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Duckweed chemical composition: A potential source of biofuel, food and feeds

Naseem Zahra*, Ali Imran, Awais Ali, Syed Hussain Imam Abidi, Quart-ul-Ain Syed and Muhammad Khalid Saeed

PCSIR Laboratories Complex, Ferozepur Road, Lahore 54600, Pakistan
*Corresponding author's E. mail: drnaseemzahra@gmail.com

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Duckweed belongs to *Lemnaceae* family and is known as smallest species of flowering plants, i.e., macrophytes. Duckweed floats on or just beneath the surface of freshwater and wetlands. It is protein enriched source, which may produce larger quantities of protein rich biomass. Duckweed is consumed as human food in some poor areas of South Asia like Thailand, Myanmar and Laos. In Israel, it is also cultivated as vegetable. Duckweed is widely accepted as best animal feed internationally. It has also potential of reducing chemical loads in facultative sewage lagoons. These plants are used as food for fresh/pond water animals and fish. This review entails the information regarding importance of duckweed as best nutritional composition for human food and animal feed as well as a viable source of biofuel.

Capsule Summary: Duckweed is a whole fresh plant which is an enriched protein source and can be used as human food as well as animal feed. Duckweed is also functionally and nutritionally very important for health as it contains other essentials such as minerals, vitamins and antioxidants.

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INTRODUCTION

It is expected that world population may rise from 6.7 billion in 2006 to over 9.0 billion in 2050 (UN population division, 2007). With drastic increase in population, the demand of protein rich food will also increase. It is imperative now to explore protein rich sources in order to tackle with future drastic conditions (Mwale and Gwaze, 2013). All the issues regarding protein rich food and feed will rise in future and resource base for livestock may shrink and cost of feeding non-ruminant may be unaffordable, so it is direly needed to search other protein sources which are cheap and easy to establish to produce food and feed and their respective products (Teguia and Fru, 2007). By keeping all the future prospects and challenges of future regarding protein enriched food, duckweed has a genuine potential to address the protein shortage in future. The recovery of this valuable nutritional source may be beneficial as both ecologically and economically (Ansal et al., 2010). Duckweed is suitable for the consumption of both human and animals as protein source and invaluable nutrients (Sońta et al., 2019). Duckweed is also important to treat industrial and agricultural waste water, used as biofuel (Figure 1) and feed (Cao et al., 2018).

Duckweed has around 40 plant species worldwide among which the popular and the major ones belongs to genus *Lemna, Spriodella, Wolffia, Wolffiella* (Appenroth et al., 2013). This plant is enriched in both micro and macro

nutrients required for life sustainability. Duckweeds are found everywhere except frozen areas and waterless deserts. Duckweed provides sufficient essential amino acids meeting the recommendations of WHO (World Health Organization) and it is also rich is essential and beneficial antioxidants and pigments (Stejskal et al., 2022).

Properties of duckweed

Duckweed is morphologically, an ovalshaped 5mm long specie that grows faster through clonal growth (Figure 2). It is without true leave and stem and can be doubled its biomass within 2-3 days under proper environmental conditions like pH, temperature and nutrients concentration, light and wind speed (Xu et al., 2022). Duckweeds are the floating plants and are monocotyledons. These are the world simplest and smallest plants having flowers. Each plant has a poorly differentiated combination of more than two stem and leaf. The tissues of duckweeds are basically composed of chlorenchymatous cells which are separated by larger intercellular spaces. The epidermis (upper) is cutinized and sheds water on surface. It lacks root hairs and there is no woody tissue. In America there are 60% species recorded while Europe and Australia have 30% of the total (Inoue et al., 2022). The habitat requirements for different duckweed species may differ but overall, all share the sheltered still water for the growth. Duckweed is gaining attention these days because of following reasons (De Beukelaar et al., 2019).

1. It contains high protein contents ranging from 35-45%.
2. It contains a better amino acids composition covering all the nutritional requirements for the growth.
3. It can grow at a highest rate and can bear extreme environmental conditions
4. It can be cultivated in a basin on non-arable land evading the use of farming land

Duckweed has great reproductive capacity under favorable conditions even it double its biomass within 16 to 48 hours. Duckweed has ability to be used as a protein source with good profile of amino acids Table 1 and 2. Certain duckweed species may contain protein levels upto 45% and provide all the essential amino acids required to meet the levels of FAO reference to support the growth and development of human as well as animal body (Xu et al., 2022; De Beukelaar et al., 2019).

From the Table 2, it is clear that the four species contains the highest amounts of amino acid Glutamic i.e., 8.00g/100g in *S. polyrhiza*. However, the least quantities of Methionine are present in duckweed species. The average contents of protein in the species of duckweed i.e., *L. gibba, L. Polyrhiza, L. Puntata and W. Columbiana* are 25.2, 29.1, 28.7 and 36.5% respectively (Rusoff et al., 1980; Appenroth et al., 2013). The protein contents of duckweed may vary among different species depending on growth and the extraction methods adapted (Yu et al., 2011). In a study conducted by Fasakin (1999), it was reported that protein extraction from duckweed specie *S. Polyrhiza* contain 64.6% and 19.9% protein concentrate and residual pulp fiber respectively. The processing methods of duckweed affect protein extractability in case of fresh, frozen and drying processes.

Cultivation of duckweed

Duckweed grows in fresh water such as lakes, rivers and pond naturally. The natural environmental conditions may restrict the growth of duckweed like insufficient supply of nutrients, drought and contamination of fungus and insect infestation. So, it is required to identify much more appropriate culture ways to improve the growth and yield of duckweed while removing the safety issues for potential human utilization (Baek et al., 2021). There are various culture systems like static system, vertical aeration,

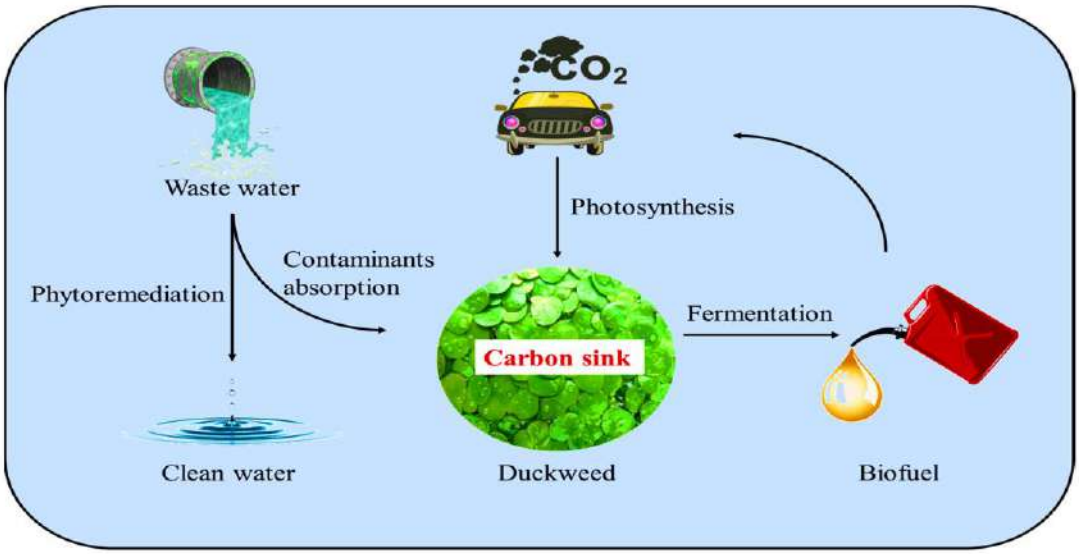

Fig. 1: Utilization of duckweed to make biofuel (Yang, 2022)

Fig. 2: Duckweed-the smallest plant in Petri dish (Braglia et al., 2021)

horizontal surface agitation, system with top water spraying, and layer culturing system with top water spray for the cultivation of duckweed (Ruekaewma et al., 2015). The results showed that horizontal surface agitation system is much better to cultivate duckweed biomass within 28 days. In this system a blade paddle wheel is driven by a mini-motor which circulates water at 3500 rpm horizontally. Sharma et al. (2019) designed three culture media for the cultivation of *S. polyrhiza* in outdoor tanks including; manure 1: poultry droppings, cattle manure and mustard oil cake, manure 2: potash, urea and tri-superphosphate and manure 3: urea, cattle manure, triple superphosphate and potash.

The results showed that manure 1 as organic manure showed the highest yield of duckweed as compare to manure 2 and 3. The production of 2020 kg ha^{-1} month (on dry weight basis) from the duckweed pond culture was obtained. Temperature, sunlight, pH, phosphate, medium conductivity and ammonia concentration are the main factors which affect duckweed productivity (Chen et al., 2022). Figure 3 showed the cultivation of duckweed in pond installed at PCSIR Laboratories Complex, Lahore, Pakistan.

Duckweed as human food

The global challenges regarding the fulfillment of human desires regarding food, the demand of healthy, nutritious and beneficial food is also increasing. There is dire need to explore new supplemental and agricultural products system. Duckweed is demonstrated as a best food for humans having so many health benefits. The human body

Fig. 3: Growth of duckweed in pond at PCSIR Laboratories Complex, Lahore Pakistan

Table 1. Duckweed proximate analysis (as % of dry matter) (Rusoff et al., 1980; Said et al., 2022)

Duckweed species	Dry matter	Ash	Crude protein	Crude fiber	Fat
L. gibba	4.6	14.1	25.2	9.4	4.7
S. polyrhiza	5.1	15.2	29.1	8.8	4.5
S. puntata	5.2	13.7	28.7	9.2	5.5
W. Columbiana	4.8	17.1	36.5	11.0	6.6

growth is positively affected by the use of duckweed in products as it contains high protein contents, i.e., upto 45%. Duckweed provides all the essential amino acids fulfilling all FAO references for the body growth and development. Duckweed also has versatile carbohydrates including cellulose, starch, pectin and trace hemicelluloses that may deliver essential nutrients and functional properties (Liu et al., 2021; Xu et al., 2022). Duckweed is also enriched in vitamins, minerals and phytochemicals especially beta carotene and lutein which are associated with reducing risk of chronic diseases. Duckweed could be either used in conventional cereal products by partial substitution of wheat flour or for extracting phytochemicals and proteins as functional ingredients. It is rich in antioxidants which maintain cell integrity (Xu et al., 2012). Duckweed is being consumed in some Southeast Asian countries like Myanmar, Thailan and Laos with localized name of Kahi nam, Kai nhae, kaipam as human food (Guo et al., 2023). Cereal based products especially wheat products like cookie, bread, pasta, snacks and biscuits are staple food and are great energy source having high concentration of carbohydrates with high glycemic index. The substitution of wheat flour with duckweed can greatly improve the nutritional aspects providing healthier benefits for human body (Yahaya et al., 2022). Duckweed is also accepted as salad, cakes and in drinks in some countries.

The space foods are designed to fulfill the recommended calories and balanced diet of minerals and vitamins for astronauts for performing well in space environment. NASA (National Aeronautics and Space Administration) has identified the importance of life sustainability system for long term mission. This system requires maintaining the demands of system closure and resource recovery with minimal expenditures. To meet the challenges in space for the human requirement work on certain duckweed species (*L. gibba*, *L. minor*, *L. punctata*) has been started which may be a good source of food for seeding and cultivating in space (Romano and Aronne, 2021). So, duckweed can be a best human food for future.

Duckweed as animal feed

Duckweed is being used as animal feed for complementing nutrition and for the animal growth. Many researches have been conducted to replace alfalfa meal, soyabean meal and fish meal with duckweed in animal feed especially species of duckweed i.e., *S. polyrhiza* and *L. minor* are being used as feed for fish and poultry (Goopy and Murray, 2003). Duckweed utilization as feed is equally important for the preparation of fish, poultry and cattle feed.

In research conducted on fish by feeding duckweed as a substitute of fish meal and soya meal it was found that the weight was gain as nutritional aspects were covered by duckweed as fish feed. Duckweed specie *S. polyrhiza* and *L. perpusilla* was added to the diet of Nile tilapia (Oreochromis niloticus) in 30 gDM/kg. The remarkable weight was gained by the fish (Hassan and Edwards, 1992). Similarly, in another research the culture of tilapia was fed with varying levels of *S. polyrhiza* and again weigh gain was found. The growth rate was improved and food conversion ratios were unchanged from the control group upto 30% at inclusion rates (Fasakin et al., 1999). The attributes of duckweed as fish feed are as follows;

1. Duckweed can easily be grown locally in ponds.
2. Duckweed can be fed fresh as it floats, so can easily be utilized by fish.
3. It is consumed efficiently by fish tilapia and other fish species.
4. Duckweed is inexpensive source of protein and other ingredients and can easily be cultivated.

Duckweed could be utilized by poultry as vegetable protein substitute in cereal based diets (O'Neill et al., 1996). Chicken feed costs account for 60-70% of total broiler chicken production, so it was needed to explore cheaper source of protein to get maximum poultry yield (Ojewola et al., 2005). In research conducted by Ahammed et al., 2003, it was investigated that the weight of Titan broiler birds was gained when they were placed on diets with duckweed (*L. gibba*). The sesame oil cake was replaced with duckweed in this study. In a study conducted by Haustein et al., 1994, the birds' weight was significantly gained when they were fed with 5% levels of duckweed. The pigmentation of all birds containing duckweed as feed was also increased. In Czechoslovakia, at the duck farms, the ducks are fed with the prepared feed containing small quantities of duckweed (Culley et al., 1981). Duckweed can easily be utilized as major resource for poultry industries of under developed or developing countries and could easily be incorporated in poultry diets on a very least cost basis (Leng et al., 1995).

Utilization of duckweed by large animals requires the development of large-scale duckweed culture system including proper cultivation, harvesting and transportation systems. The daily intake of duckweed by cattle is well accepted according to the study conducted by Huque et al. (1996) at the rate of 10% of their live weights. It was

Table 2. Amino acids (g/100 g) profile of different duckweed species (Rusoff et al., 1980; Demann et al., 2023)

Amino acids	*L. gibba*	*S. polyrhiza*	*S. puntata*	*W. columbiana*
Glutamic	7.60	8.00	7.69	5.76
Leucine	7.15	6.85	6.88	5.53
Aspartic	7.12	7.55	7.38	5.63
Valine	4.96	4.40	4.71	3.49
Alanine	4.59	4.48	4.79	3.75
Phenylalanine	4.45	4.20	4.38	3.60
Arginine	4.29	5.25	4.86	3.78
Lysine	4.13	4.30	4.26	3.37
Isoleucine	3.87	3.75	3.76	3.06
Glycine	3.79	3.95	3.93	3.04
Threonine	3.20	3.45	3.31	2.55
Proline	2.93	3.28	2.95	2.41
Tyrosine	2.91	3.05	3.14	2.17
Serine	2.61	2.80	2.83	2.28
Histadine	1.89	2.15	1.90	1.18
Methionine	0.83	0.83	1.07	0.87

further noticed that duckweed was highly digestible and the protein was highly ruminal degradability. Various types of duckweed (*Lemna, Wolffia* and *Spirodela*) differing in approximate composition were studied and found promising results of duckweed utilization as cattle feed. In a study conducted by Omojola et al. (2006) on dwarf goats fed with duckweed, it was observed that goats were more eager to consume fresh and dried duckweed than aquatic fern. In another study conducted by Reid (2004), the Boer goats were fed with four types of feed to different groups of goats. The feed was consisted of ground maize, wheat hay, soybean hull and duckweed. It was concluded by the researcher that duckweed was nutritionally comparable to soyabean meal. There were no harmful effects on goats were observed. The amount of ammonia ions, volatile fatty acids and pH had no adverse effect on animals using duckweed. So, from the above studies it can be concluded that duckweed is the best feed for fish, poultry and cattle (Al- Hashimi and Joda, 2010; Azim and Wahab, 2003; Bikker and J. M. Jansman, 2023; Mbagwu and Adeniji, 1988; Moyo et al., 2003; Petersen et al., 2022; Sharma et al., 2019; Stadtlander et al., 2019).

CONCLUSIONS

It is concluded from the findings that duckweed is enriched in protein which can be utilized and equally important for both humans and animals. Also, it is one of viable source of biofuel production. Duckweed has also other important constituents like carbohydrates, fats and phytochemicals which are functionally and nutritionally beneficial as well. However, future research should be conducted for better understanding of the structure, chemistry, functions as well as humans and animal health beneficial effects.

DECLARATION OF COMPETING INTEREST

The authors declare no competing financial interest.

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