest as a model plant because of its differences compared to other plants. It can be used to treat wastewater, providing new raw materials for fuel and biogas production with very little land requirement (Lam et al., 2014). Currently, scientists are focusing on researching the important physiological properties of duckweed to bring it back to its position as a model plant, a position it lost during the period of strong growth of Arabidopsis (Appenroth et al., 2015).

It can be easily seen that the period from 2006 until now is considered the golden age of duckweed when the number of related scientific works increased rapidly (Fig. 3A) (https://pubmed.ncbi.nlm.nih.gov/?term=duckweed&timeline=expanded). Duckweeds have been studied for various applications, currently focusing on growing systems, human food,
animal and fish feed, pet food, ecotoxicology, water treatment, bioenergy, circular economy and supplements for human consumption (Fig. 3B). The highest number of activities in the duckweed application filed it is still in the USA, there is a significant growth in the activities in Germany and a significant penetration into additional new regions as Taiwan, Jordan, Egypt, New Zealand, Thailand, Russia, Singapore, Canada, Ukraine, and China (Fig. 3C) (ISCDRA, 2022).

Fig. 3. Number of publications related to duckweed (A), diversity of duckweed application (B) and global distribution of activities in the development of duckweed applications (C)

4. DIRECTIONS FOR RESEARCH AND APPLICATION OF DUCKWEED

4.1. Biofuel source

Due to population growth as well as the development of large industrial zones, the demand for energy around the world is increasing very rapidly. Crude oil and natural gas (fossil fuels), the main fuel sources today with limited reserves, will run out in the near future. To meet the increasing demand for fuel, finding new alternative fuel sources is extremely urgent. Ethanol, butanol and biogas are new, renewable fuel sources that will gradually replace crude oil and natural gas. Over the past 10 years, bioethanol production has increased very rapidly and reached 85.2 million liters in 2012. Raw materials for bioethanol production are very diverse such as corn (in the US), sugar beets (in Brazil, India), sweet potatoes, cassava... However, these are not optimal sources of raw materials because they take up arable land, causing environmental impacts (soil erosion) and are currently being used as the main food crops for humans and livestock (Cui and Cheng, 2015). With its advantages (aquatic plants, fast growth rate, can grow in polluted water environment, high ability to absorb N and P, low environmental requirements, no competition with people for food and land, high starch content, and low cellulose content...), duckweed is a starchy plant showing notable potential option as an alternative raw material source for "energy gathering and environment clearing" production. Below are some studies on the applicability of duckweed in biofuel production:

**Using duckweed to produce bioethanol and biobutanol:** Duckweed is very easy to grow, contains only a very small amount of lignin, while accumulating other high-energy components in the easily fermentable starch (accounting for 40-70% of total biomass) (Wang and Messing 2015). There are many studies focusing on increasing the starch content in duckweed for biofuel production. There are two processes that affect starch accumulation in duckweed biomass: photosynthesis to form starch and starch consumption in metabolic processes. With current duckweed farming techniques, the starch content synthesized through photosynthesis is very large, so research mainly focuses on limiting starch degradation processes (Cui and Cheng 2015). The main studies include: (1) Deficiencies of P, K and N cause a decrease in catabolism, thereby increasing the amount of starch accumulated in the plant. In 2009, Cheng and Stomp researched and found that when duckweed was transferred from a nutrient-rich environment to an environment containing only tap water, the accumulated starch content in *S. polyrhiza* increased from 20-45.8% after 5 days (Cheng and Stomp 2009); (2) In 2011, Cui and colleagues announced that low temperature conditions and long light periods will increase starch accumulation in *S. polyrhiza* (Cui et al., 2011). Specifically, when the daytime temperature does not change, the low temperature at night will stimulate starch accumulation. In contrast, starch content did not differ under conditions of changing daytime temperature...
and keeping night temperature constant; (3) In 1976, McLaren and Smith researched and found that: after 6 days of culturing L. minor in an environment with 10.6 mM ABA, the fresh weight decreased by 60% but the dry biomass increased by 220% and starch in dry biomass increased nearly 500% (McLaren and Smith, 1976). Particularly interesting, Su’s group has shown that duckweed is a potential substrate in fermentation because under the influence of yeast it is not only converted into ethanol but also produces high-energy alcohols other quantities for biofuel production (Su et al., 2014). In addition, large-scale biomass production testing has also been carried out. In 2011, the first duckweed biomass farming and harvesting system for ethanol production was built in North Carolina, USA. In 2012, duckweed was grown in a 23-hectare lagoon and was found that under nutrient-deficient conditions, the starch content increased from > 10% to an average of 19%. The main factors to consider when cultivating are duckweed density, harvest time and nutritional supplementation (Cui et al., 2011). Li conducted a study on the production of fuel butanol by using Clostridium acetobutylicum to ferment L. punctata. At the first stage, the starch and monosaccharide compositions of L. punctata were analyzed, and it was found that treated L. punctata could be fermented smoothly. Finally, the residual sugar analysis of the fermented mash showed that it had a high proportion of the target product butanol (Li et al., 2012).

**Using duckweed to produce biogas:** Using anaerobic fermentation of agricultural and livestock waste to produce biogas has been researched for many years. Clack found that adding duckweed to the fermentation substrate significantly increased the amount of biogas produced (more than 44% compared to the control) (Clark and Hillman, 1996). Triscari’s research showed that adding only 0.5-2% duckweed produced a large increase in the total amount of biogas and methanol, but if more than 2% were added, the increase no longer continued (Triscari et al., 2009). Subsequent research by Huang and colleagues also continued to confirm the role of duckweed in the fermentation process to create biogas (Huang et al., 2013). In another research, Cu et al., 2015 conducted a project investigating the formation of biogas from common raw materials in Vietnam (animal manure, plant residues and organic waste...) and showed that, S. polyrhiza has a higher CH4 content (340 L/kg) than grass (220 L/kg) and spinach (110.6 L/kg).

### 4.2 Wastewater treatment

Water is a limited natural resource while the demand for water for human consumption and agricultural production is increasing. In addition, the excessive use of fertilizers and pesticides in agricultural production has led to groundwater pollution (FAO, 1999). The shortage of clean water for domestic use has been directly affecting more than 1 billion people worldwide. The use of some aquatic plant species capable of absorbing and metabolizing substances in wastewater is considered a promising biological treatment to solve the problem of wastewater pollution and reuse water sources (Muradov et al., 2014). Due to its ability to grow in oxygen-deficient water environments and absorb necessary nutrients such as PO43- and NO3-, duckweed is effectively used for wastewater treatment. Therefore, this plant is used in biological analysis methods to evaluate water quality and to treat wastewater contaminated with heavy metals (Appenroth et al., 2015). The ability of duckweed and azolla cultures to grow and remediate nutrients (PO43- and NO3-) from different dilutions of anaerobically digested sewage wastewater prepared from sewage lagoon wastewaters was assessed (Muradov et al., 2014). In addition, the accumulation of heavy metals is a concern in wastewater treatment. All species of duckweed have the ability to absorb and accumulate in the body a very high level of heavy metals such as Cd, Cr, Pb... Therefore, they have great potential in being used for treatment of wastewater sources or areas contaminated by heavy metals such as leather tanning technology, mines... to minimize the presence of these metals in the food chain. According to many publications, duckweed has the ability to absorb Cd, N, Cr, Zn, Sr, Co, Fe, Mn, Cu, Pb, Al and even Au (FAO, 1999). The ability of L. minor to absorb Fe has opened up prospects for using duckweed to address Fe contamination of water in abandoned coal mine areas (Teixeira et al., 2014). Besides, this species also has the ability to absorb Bo (Tatar and Öbek, 2014), As (Goswami et al., 2014), Cd (Chaudhuri et al., 2014), Cu and Si (Rofkar et al., 2014). L. gibba is also a suitable species for use in domestic wastewater treatment, and it also has high protein and carbohydrate content, suitable for biofuel production (Verma and Suthar, 2014). Zhao (2014) compared the application potential of 4 duckweed clones belonging to 4 different genera for wastewater treatment in pilot trials over 1 year and found that duckweed clones performed different advantages: (a) L. japonica 0223 and L. punctata 0224 grow all year round, while S. polyrhiza 0225 and W. globosa 0224 do not survive in winter conditions; (b) L. japonica 0223 has the highest dry biomass, crude protein, total amino acids and phosphorus content, and the ability to accumulate total N and P is also very high; (c) Under poor nutritional conditions, L. punctata 0224 has the highest starch content, dry biomass and starch accumulation ability; (d) S. polyrhiza 0225 and W. globosa 0222 have high proportion and content of total flavonoids. Therefore, based on the results of this study, suitable duckweed clones can be selected for production purposes. For example, L. japonica 0223 is the strain with the best ability to treat wastewater and produce biomass, while L. punctata 0224 is suitable for starch production (Zhao et al., 2014a).

### 4.3. Source of food for humans and animal feed

The world’s population nearly doubled between 1950 and 2000 (from 2.7 to 6 billion people), but the demand for meat increased fivefold (from 45 million tons to 233 million tons/year). The World Food and Agriculture Organization predicts that as the population increases to 9 billion people, meat production must reach 410 million tons/year. Meanwhile, protein sources from meat only meet 40% of human daily protein needs. Therefore, the issue of ensuring food sources to meet human needs is an extremely urgent issue (Spiegel et al., 2013). The main traditional sources of animal protein for humans are meat, fish, eggs, milk and vegetable proteins, mainly soybeans, wheat, potatoes, green vegetables... However, today there are many other sources of protein noted as insects (crickets or some larvae), algae and microalgae (Spirulina, Arthrospira...), seaweed (Monostroma, Laminaria...), canola and duckweed... (Appenroth et al., 2015; Spiegel et al., 2013). Around the world, especially in Asia, people often harvest natural aquatic plants such as sea lettuce Pistia, Eichhornia, Azolla and duckweed (Lemna species) for use as animal feed, manure and even for human food (FAO, 1999). Duckweed accumulates a high amount of protein (from 6.8 to 45% of dry weight depending on the species) and is almost equivalent to soybeans. The biologically active groups and medicinal potential of L. minor have also been surveyed (Vladimirova and Georgiyants, 2014).
Because of its high content of N, P, K as well as some minerals and proteins, duckweed is cultivated to provide an important source of nutrients in the diets of pigs, fish and poultry (FAO 1999). Results have shown that duckweed can be used as a substitute for soybeans and fish in the diets of both roosters, hens and chicks (Skillcorn et al., 1993). Hens using 40% duckweed in their daily diet produce more eggs with better quality. Ensuring water quality in duckweed farming for animal feed purposes is an extremely important factor. Toxic elements (Cd, Se, Ni, Pb...) need to be controlled to avoid entering the food chain and affecting the development of livestock (Spiegel et al., 2013).

Duckweed is an aquatic plant and has the fastest division rate in the flowering plant group, so the average harvest yield per cultivated area is higher than other crops such as soybeans, rice and corn. Under optimal growth conditions, duckweeds yield 10-30 ton dry mass/ha/year in comparison to 1.5 to 2.5 ton/ha seed of soybean or 3 to 6 ton/ha seed of rice (FAO 1999). In addition, duckweed dry biomass containing up to: 43% crude protein; rich in essential amino acid such as leucine, threonine, valine, isoleucine and phenylalanine; 5% lipids and highly digestible dry matter (little or no indigestible material vs 50% low digestibility residues of soya beans, rice or maize biomass). Therefore, duckweed can solve the problem of lack of agricultural land for food or animal feed production. Studies have shown that duckweed contains starch, fatty acids, proteins and other secondary metabolites used in the food and feed industries. Plant protein has advantages over red meat because it is less associated with cardiometabolic problems and diabetes. Besides, duckweed does not have a special taste (almost neutral), so it is convenient to mix with other foods without changing the inherent taste. Due to its special characteristics such as high productivity, economic efficiency, and nutritional value, duckweed has been used as a food source for humans, some duckweed species used as a source of plant protein for human consumption in Asia. Currently, products from duckweed are produced in the form of functional foods supplementing amino acids. Some companies in Europe are also researching and developing different product lines (fresh, dried, powder,…) from duckweed biomass (Table 1). Switching consumption of animal proteins to plant proteins will help reduce energy use and reduce greenhouse gas emissions. W. globosa has been shown to help reduce the risk of iron deficiency due to its ability to balance homeostatic folic acid levels (Turck et al., 2021). Clinical studies on nutrition have proven that the amino acid and vitamin B12 content in duckweed is equivalent to that of peas and cheese (Baek et al., 2021). The content of iron, zinc, sodium/potassium ratio as well as the ratio of omega 3/6 reached the balanced homeostatic folic acid levels (Turck et al., 2021). However, it should be noted that some duckweed species have oxalic acid content or absorb heavy metals, so it is necessary to control the quality of water sources for duckweed cultivation as a food source for humans.

Table 1. Companies, Academy and research institutions that develop duckweed based new products and applications (summarized from (Cao et al., 2020))

<table>
<thead>
<tr>
<th>No</th>
<th>Company/Institute Name</th>
<th>Field of application</th>
<th>Focused on</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rubisco Foods</td>
<td>Human food</td>
<td>Sports nutrition, supplements, bakery, meat replacement, egg replacement in noodles</td>
<td>The Netherlands</td>
</tr>
<tr>
<td>2</td>
<td>Plantible Foods</td>
<td>Human food</td>
<td>Plant-based protein - alternative Egg proteins</td>
<td>USA</td>
</tr>
<tr>
<td>3</td>
<td>Lemnature AquaFarms</td>
<td>Human food</td>
<td>Plant-based proteins and other ingredients</td>
<td>USA</td>
</tr>
<tr>
<td>4</td>
<td>GreenOnyx</td>
<td>Duckweed growing systems</td>
<td>Fresh green vegetables</td>
<td>Israel</td>
</tr>
<tr>
<td>5</td>
<td>Hinoman</td>
<td>Human food</td>
<td>Frozen green biomass of Wolffia globosa ‘Mankai’</td>
<td>Israel</td>
</tr>
<tr>
<td>6</td>
<td>Advanced Greenfarm Ltd.</td>
<td>Human food</td>
<td>Plant-based source of protein</td>
<td>Thailand</td>
</tr>
<tr>
<td>7</td>
<td>University of Colorado Boulder</td>
<td>Human food</td>
<td>Space Health, Space food</td>
<td>USA</td>
</tr>
<tr>
<td>8</td>
<td>Wageningen University</td>
<td>Human food</td>
<td>Alternative protein</td>
<td>The Netherlands</td>
</tr>
<tr>
<td>9</td>
<td>Biwol</td>
<td>Human food</td>
<td>Plant based food ingredient, proteins and other, via vertical bioreactor</td>
<td>Russia; Singapore</td>
</tr>
<tr>
<td>10</td>
<td>Carbon Clouds GmbH</td>
<td>Duckweed growing systems</td>
<td>Dry mass products via vertical bioreactor</td>
<td>Germany</td>
</tr>
<tr>
<td>11</td>
<td>Integrated Explorations Inc.</td>
<td>Duckweed growing systems</td>
<td>Producing fresh product</td>
<td>Canada</td>
</tr>
</tbody>
</table>

In 2011, the study on energy properties of proteins in duckweed (S. polyrhiza) was done. In this study, duckweed proteins were extracted, purified and characterized in terms of chemical composition, molecular weight, surface hydrophobicity, emulsification, thermal stability and rheological properties. S. polyrhiza clone with an initial protein content of 34.5% was selected for this study and the protein was extracted from fresh, frozen and dried duckweed at room temperature. The highest extraction rate (52.1%) was obtained from fresh duckweed, followed by naturally dried duckweed.
(45.6%) and frozen duckweed (44.3%). Protein samples extracted from naturally dried duckweed had the highest purity (67.8%) among the three prepared duckweed sources (Yu et al., 2011).

In 2015, a survey of duckweed diversity in Chao Lake and the total fatty acids and triacylglycerol of representative duckweed lines was conducted. A survey of the genetic diversity of duckweed in Chao Lake indicated that the 54 geographical clones could be classified into four species belonging to four genera (L. aequinoctialis, S. polyrhiza, W. globosa and L. punctata) have a uniform fatty acid composition, with three fatty acids (palmitic acid, linoleic acid and linolenic acid), accounting for more than 80% total fatty acids (TFA). TFA in biomass varied between species, ranging from 1.05% (dry weight) for L. punctata and S. polyrhiza to 1.62% for W. globosa. The four duckweed species had similar triacylglycerol (TAG) content of 0.02% per mg DW. The fatty acid composition of TAG differs from the fatty acid composition of TFA and also differs between the four species (Tang et al., 2015).

In 2017, research on protein, fat and starch content, as well as amino acid and fatty acid distribution on duckweed plants belonging to the genera Spirodela, Landoltia, Lemna, Wolffia and Wolffia was conducted. The obtained results showed that the protein content of duckweed species ranged from 20-35%, fatty acid 4-7% and starch from 4-10% of dry weight. The amino acid distribution is close to WHO recommendations. e.g. 4.8% Lys, 2.7% Met + Cys and 7.7% Phe + Tyr. The polyunsaturated fatty acid content ranges from 48-71%. The phytosterol content of the W. microscopica, is 50 mg/g lipid. Accordingly, species of the Wolffia genus are recommended for human nutrition (Appenroth et al., 2017). In 2018, he continued to study components related to human nutrition on duckweed of 11 species belonging to the genus Wolffia. The results showed that the total protein content varied from 20-30%, starch 10-20%, fatty acid 1-5% and fiber content about 25% of dry weight. The essential amino acid content is higher or close to the needs according to Food and Agriculture Organization standards. The amount of fatty acid in the Wolffia genus is low, in which the ratio of polyunsaturated fatty acids accounts for over 60% of the total fat, n-6 are higher than n-3 polyunsaturated fatty acids. The content of macro and trace elements (minerals) depends not only on farming conditions but also on the genetic background of the species. Due to its very fast growth rate and highest yield in most nutrients, Wolffia has high potential for practical application in human food (Appenroth et al., 2018).

In 2019, Sharma’s group studied the production potential of S. polyrhiza and evaluated its biochemical composition. The results of amino acid research showed the presence of essential (37.4%), non-essential (58.2%) and free (4.5%) amino acids. Leucine, isoleucine and valine contribute 51.4% of the total essential amino acids. Duckweed contains 7% lipid and α-linolenic acid (36-37%) is the main fatty acid. Research shows the nutritional value of duckweed as a food supplement (Sharma et al., 2019).

In 2020, the result of study on vitamin B12 content in W. globosa (also called Mankai) showed that the B12 content of Mankai was stable in different seasons (p = 0.76). Some cobalamin derivatives (Hydroxocobalamin; 5-deoxyadenosylcobalamin; methylcobalamin; cyanocobalamin) were identified in Mankai extract. Research results show that Mankai contains biologically active B12 compounds and can be used as a plant-based food source of B12 (Sela et al., 2020).

In 2022, the nutritional value and growth ability of W. globosa was investigated and the results show that W. globosa contains high nutritional content including protein: 45.54%, fatty acid: 5.33%, crude fiber: 9.98%, ash: 20.43% and nitrogen-free extract: 19.21%. It also contains 15 types of amino acids with a ratio of up to 1.51% w/w. It has been pointed out that the genus Wolffia has great potential as an alternative natural food source for aquaculture or other purposes (Said et al., 2022). In addition, the nutritional value and antioxidant capacity of another species - W. arrhiza was done by Hu’s group, they obtained a high-protein strain (W. arrhiza 7678a) under artificial conditions and determined its protein content in 50.89% of dry weight. The result of digestible amino acid scores reached 0.75, showing good protein quality of W. arrhiza. The proportion of unsaturated fatty acids in total fatty acids (TFA) is 77.8% and 3 main fatty acids (palmitic acid, linoleic acid, α-linolenic acid) account for 87.9% of TFA. Compared with common plants, it has much higher levels of total phenolics and flavonoids and also shows higher antioxidant activity. Therefore, W. arrhiza shows great potential value for human food (Hu et al., 2022).

The latest research on the protein and fiber content of W. globosa to use as a nutritional snack. The results showed that W. globosa optimally formulated snacks with 64% glutinous rice flour, 10% tapioca starch and 26% WP (Wolffia freeze-dried powder), giving a very high preference score of 1.00. WP supplementation increased crude protein, essential amino acids and fiber intake compared to the control snack by 51%, 14% and 83%, respectively. Furthermore, the phytochemical content and antioxidant activity of W. globosa snack such as total phenolic content, flavonoid content, iron deionization activity and oxygen radical absorption capacity were significantly higher than other snacks. The novel combination of WP with other ingredients has significantly enhanced the nutritional value of species of the Wolffia genus (On-Nom et al., 2023).

5. STATUS OF DUCKWEED RESEARCH IN VIETNAM

As a tropical country, Vietnam is suitable for duckweed research and farming activities. There are 3 species of duckweed belonging to 3 different genera found in Vietnam: L. aequinoctialis, S. polyrhiza, W. globosa and they are widely distributed in the Northern and Southern Deltas (Tran 2009).

In the RDSC international duckweed archive (at Rutgers University, USA; http://www.ruduckweed.org/database.html), there are currently 18 duckweed lines from Vietnam belonging to the species S. polyrhiza, L. punctata, L. aequinoctialis, and L. tenera. Some Vietnamese duckweed clones have been surveyed in works by research groups from China, Japan, India, and Germany.

Duckweed farming in Vietnam is almost done on a family scale. Animal manure is collected in a small tank, then the water flowing from this surface is put into a larger tank, in this tank people grow a thin layer of duckweed on the surface. Duckweed is harvested daily and mixed with agricultural waste to make food for ducks (FAO, 1999).
The use of duckweed as a research object in Vietnam has not yet received much attention. Most of the research focuses on the applications of duckweed in agricultural production. For example, when using duckweed in the diet of meat ducks and breeding ducks, the weight gain of meat ducks, laying rate and percentage of eggs with embryos of breeding ducks are all equivalent to ducks supplemented with soya powder and fish meal (Bui, 2009). In terms of molecular biology research on duckweed in Vietnam must include the research under the topic "Research on creating duckweed varieties carrying H5N1 antigen gene to prevent influenza in poultry" (Le, 2011). Factors controlling ubiquitin gene expression from two duckweed species L. aequinoctialis DB1 and S. polyrhiza DB2 were isolated (Tran, 2009). Vu successfully developed a callus culture process of L. aequinoctialis, and also investigated the possibility of using Agrobacterium to perform gene transfer into this subject (Vu, 2007).

6. OUR DUCKWEED RESEARCH GROUP

Although our research group has just been established (since 2020), it has already achieved encouraging initial research results. Currently, we have collected and stored over 100 duckweed clones (belonging to three genera Spirodela, Lemna and Wolffia) and have surveyed some characteristics of duckweed. The research and training results of our group are shown through the following publications and theses:

PUBLICATIONS:


MASTER’S AND BACHELOR’S THESSES:

1. Investigating the ability to absorb Cadmium and lead of duckweed Lemna minor within the laboratory conditions - Lu Vo Uyen Trinh - Master's thesis - Da Lat University - 2022.
2. Investigating the ability to absorb Cadmium and lead of duckweed Lemna minor within the laboratory conditions - Le Nguyen Duc Hanh - Master's thesis - Da Lat University - 2022.
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7. CONCLUSION

With interesting biological characteristics and wide application potential, duckweed is increasingly being researched by scientists in many countries around the world. The biggest advantage of duckweed is its fast biomass production rate and does not affect agricultural land resources of traditional food crops. Basic physiological, genetic, and cellular research shows the important role of collecting, surveying, and screening duckweed strains in different geographical and climatic regions. Vietnam has many advantages in terms of climate, lake topography as well as experience in cultivating and applying duckweed to promote duckweed to become an important aquatic food crop in the modern agricultural economy. Surveys on the potential of duckweed biodiversity in Vietnam should be prioritized concurrently with the organization of classification, storage and international registration of these geographical duckweed strains. This will be the basic foundation for research and application of duckweed in Vietnam and the world.

From the results achieved during our group’s research, we can see that Vietnamese duckweed clones have different potential applications in wastewater treatment and producing biomass for biofuel production as well as cytogenetics. Therefore, promoting research and cooperation with domestic and foreign scientists is essential to bring duckweed into practical applications.

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DECLARATION

The authors declare they have no conflict of interest.

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