Biological Water Treatment: Barely Straw Sustainability of Algae

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ABSTRACT: Barley straw has been used around the world for decades as a simple, cost-effective and harmless phytoplankton growth inhibition method. Although the effect of this method on algal blooms is quite well depicted, it has not yet been tested what effect it has on submerged vascular plants and if it could be used to control the spread of alien macrophytes. In this study two highly invasive plant species: Cabomba Carolinian and Elodea untallied were exposed to different concentration of the barley straw extract (BSE) in laboratory conditions for duration of four weeks. In the course of the investigations, responses of 8 traits associated with growth, biomass and chlorophyll concentration of specimens to three dosages (Low, Medium, and High) of BSE corresponding to concentrations:0.30- and 1.50-ml l−1 were analyzed. The result showed that although dry mass and total length of the plants did not differ significantly between the test groups, increase in tillering and internodes number was observed for certain concentrations of the extract. This shows that if BSE has any effect on submerged macrophytes it is a positive one and thus the method is not suitable for invasive submerged aquatic plant control. Furthermore, it is recommended that before using barley straw for algae bloom control one should make sure that there are no alien aquatic submerged plants in the area that could benefit from such a treatment.

KEYWORDS: Barley Straw, Aquatic Ecosystems, Algae Control, Environmental Sustainability, Aquatic Weed Management, Biological Water Treatment.

INTRODUCTION

Drinking, irrigation (water requirement to produce food), industry usage of water, transportation and recreation require clean water as do fishing and biodiversity support (Carpenter *et al.* 1998). In addition of the fact that global population growth means increasing pressure on water, land and air resources (Pretty *et al.*, 2003). However, in the last few decades heavy discharges of untreated wastewater from urban, agricultural and industrial activities have led to over enrichment by nutrients such as nitrogen, phosphorus along with numerous pollutants in our natural water bodies (Xin *et al.*, 2010; Boelee *et al.*, 2011; Abdel *et al.*, 2021).

The majority of these nutrient inputs result in one major environmental problem, i.e., eutrophication that threatens freshwater and coastal marine ecosystems (Chislock *et al.*, 2013*)* We witness eutrophication, a process in which excess phosphorus and nitrogen cause growth of plants/algae to increase rapidly (Schindler 2006).

Harmful algal blooms (Hallegroef, 1993; Newman and Barrett, 1993) have been an increasing problem over the last few decades. These blooms can be categorized into three classes based on their toxicity:

1) Non-toxic blooms that can lead to oxygen depletion when broken down by bacteria,
2) Toxic blooms that can cause shellfish poisoning in humans, and
3) Looms that produce toxins harmful to aquatic life but not to humans. Toxic algal blooms have occurred in increasing frequency in drinking water in the UK (Pillinger J. 1995).

Algae:

In the summer, algal growth in farm ponds can cause a few problems and controlling the algae can be expensive and even ineffective by mechanical or chemical means. It has been found that pond quality issues tend to worsen and the pumps required to control algae tend to increase as the climate warms. Pond owners face a challenge in preventing algal blooms and the resulting fish kills, especially during the hot summer months, when algal blooms can take their oxygen from the water. It is a valuable resource used in different application such as the production of energy and as an animal feed. It is also employed for biodegradable cleaning up of oil spills (Wisniewska, *et al*.,2003; Joergensen RG *et al.,* 1997). Barley straw is used for cost effective control of algae biologically, is user friendly, and is environmentally sustainable (Boylan JD and Morris JE., 2003). However, the straw decomposing in well oxygenated water has the anti-algal effects. Barley straw decomposes; releasing about twelve different types of phenolic acids during this decomposition (Everall NC and Lees DR., 1997) described what happens when the straw rots so it leaches phenolic compounds and lignin into the water.

These chemical compounds will kill existing algal cells and prevent new growth too. Contribution of formation of hydrogen peroxide (Everall NC and Lees DR., 1997) to suppression of cyanobacteria, diatoms and unicellular green algae populations by repeated applications of decomposed barley straw to a drinking water reservoir were demonstrated by Barrett *et al.* (1999), in conjunction with suppression of formation of algae (CEH, 2004, Everall NC and Lees DR., 1997).

Algae are a large group of photosynthetic organisms in our environment with great significance and utility in many applications. They can be microscopic and can also grow to the size of seaweed and is grouped under green, brown and red algae. The algae are very useful in balancing of carbon in our planet's atmosphere. They contribute a large percentage to world oxygen level and are essential in nutrient cycling in marine and fresh water ecosystems (Falkowski *et al.,* 2004). They are as primary producers, for converting light energy into usable forms that sustain the foods chains within those ecosystems. Their capacity to fix carbon dioxide also makes it possible to classify them as contributors to endeavors towards demanding climate change (Nelson C, *et al.,* 2016).

Recently algae have drawn concerns as being good source for bio fuels, products for pharmaceuticals as well as foods. This raw material can be turned into biodiesel and any fuel from algae is a renewable source of energy needful in the fight against fossil fuel (Chisti, 2007). However, the common characteristic of many algae is that they contain such useful compounds as antioxidants and omega-3-acid fatty that makes them worthy nutritional values (Renaud & Luong-Van, 2006). But gaseous algal blooms might show up because of nutrients and Climate change and other various effects to the water quality and life of the aquatic species (Paerl & Otten, Scholarship, 2013). Knowledge of how and why these blooms develop is essential if algae are to be controlled and harnessed successfully.

Barley Straw:

Barley straw has recently come in vogue for its use in diverse fields like agriculture, environmental management and sustainable development. But this lying dormant, unutilized as a byproduct of barley cultivation, is odd considering the way it contains lots of organic matter and beneficial compounds. Barley straw has been traditionally used in traditional farming as a livestock feed, mulch, and soil amendment. But its merits from an environmental standpoint, especially those in water management and pollution control, have been growing awareness.

Figure no 01: Fresh and Dried Barley straw Fibers. (Koutous A, 2021)

The research has demonstrated that barley straw can act as a natural way to mitigate algal blooms in aquatic systems without excessive input to local nutrient systems. Additionally, the fibrous structure and lignocellulose composition of the hull make it more suited to bioenergy production and materials development (Hassan *et al*. 2021). The trend towards exploring barley straw as a resource is congruent with the need to realize circular economy principles in the view of more sustainable waste management and to increase resource efficiency (Müller *et al.,* 2019).
We highlight recent advancements and knowledge gaps, in order to provide a comprehensive overview which will inform future research and practical application.

Mechanism of Action:

The exact mechanism by which barley straw controls algae is not entirely understood, but several hypotheses have been proposed:

1. Release of Inhibitory Compounds

Upon Barley straw decomposes releasing several organic compounds as phenolic acids (ferulic acid – p-coumaric – acid), lignin's, and tannins upon decomposition. These compounds have been observed to inhibit algal growth by:

Disrupting Photosynthesis: The inhibition of photosynthesis in algae by phenolic compounds can occur by interfering with chlorophyll production, the electron transport chain in the photosynthetically process (Ridge *et al*., 1995; Ball *et al*., 2001).

Impacting Membrane Integrity: Released substances could increase the permeability of algal cell membranes so that cellular content (or damage) was leaked (Everall NC and Lees DR., 1996; Pillinger *et al*., 1994).

2. Production of Reactive Oxygen Species (ROS)

Hydrogen peroxide and other ROS (including under aerobic conditions) can be produced during degradation of barley straw by water, and such decomposition may take place in the field. Oxidative stress by these ROS will damage vital cellular components such as lipids, proteins and DNA (Pillinger, Cooper, & Ridge, 1994; Waybright *et al*., 2009).

Photo-Fenton Reaction Enhancement: Decomposing barley straw may release iron and sunlight will help to drive the photo- Fenton reaction to produce hydroxyl radicals, that may further contribute to algal growth inhibition activity (Welch *et al*., 1990).

Figure no 02: Centre for Ecology and Hydrology (CEH):2004 information sheet 1: control of algae with Barley straw (Everall NC and Lees DR, 1997)

3. Allelopathy

Barley straw may exhibit allelopathic effects, where the release of specific allelochemicals inhibits the growth of other organisms (Lembi, 2009). These allelochemicals can act through several pathways:

Inhibition of Cell Division: (Everall N, Lees D. 1996) report that certain allelochemicals can interfere with mitosis in algae, slowing or stopping cell division.

Blocking Nutrient Uptake: Some compounds may compete with, or block, essential nutrients (e.g. phosphate, nitrate) utilized by algal cells that aid in their growth (Newman & Barrett, 1993).

4. Nutrient Sequestration

Barley straw decomposition can contribute to nutrient sequestration around the straw, in particular nitrogen and phosphorus critical to algal growth (Gibson *et al*., 1990; Geiger *et al*., 2005). Indirectly it reduces water algal proliferation by tying these nutrients up.

Microbial Competition: Microbial community working to decompose straw may also directly compete for nutrients with algae (Ball *et al*. 2001).

5. Biofilm Formation

Decomposition of barley straw enables bacteria and fungi to grow on a substrate to form biofilms. Depending on the conditions of the environment these biofilms may produce secondary metabolites that are harmful to algae or outcompete the algae for light and nutrients (Ridge & Pillinger 1996; Caffrey & Monahan 1999).

Bacterial Antagonism: Certain bacteria associated with the decomposing straw can produce algicidal substances or enzymes that degrade algal cell walls (Welch *et al*., 1990).

6. Changes in Water Chemistry

The decomposition process can cause various changes in water chemistry that inhibit algal growth.

pH Alteration: The breakdown of organic material may lead to shifts in pH, making the water less favorable for certain types of algae (Everall NC and Lees DR., 1996).

Reduction in Light Penetration: Suspended organic matter from the decomposing straw can reduce light penetration in the water, which in turn can limit photosynthetic activity in algae (Geiger *et al*., 2005).

7. Enhanced Microbial Activity

Onset of barley straw presence in the water promotes dominance of specific microbial communities over algae to compete for available resources in the water. In addition to species selection, increased microbial decomposition activity may lead to the production of organic acids and other metabolites which may further inhibit algal growth (Waybright *et al*., 2009).

Bacterial Production of Algicidal Compounds: Many bacteria associated with barley straw decomposition can yet produce algicidal substances such as proteolytic enzymes, organic acids or antimicrobial peptides which kill algal cells (Ball *et al*., 2001).

8. Direct Physical Effects

The physical presence of straw in the water can have a shading effect that reduces light availability for algae, which is essential for photosynthesis. This can be especially important in small ponds where straw application is dense (Welch *et al*., 1990; Newman & Barrett, 1993).

9. Chelation of Metal Ions

Humic substances released from barley straw can bind with metal ions (e.g., iron, copper), making these metals less bioavailable to algae. Since certain algae require trace metals for growth and enzyme function, this chelation process can inhibit their proliferation (Pillinger *et al*., 1994).

10. Induced Dormancy or Encystment in Algae

Some inhibitory compounds released during the decomposition process can trigger dormancy or encystment in certain algae, especially dinoflagellates and some cyanobacteria. This dormancy reduces active growth and reproduction, effectively limiting algal blooms (Caffrey & Monahan, 1999).

11. Suppression of Cyanobacteria by Targeting Nitrogen Fixation

Blute-green algae, also known as cyanobacteria, are a good fixer of nitrogen, and can survive in nitrogen poor conditions. The decomposition of barley straw can specifically inhibit nitrogenase enzyme activity thereby limiting cyanobacterial growth more effectively than other types of algae (Ridge & Pillinger, 1996).

12. Influence on Algal Community Structure

Barley straw may change community composition of algae through the selective inhibition of some species and the promotion of others. Such a shift could help favor ecologically more balanced ecosystems and prevent blooms that are detrimental (Geiger *et al*., 2005; Perez *et al*., 2011).

13. Induction of Algal Cell Death through Programmed Cell Death (Apoptosis)

Recent investigations also show that some of the inhibitory compounds released by barley straw will provoke programmed cell death of some types of algae. This mechanism involves oxidative stress pathways and the activation of some enzymes that degrade cellular components (Ball *et al*., 2001; Waybright *et al*., 2009).

Factors Influencing the Effectiveness of Barley Straw:

1. Type of Algae: Some algae are more affected by barley straw than others. As it is, it tends to work well against green algae and cyanobacteria, but is less effective against diatoms (Geiger *et al*., 2005).
2. Water Conditions: Decomposition of barley straw and release of inhibitory substances are affected by water temperature, pH and toxicity. Since it is dependent on warm temperatures and high levels of dissolved oxygen for decomposition, the decomposition process is accelerated and the release of algistatic compounds (Welch *et al*., 1990) increased.
3. Quantity of Straw Used: Critical is how much barley straw is applied. The application rate that is generally recommended ranges between 25-50 grams of straw per square meter of water surface area (Everall NC and Lees DR., 1996). The straw wouldn't inhibit the growth of algal, however using too little may not and excess would cause oxygen depletion as the straw decomposes.
4. Age and Conditioning of Straw: Barley straw that is freshly harvested is less effective than that which has weathered for a few weeks. Natural microbial colonization with subsequent weathering permits the decomposition process and the release of inhibitory compounds (Pillinger *et a*l., 1994).

Advantages of Barley Straw Use:

1. Environmentally Friendly: Barley straw is a natural product, unlike chemical algicides, that does not introduce synthetic chemical pollutants into the environment. It is declared to be of minimal risk to aquatic life when used at recommended doses (Newman & Barrett 1993).
2. Cost-Effectiveness: One cheap, readily available and easy to apply treatment is barley straw, which can be used in, ponds, lakes, reservoirs and so on.
3. Long-Lasting Effects: The inhibitory compounds released by the continued decomposition process can be present in barley straw up to several months after application of the straw with the algistatic effects (Everall NC and Lees DR., 1996).

Limitations and Challenges:

1. Inconsistent Results: Barley straw application can be variable in effectiveness relative to the environmental conditions, type of algae present and application of the straw. However, complete control over algal blooms cannot be guaranteed (Geiger *et al*., 2005).
2. Delayed Action: Barley straw doesn't give immediate relief of algal blooms. Decomposition of the straw may not occur until several weeks, during which time inhibitory substances would begin to be released (Welch *et al*., 1990).
3. Potential for Oxygen Depletion: Barley straw decomposition may be applied in excessive amounts, consuming a large amount of dissolved oxygen, thereby harming aquatic organisms.
4. Not a Universal Solution: Barley straw is effective against some algae but not all. She is, in particular, less efficient against diatoms and some of the filamentous algae (Everall NC and Lees DR., 1996).

Field Applications and Case Studies:

1. Lake Management:

Barley straw has been reported to be successful in suppressing algae in a small eutrophic UK lake, as reported. (Everall NC and Lees DR., 1996). Complete eradication was not possible but algal biomass was significantly reduced. But algal biomass was significantly reduced, and complete eradication was not possible.

2. Aquaculture Ponds:

Barley straw has been used in fish farming to control algal blooms and keep water better qualities with less use of chemical treatments (Newman & Barrett, 1993).

3. Reservoirs:

In large reservoirs, barley straw has been applied with mixed results, depending on the time of application and the algae species (Pillinger *et al*., 1994).

4. Drinking Water Treatment:

Barley straw is being used at some water treatment facilities in situ to reduce algal growth in raw water storage reservoirs, especially in warm seasons when algal growth is abundant (Everall NC and Lees DR., 2000). Success depends upon the concentration of straw used and the algae types.

5. Golf Course Ponds:

On golf courses, barley straw has been used to improve the quality of ornamental ponds, resulting in a reduction of unsightly algal blooms, and improvements in aesthetics. And this approach seems to have been working well to keep clearer water for longer (Welch & Perkins, 1995).

6. Canals and Irrigation Channels:

Barley straw reduction in file frequency of algal blockages reduces frequency of algae blockages which maintains flow of water for agricultural channel use (Geiger and Schupp, 1996). It is noted that this is more effective in slower moving water than in fast flowing channels.

7. Urban Stormwater Ponds:

Barley straw applications have been evaluated for reducing algal growth caused by nutrients, in urban environments where stormwater ponds are used to manage runoff, to improve water quality prior to discharge into natural water bodies (Barrett & Newman, 1997).

8. Recreational Lakes:

Recreational lakes which have used barley straw to control seasonal algal blooms have reported water clarity improvements and decreased public complaints (Lewis *et al*., 1998).

9. Restoration of Wetlands:

In wetland restoration projects, too, the use of barley straw has been explored in order to help control invasive algal species and encourage growth of native plants (Rivett *et al*., 2008). In these environments, the use of barley straw has also been shown potential for increasing biodiversity.

10. Bioenergy Production:

Barley straw had been identified to be used not only for the control of algae but also as a feedstock for bioenergy development. Barley straw breakdown in aquatic environment promotes organic matter to support anaerobic digestion processes (González-Fernández *et al*., 2014).

11. Impact on Sediment Quality:

Application of barley straw has been demonstrated to alleviate sediment quality and reduce nutrient release from sediments to the water column, thereby reducing overall nutrient loading to the water column (Sondergaard *et al*. 2005). This has implications for long term water quality management.

12. Synergistic Effects with Other Treatments:

Combining barley straw treatments of algae with other algal control methods, such as aeration or biomanipulation (manipulating the aquatic food web), have been shown to increase the effectiveness of algal control strategies (Jeppesen *et al*., 2005).

Name of compound	Name of chemicals
Decomposing Straw	Acetic acid, 3-Methylbutanoic acid, 2-Methylbutanoic acid, Hexanoic acid, Heptanoic acid, Octanoic acid, Nonanoic acid, Decanoic acid, Dodecanoic acid, Tetra decanoic acid, Hexadecenoic acid, 1-Methylnaphthalene, 2-(1,1-Dimethylethyl phenol), (1,1-Dimethylethyl)-4-methoxyphenol, 2,6-Dimethoxy-4-(2-propenyl) phenol, 2,3-Dihydrobenzofuron, 5,6,7,7A-Tetrahydro-4,4,7A-trimethyl-2 (4H) benzofuranone, 1,1,4,4-Tetramethyl-2,6-bis(methylene) cyclohexone, 1-Hexacosene

Table no 01: Chemical constituent of barley straw (Everall NC and Lees DR., 1997)

CONCLUSION

It will be concluded that, the barley straw used for preventing growth of algae as a chemical algicides. It is a safe and a sustainable method, more suitable for small to medium water bodies and for aquaculture. However, the variability in its effectiveness and the time delay in achieving results require careful planning and application. Further research is needed to better understand the mechanisms behind its algistatic effects and to optimize application techniques for different water conditions.

Barley straw extract is found to be ineffective to control invasive submerged aquatic plants such as Cabomba Carolinian and Elodea untallied, and has even promoted their growth, according to the study. Given the presence of alien plants, this in turn demonstrates BSE’s unsuitability for managing invasive macrophytes, with potential for stimulating growth of non-target species and imbalances in aquatic ecosystems. The literature also suggests that environmental factors such as water temperature, pH, and oxygen levels significantly influence barley straw's effectiveness in algal control, making it necessary to consider local conditions carefully to optimize algistatic compound release. Additionally, barley straw's inhibitory effects are not immediate and may take weeks to manifest, posing challenges for rapid algal bloom management.

Despite these limitations, barley straw remains a sustainable and eco-friendly option compared to chemical treatments, as its natural origin avoids introducing synthetic substances into the environment, making it a safer choice for water quality maintenance. However, the need for proper application rates is critical to prevent potential negative effects like oxygen depletion in water bodies, which could harm aquatic life. Further research is necessary to understand the specific mechanisms through which barley straw inhibits algal growth and to optimize its application across various aquatic conditions.

Given these factors, barley straw should not be used as a standalone solution but as part of a broader integrated algae management strategy, which could include nutrient control and other biological or mechanical methods. It is advisable to avoid applying barley straw in areas with invasive submerged aquatic plants, as it may inadvertently enhance their growth. These findings can inform water management practices, advocating for the cautious use of barley straw primarily in environments free from invasive species and emphasizing the need for thorough environmental assessments before application.

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