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Advances in Duckweed Research: A Comprehensive Review of Ecological Significance, Applications, and Future Prospects

Shweta Chikhale*, Pranay Abhang and Girish Pathade

Krishna Vishwa Vidyapeeth, Deemed to be University, Department of Allied Sciences, Karad, Maharashtra, India

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ABSTRACT

In recent years, the tiny aquatic plant duckweed has gained prominence as a source of protein-rich animal feed, organic fertilizer, and biofuel. It has great applicability in wastewater treatment, toxicity testing, basic research, and evolutionary model systems. With that in mind, this paper briefly reviews general characteristics, distribution, environmental requirements, aquaculture, and some uses of duckweed.

***Key words**: Duckweed, Lemnaceae, Lemna*

Taxonomy

Duckweeds, belonging to the botanical family Lemnaceae, are bitsy free-floating vascular with a worldwide distribution. There are five common rubrics of duckweeds (Lemna, Wolffia, Landolita, Spirodela and Wolffiella) and about 40 species (Landolt, 1986).

Growth and Reproducible Conditions

They reproduce by vegetative reduplication and are characterized by rapid-fire clonal growth. Likewise, they cluster in colonies and form green robes or a type of mat on the face of the water (Armstrong, 2011).

The optimum temperature for the growth of multitudinous duckweed species and duplicates was set up to vary between 20 °C and 30 °C; minimal temperatures that just enable a veritably show endless growth rate were set up to range between 34 °C.

The niche conditions of duckweed vary between species, but all partake in the need for sheltered still water. The depth of the factory mat is an important limitation to growth. A striking point of duckweed species is their enormous reproductive capacity. Under favorable conditions, they have been reported as doubling their biomass every 16 to 48 hours. Duckweed growth and propagation are driven by the photosynthetic application of light, which is dependent on the temperature and nutrient and CO_2 forcing. Numerous duckweeds are suitable to grow well at pH values of between 5 and 8 Although duckweeds have been set up in natural waters with pH values between 3.5 and 10.4, High temperatures, light intensities, and pH values can all disrupt duckweed growth and propagation, and can similarly be seen as stress factors that can induce flowering to insure by the setting of feasible seeds.

Importnace

Duckweeds have attracted considerable attention for several reasons, viz.(1) they're the fastest-growing flowering shops known to date (Ziegler *et al.*, 2015); (2) they can be cultivated in a receptacle on non-arable land, thereby not making use of tilling land; (3) they don't bear external operation of diseases for their growth as they can take up nutrients from wastewater using their function of bioremediation, thereby barring fresh trouble to the terrain; (4) their carbon footmark is minimum primary computations reveal a score of 0.4 kg of carbon dioxide original produced per 1 kg of duckweed compared to e.g. 0.9 kg for lentils and 27.0 kg for beef; (5) they contain high quantities of high-quality protein when grown under optimal conditions, including temperature, light and nutrient vacuity.

The restriction of duckweeds to small floating assimilatory organs facilitates rapid-fire growth. Duckweed fronds correspond substantially to the photosynthetic towel, and the channelling of produced photosynthate into the product of a new, simply constructed photosynthetic towel constitutes a streamlined application performing in rapid-fire addition of frond biomass. Indeed, duckweeds have been shown to be the most fleetly growing advanced shops in laboratory trials and produce large quantities of biomass under natural conditions and in artificial surrounds that can be employed for e.g., bioenergy products (Appenroth, 2023).

The growth of duckweed vegetative occurs by expiring within the sacks or depressions of the rudimentary sections of the fronds. Each son frond arising from the poke of the mama cub formerly contains two new generations of son fronds. Thus, under optimal conditions, the growth rate of duckweed is nearly exponential.

The lemnaceae family was one of the foremost model shops due to their ease of sterile civilization in the laboratory and simple morphology (Landolt, 1987). The first duckweed conference added up the duckweed exploration stating that duckweeds were the main model for factory biology from 1950 to 1990, In that time examinations of duckweeds revealed the tryptophan-independent conflation of auxin (Baldi *et al.,* 1991). Translational regulation in eukaryotes (Slovin *et al*., 1982), and seven of the first stable factory mutants (Posner, 1962). Duckweeds are also seductive model shops for physiological exploration, similar as for examining circadian timepiece regulation by light at the cellular position (Muranaka *et al.,* 2016).

Scientific study of Duckweed

The first recorded scientific studies of the Lemnaceae focused on describing their morphology and histology. A work focused on the Lemnaceae was published by the botanist Matthias J. in 1839. Schleiden (Schleiden, 1839). The simplified vegetative body of duckweed is called a frond or thallus (Hillman, 1961). Although vegetative cloning is most common in duckweed, they can also reproduce generatively through sexual duplication.The duckweed root is an accidental organ set up in Spirodela, Landoltia, and Lemnaspecies (Bellini *et al*., 2014) that develops on the lower side of the frond, coming to the budding sacks, and is subtended by both the epidermal jacket at the junction and by the root- cap at the root tip. Apical root growth is followed by the isolation of the epidermis, cortex, tracheary rudiments, and phloem cells (Melaragno and Walsh, 1976; Echlin *et al*., 1982; Landolt, 1986 and Kim, 2007).

The disbandment of Lemnaceae over longer distances most likely occurs through a "step-by-step" process involving a series of intermediate waterbodies with catcalls acting as dispersing agents (Coughlan *et al.,* 2017), which might explain the disconnected population distribution for some species of Lemnaceae (Les *et al.,* 2003). While the liability that a propagule survives a long flight may be low, stunning figures of catcalls covering large distances as part of their periodic migration (occasionally in excess of 10,000 km) could give an implicit transport trace, with a significant number of successful dissipations of feasible individualities.

Numerous species of Lemnaceae have dispersed vastly beyond their natural distribution range and are considered to be more invasive than other species rested on traits similar as rapid-fire vegetative propagation (Moodley *et al*., 2016).

Duckweed: Secondary metabolites and other applications

Duckweeds contain various useful secondary metabolites including phenolic mixes (flavonoids, phenylpropanoids, and tannins) and terpenoids. various physiological parcels have eased their avail, and they have been stressed in the medicinal, cosmetics, and food industriousness Duckweeds are medicinal gravies that do not have severe side effect (Snafi, 2019) disquisition has revealed the various pharmacological effects ofduckweeds. *L. minor* has

1) Antibacterial exertion against gram-negative bacilli (*Pseudomonas fuorescens, Shigellafexneri, Escherichia coli,* and *Salmonella typhi*) and gram-positive bacteria (*Bacillus subtilis*)

2) Duckweed species have been used as beast feed for hundreds of times and have been shown to be nutritive (Goopy *et al*., 2003) Duckweed feed can supply brutes with phosphate and nitrogen. *L. minuta* can be reclaimed as a feed supplement by adsorbing micronutrients analogous as selenium and zinc, which are essential for brutes (Li *et al*., 2020). *W. arrhiza*, used as beast feed, yields protein content analogous to that of soybeans.
3) The protein content of duckweeds grown in organic excreta is truly high, and the operation of duckweed as feed has been suggested as a result of environmental issues related to excreta sanctification and feed product Duckweeds are protein sources that could replace soybean mess and are anticipated to be used as backups to reduce environmental pollution created by expanding soybean civilization (Sharma *et al*., 2019)
4) Duckweeds have been used as a resource for biomass and biofuel product. Duckweeds with a high brio content, high biomass product, and low lignin content could be promising sources of bioethanol products (Su *et al*., 2014)
5) Duckweeds can be employed as resources for biodegradable plastics. Biodegradable plastics are polymers that can be degraded by living organisms and are constructed as druthers to non-degradable plastics (Shen, 2020) Lemna species produce biodegradable plastics for various artificial products. Duckweeds, tolerant to extreme conditions, are known as effective remediation resources for pollutants in wastewater. They purify sewage through the important accumulation of chemicals by adsorption or uptake (Cheng *et al*., 2009)

Conclusion

In this article we have seen nutrient recycling and duckweed as a potential feedstock for biofuels also investigated its potential as a sustainable food source of animal feed and phytoremediation agent duckweed is proving to be a versatile and environmentally friendly crop with immense potential to address pressing challenges in biofuel production food security animal feed and environmental remediation by harnessing its unique properties and addressing the challenges it presents we can pave the way for a more sustainable green environment and further interdisciplinary collaborations investments are needed to exploit the full potential bring it to practical implementation on a larger scale

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