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Biorecovery of nutrient waste as protein in freshwater macroalgae

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Over 150 million tonnes of protein are consumed annually by domesticated animals and this demand is expected to double by 2050. Freshwater macroalgae are a group of organisms that could contribute significantly to these future protein requirements as they can be cultured on-site, utilising the nutrient waste water from animal production. The aims of this study were to investigate the relationship between nitrogen supply, biomass productivity and the quantity and quality of protein in the freshwater macroalga, *Oedogonium*, cultured in situ in the waste water from an intensive freshwater fish farm. The dry weight (DW) productivity of *Oedogonium* ranged between 23.9 and 35.7 $g \cdot m^{-2} \cdot day^{-1}$, whilst on an ash free basis the rate of productivity ranged between 17.1 and 23.6 $g \cdot m^{-2} \cdot day$. These productivities are the highest documented for freshwater macroalgae. The protein content (sum of amino acids) of this biomass increased linearly with increasing nitrogen content of the biomass from a minimum of 3.96 $g \cdot 100\ g^{-1}$ DW when the internal nitrogen content was 0.86%, to a maximum of 18.07 $g \cdot 100\ g^{-1}$ DW when the nitrogen content was 4.16%. The quality of the protein in *Oedogonium* was high, with the essential amino acids accounting for 43.1–43.8% of the total amino acids. Methionine accounted for between 1.6 and 1.9%, and lysine 6.8 and 7.3% of this protein, with the proportion of each slightly increasing as the internal nitrogen content of the biomass decreased. The quantity and quality of protein in the *Oedogonium* biomass in this study are equivalent to, or higher than, many terrestrial crops that are currently used as a protein source in animal feeds. As such, integrating the production of *Oedogonium* into the waste management of intensive animal production will provide a mechanism to recover nutrients which, firstly, delivers a novel source of protein for the agricultural sector and, secondly, contributes to the environmental sustainability of intensive animal production through bioremediation.

1. Introduction

Approximately 70% of all harvested agricultural crops, which account for more than 150 million tonnes of protein, are consumed annually by domesticated animals [10,59]. By 2050 the world's population is predicted to increase by 2–4 billion people and the global demand for protein to feed to animals is predicted to double [13,28,57]. It is unlikely that the cultivation of traditional protein sources such as legumes, cereals and grains can meet this demand [23,25,33,39,56]. These crops are restricted to arable, fertile land and there is a very limited scope to increase the production of these crops without clearing large areas of rainforest [19,25,56,57] and using large quantities of synthetic fertilisers, which are themselves a finite resource with environmental consequences for poor application practices [16,38,39,54]. Overcoming these challenges and meeting the protein requirements of the future will require the adoption of unconventional sources of protein [2,10,62]. Furthermore, as the majority of these novel sources of protein will ultimately be fed to animals, they need not be tasty or attractive to humans. Rather, they need only be nutritionally complete and supply the protein required to facilitate the rapid growth of animals.

Freshwater macroalgae are a group of organisms that could contribute significantly to these requirements and provide protein at an industrial scale [14,34,44,45,47]. Two major advantages of freshwater macroalgae are that they do not compete directly with terrestrial crops for arable land, and they do not require fertiliser inputs as they can be cultivated using high-nutrient waste water [14,32,43,44,63]. Moreover, freshwater macroalgae have high rates of biomass production, often exceeding 15 $g \cdot DW \cdot m^{-2} \cdot day^{-1}$, and high rates of nutrient uptake and uptake efficiency [14,43]. At these high productivities between 50 and 85% of the supplied nitrogen is incorporated into the algal biomass [14,44,63]. This translates to two key features — the ability to efficiently recover dissolved nutrients at high rates and the conversion of these nutrients into protein. Moreover, freshwater macroalgae have relatively simple structures, characterised by limited cell differentiation which means that all cells are capable of photosynthesis and nutrient assimilation, such that the entire cultured biomass can be treated as a homogenous protein source.

The amount of crude protein in any organic matter is closely linked to its nitrogen content and can be calculated by using a feedstock

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specific nitrogen-to-protein conversion factor that varies between 4.1 and 6.25 [40,65] with algae at the lower end of this spectrum [47]. Whilst there is limited data on the amount of crude protein in freshwa-

2.2. Experimental design

This experiment examined how both the total content of amin