Potentialities of the Asian Watergrass (*Hygroryza aristata*) as Feed in Aquaculture

Md. Moazzem Hossain, Md. Shahjahan, Saleha Khan, Abdul Shukor Juraimi, Md. Kamal Uddin and Mahmudul Hasan

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Abstract: Asian watergrass (*Hygroryza aristata*) is an herbaceous glabrous aquatic-rooted floating grass naturally growing in the tidally inundated coastal marshes, beels and canals. The ecology and growth performance of Asian watergrass were evaluated in the coastal wetland (CWL), in an artificially created canal (ACC) within the coastal wetland and in the university research ponds (URP). The study was conducted with three replications in each area. The proximate compositions of the leaves, roots and stems of the grass were determined. Important water and soil quality parameters were found favorable for the growth and production of Asian watergrass. The growth performance and total production of the grass were significantly higher in ACC (length: 2.78 m and weight: 386.86 metric ton ha$^{-1}$) in comparison with those in CWL (2.36 m and 256.67 metric ton ha$^{-1}$) and URP (2.22 m and 137.10 metric ton ha$^{-1}$). Higher content of crude protein was found in leaves (17.49%) followed by roots (12.17%) and stems (9.39%), while the minerals (ash) and fiber contents were found higher in stems (25.68% and 9.53%) in comparison with those in leaves and roots. The findings indicate that the coastal wetlands of Bangladesh having available nutrients in both water and soil are suitable for higher growth and production of Asian watergrass. Considering the nutrient compositions, the Asian watergrass may be an important potential source of feed ingredient that may be used as fish feed in aquaculture throughout the world.

Keywords: *Hygroryza aristata*; coastal wetland; nutrients; proximate composition; fish feed

1. Introduction

The Asian watergrass (*Hygroryza aristata*) is an herbaceous glabrous aquatic-rooted floating grass. The root of this grass attaches onto the bottom soil and its stem is spongy with feathery branched superficial whorled roots at the nodes, and it naturally becomes long with the increase of water level [1]. It is native to China, Nepal, India, Bangladesh, Pakistan, Sri Lanka, Myanmar, Cambodia, Laos, Malaysia, Thailand and Vietnam. This grass naturally grows in the tidally inundated low-lying coastal wetlands in Barishal, Pirojpur, Gopalgonj, Jhalokati, Patuakhali, Barguna and Bhaba districts of Bangladesh, and in the rainy season, some of these wetlands become as deep as 1–2 m. The grass increases with the increase of water level during the summer season, but in the winter season when the water level is decreased significantly in the wetlands, it becomes attached onto the bottom soil, growing new branched superficial roots at stem nodes with stunted growth [1]. Naturally, it grows again with increasing temperature and water level. This grass provides good hiding places to aquatic insects, crustaceans and mollusks, which are eaten by many species of fish. This grass is a preferred food of some species of fish, particularly the grass...
carp. The local farmers cultivate this grass in their tidally inundated low-lying wetlands instead of rice production for getting more profit. In some cases, the farmers grow one crop of rice during dry/winter season in their wetlands and after harvesting it they cultivate the grass and use it for production of organic compost that is used for producing vegetables and seedlings of spice crops on the floating beds.

In recent years, the price of commercial fish feed has been increased globally due to the increase of fish meal cost that created perilous situation to the aquaculturists throughout the world [2]. Fisheries scientists and aquaculturists have been working to replace the fish meal by plant protein sources to reduce fish feed cost as well as fish production cost. Many species of aquatic plants are considered important nutritional sources for herbivorous-omnivorous fish [3,4], and utilization of plant leaves in the diet of fish due to its high nutrient content is well documented [5,6]. Various types of grasses, vegetables, aquatic weeds, plant’s leaves, seeds and seed extracts are commonly used in the fish feed industry [7]. Utilization of plant protein sources in the feed industry is sustainable, environment-friendly and cost effective [8,9]. In our recent studies, the direct use of Asian watergrass as fish feed exhibited improved growth of cultured fish [1,10].

Aquatic plants are very important sources of fish feed and have positive effects on improvement of water quality and remediation of aquaculture effluents [11–14]. These eco-services may be beneficial for increasing the sustainability of small-scale aquaculture all over the world. Aquatic plants have the ability to improve the water quality by absorbing nutrients with their effective root system. Simultaneously, they actively contribute to the promotion and maintenance of food webs and services in freshwater ecosystems [15,16]. The aquatic plants may influence the nutrient cycle, absorbing solids and nutrients by their submersed roots and leaves [17] and reducing nutrients released from sediment by protection against the wave action [18]. Gupta [19] reported that the *Eichhornia crassipes* is found to be most efficient for removing biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrogen, phosphorus, organic carbon, suspended solids, phenols, pesticides, heavy metals, etc., from wastewater. The whole plant body of *Hydrilla verticillata* (submerged macrophyte) plays an important role in absorbing nutrients. Moreover, diversified usages of aquatic plants have been practiced worldwide. The biomass of some aquatic plants such as *Elodea nuttallii* (Planch) has already been investigated with regard to its suitability as a raw material for cosmetics [20], as a starting material for hydrothermal carbonization [21] and as a substrate for energy production in biogas plants [22].

The development and sustainability of aquaculture is subjected to the identification and formulation of new, suitable and economically feasible alternative plant protein ingredients for fish feed [23]. Utilization of local ingredients and identification of alternative raw materials for fish feed formulation become necessary due to the increase of the cost of fish meal throughout the world. These less conventional ingredients are often ideal for producing farm-based aqua feeds. The Asian watergrass can be used as an alternative source of protein in fish feed due to its high nutrient contents. Simultaneously, it may serve as a natural bio-filter absorbing excess nutrients from the aquaculture ponds. The ecology and growth performance of this grass as well as proximate composition of different parts such as leaves, roots and stems were studied to know the potentialities of the grass as fish feed in aquaculture and a feed ingredient in the formulation of aqua feed. Therefore, the aim of this work was to study the ecology, growth performance and proximate composition of the Asian watergrass in the inundated low-lying coastal wetlands of Bangladesh.

### 2. Materials and Methods

#### 2.1. Study Area and Experimental Design

The experiment was carried out in the coastal wetlands and in the research ponds of Patuakhali Science and Technology University (PSTU) for a period of 10 months from January to October 2019 (Figure 1). The study was conducted in the coastal wetland (CWL), in the artificially created canal (ACC) within the coastal wetland in the Banaripara upazila (sub-district) under Barishal district and in the university research ponds (URP) in PSTU.
The study was conducted with three replications in each area. About 360 m² (30 × 12 m) inundated low-lying coastal wetland was selected for CWL and another 360 m² (60 × 6 m) artificially created canal adjacent to the treatment one was selected for ACC. An approximately 0.6–0.7 m deep canal was created artificially within the wetland, making parallel dykes (locally called kandi). The excavated bottom soil was kept on the dykes at two lateral sides and the height was raised to a level where they are not inundated during high tide or even during the rainy season when the water level becomes highest in the year. As a result, the bottom of treatment two was 0.6 to 0.7 m deeper in comparison with treatment one and other adjacent coastal wetlands. Water level changed twice daily by tidal action in both CWL and ACC treatments due to high and ebb tides, but not in URP treatment due to closed water body (ponds). At the beginning of the experiment, all types of unwanted aquatic weeds were removed from the selected CWL and ACC. Subsequently, the total area of CWL and ACC were separated into 3 similar sized experimental plots (each plot: 10 × 12 m in CWL and 20 × 6 m in ACC). At the same time, URP (each pond: 15 × 8 m) was set up in the research ponds of PSTU. The ponds were de-watered and unwanted aquatic weeds were removed.

Figure 1. Map of Bangladesh showing the study area.

2.2. Plantation of Asian Watergrass

Asian watergrass was planted in the bottom soil of the total area of each treatment on 1 January 2019. During plantation, about a 0.2–0.3 m long anterior portion of Asian watergrass was used as seedling, and 4–5 pieces were planted together according to Hossain et al. [10].
2.3. Analysis of Water Quality Parameters

The water quality parameters, such as water temperature (°C), salinity (‰), pH and dissolved oxygen (DO) (mg L\(^{-1}\)), were measured at monthly intervals by using a thermometer, a digital refractometer (Brix HI 96801), a portable pH meter (pHep, HANNA Instruments, Bucharest, Romania) and a portable DO meter (DO-5509, AF.11581, Taiwan), respectively. The water samples were collected from each treatment in 250 mL plastic bottles to determine the total alkalinity (mg L\(^{-1}\)), nitrate-nitrogen (mg L\(^{-1}\)), nitrite-nitrogen (mg L\(^{-1}\)) and phosphate-phosphorus (mg L\(^{-1}\)). The total alkalinity was determined by the titrimetric method using 0.02 N H\(_2\)SO\(_4\) titrant and methyl orange indicator. The nitrate-nitrogen (mg L\(^{-1}\)), nitrite-nitrogen (mg L\(^{-1}\)) and phosphate-phosphorus (mg L\(^{-1}\)) were measured using a spectrophotometer (DR 1900, HACH, Loveland, CO, USA). NitraVer®6 Nitrate reagent, NitriVer®3 Nitrite reagent and PhosVer®3 Phosphate reagent were used for the determination of nitrate-nitrogen, nitrite-nitrogen and phosphate-phosphorus, respectively.

2.4. Analysis of Soil Quality Parameters

Soil quality parameters such as soil pH, electric conductivity (EC), exchangeable sodium (Na), exchangeable potassium (K), exchangeable calcium (Ca), exchangeable magnesium (Mg), available nitrogen (N), available phosphorus (P) and available sulfur (S) were measured in the Laboratory of the Department of Agricultural Chemistry, Faculty of Agriculture, PSTU. About 0.5–0.6 kg soil samples were collected from each treatment at the middle of the culture period. Soil samples were collected from the top 15–20 cm of the bottom using a 15 cm diameter hole plastic pipe. Collected samples were kept in previously marked polyethylene bags and stored at \(-4\) °C for analysis. The electrical conductivity (EC) was determined by a conductivity meter (EC Meter, Hanna) following the method of Tandon [24]. Soil pH was determined with the help of a glass electrode pH meter (Microprocessor pH Meter-211, Hanna) as described by Jackson [25]. Na, K, Ca and Mg were determined with neutral 1 N ammonium acetate (CH\(_3\)COONH\(_4\)) following the ammonium acetate extraction method described by Jackson [24]. Available soil nitrogen, phosphorus and sulfur were determined following Olsen et al. [26] and Tandon [24].

2.5. Determination of the Growth Performance of Asian Watergrass

The length of the Asian watergrass was measured in meters (m) using a measuring tape during plantation and thereafter at monthly intervals directly in the field to determine the growth performance. At the end of the study period in October 2019, the Asian watergrass was collected from each area, kept under a shade separately for 1 day to remove water and subsequently, the weight was measured in kilograms (kg) using a weighing balance and converted into metric tons.

2.6. Analysis of Proximate Composition

Proximate compositions of leaves, stems, and roots of Asian watergrass were analyzed following the analytical methods of AOAC [27]. After collection, the grass was kept under a shade to remove water for 1–2 h. Then, the leaves and roots were separated from the stems and dried under the sunlight for 10–12 days. After proper drying, all the samples of leaves, roots and stems were packaged in marked polyethylene bags separately and the proximate compositions were analyzed.

2.7. Data Analysis

Values of all the measured variables are expressed as mean ± standard deviation (SD). The water quality parameters were analyzed following a two-way analysis of variance (ANOVA) to reveal the statistically significant differences among the treatments. The data of the growth parameters were analyzed following a one-way analysis of variance (ANOVA). The paired comparison was made following Duncan’s Multiple Range Test (DMRT). The normality and homogeneity of variance tests were done in all groups of data.
before statistical analysis. Significance was assigned at the 5% level \( (p < 0.05) \). Statistical analyses were performed using PASW Statistics 20.0 software (IBM SPSS Statistics, IBM, Chicago, IL, USA).

3. Results

3.1. Water Quality Parameters

Among the water quality parameters, salinity, pH, dissolved oxygen, total alkalinity and phosphate-phosphorus found in URP varied with the CWL and ACC, and water temperature, nitrate-nitrogen and nitrite-nitrogen were similar in the three areas (Table 1). Comparatively higher alkalinity \( (172.3 \pm 19.9 \text{ mg L}^{-1}) \) and pH \( (7.9 \pm 0.2) \) and lower dissolved oxygen \( (4.6 \pm 0.2 \text{ mg L}^{-1}) \) were found in URP in comparison with CWL \( (108.0 \pm 16.9 \text{ mg L}^{-1}, 7.1 \pm 0.1 \text{ and } 5.4 \pm 0.2 \text{ mg L}^{-1}) \) and ACC \( (105.5 \pm 16.7 \text{ mg L}^{-1}, 7.0 \pm 0.2 \text{ and } 5.4 \pm 0.2 \text{ mg L}^{-1}) \) (Table 1). The salinity was found to be 1% in URP throughout the study period, but 2% salinity was observed in January and February in CWL and ACC (Supplementary Figure S1b). Monthly variations were found in all observed water quality parameters in all treatments throughout the study period due to seasonal changes (Supplementary Figure S1a–h). Both the highest water temperature \( (34.1 \degree C) \) in summer and lowest water temperature \( (15 \degree C) \) in winter were recorded in the closed water of URP treatment. The low levels of nitrate-nitrogen \( (0.01–0.10 \text{ mg L}^{-1}) \), nitrite-nitrogen \( (0.003–0.027 \text{ mg L}^{-1}) \) and phosphate-phosphorus \( (0.09–0.63 \text{ mg L}^{-1}) \) were observed in all three treatments (Table 1).

Table 1. Water quality parameters (mean ± standard deviation (SD), \( n = 30 \)) in three different treatments.

| Parameters                      | CWL                      | ACC                      | URP                      |
|---------------------------------|--------------------------|--------------------------|--------------------------|
| Water temperature (\degree C)   | 27.9 ± 4.3 (18.0–32.5)   | 28.1 ± 4.3 (18.5–32.8)   | 27.4 ± 6.1 (15.0–34.1)   |
| Salinity (%)                    | 1.2 ± 0.4 (1.0–2.0)      | 1.2 ± 0.4 (1.0–2.0)      | 1.0 ± 0.0 (1.0–1.0)      |
| Dissolved oxygen (mg L\(^{-1}\))| 5.4 ± 0.2 (5.1–5.8)      | 5.4 ± 0.2 (5.0–5.8)      | 4.6 ± 0.2 (4.2–4.9)      |
| pH                              | 7.1 ± 0.1 (6.8–7.3)      | 7.0 ± 0.2 (6.8–7.4)      | 7.9 ± 0.2 (7.6–8.2)      |
| Nitrate-nitrogen (mg L\(^{-1}\))| 0.06 ± 0.02 (0.02–0.08) | 0.06 ± 0.03 (0.01–0.10) | 0.05 ± 0.01 (0.02–0.08) |
| Nitrite-nitrogen (mg L\(^{-1}\))| 0.010 ± 0.002 (0.003–0.013)| 0.010 ± 0.002 (0.005–0.014)| 0.010 ± 0.006 (0.003–0.027)|
| Phosphate-phosphorous (mg L\(^{-1}\))| 0.28 ± 0.07 (0.14–0.45) | 0.34 ± 0.11 (0.14–0.63) | 0.19 ± 0.09 (0.09–0.54) |
| Total alkalinity (mg L\(^{-1}\))| 108.0 ± 16.9 (72.0–134.0)| 105.5 ± 16.7 (64.0–130.0)| 172.3 ± 19.9 (142.0–208.0)|

\( n = \) number, CWL = coastal wetland, ACC = artificially created canal, URP = university research pond, \( ^\circ \text{C} = \) degrees Celsius, \( \% = \) parts per thousand, mg = milligram, L = liter. Values within the parentheses indicate the range.

3.2. Soil Quality Parameters

The measured pH, exchangeable potassium, exchangeable calcium and available phosphorus of the collected bottom soil varied among the treatments, but no marked variation was found in electric conductivity, exchangeable sodium, exchangeable magnesium and available nitrogen and sulfur (Table 2). Significantly higher \( (p < 0.05) \) soil pH \( (7.3 \pm 0.2) \), exchangeable potassium \( (117.7 \pm 9.6 \text{ mg kg}^{-1}) \) and exchangeable calcium \( (823.2 \pm 16.0 \text{ mg kg}^{-1}) \) were found in URP in comparison with CWL \( (59 \pm 0.6, 81.4 \pm 10.7 \text{ mg kg}^{-1} \text{ and } 683.9 \pm 24.9 \text{ mg kg}^{-1}) \) and ACC \( (6.0 \pm 0.3, 78.2 \pm 4.7 \text{ mg kg}^{-1} \text{ and } 684.0 \pm 32.2 \text{ mg kg}^{-1}) \). Significantly higher \( (p < 0.05) \) available phosphorus was found in CWL \( (300.2 \pm 25.1 \text{ mg kg}^{-1}) \) in comparison with ACC \( (45.1 \pm 6.4 \text{ mg kg}^{-1}) \) and URP \( (27.6 \pm 1.8 \text{ mg kg}^{-1}) \).
Table 2. Soil quality parameters (mean ± SD, n = 3) in three different treatments.

| Area | pH  | Electric Conductivity (dS/m) | Exchangeable Na (mg kg⁻¹) | Exchangeable K (mg kg⁻¹) | Exchangeable Ca (mg kg⁻¹) | Exchangeable Mg (mg kg⁻¹) | Available N (mg kg⁻¹) | Available P (mg kg⁻¹) | Available S (mg kg⁻¹) |
|------|-----|-----------------------------|--------------------------|-------------------------|---------------------------|--------------------------|---------------------|---------------------|---------------------|
| CWL  | 5.9 ± 0.6 b | 0.4 ± 0.2 (0.3–0.5) | 83.6 ± 11.7 (71.0–94.1) | 81.4 ± 10.7 b | 683.9 ± 24.9 b | 25.2 ± 0.2 (25.0–25.4) | 0.085 ± 0.006 (0.081–0.092) | 300.2 ± 25.1 a (274.0–324.1) | 141.0 ± 14.5 (124.3–149.7) |
| ACC  | 6.0 ± 0.3 b | 0.2 ± 0.1 (0.1–0.2) | 73.1 ± 3.7 (70.8–77.3) | 78.2 ± 4.7 b | 684.0 ± 32.2 b | 25.3 ± 0.2 (25.1–25.5) | 0.087 ± 0.009 (0.076–0.095) | 45.1 ± 6.4 b (39.1–51.8) | 117.8 ± 29.1 (85.4–141.8) |
| URP  | 7.3 ± 0.2 a | 0.2 ± 0.1 (0.2–0.3) | 87.2 ± 4.6 (81.9–89.9) | 117.7 ± 9.6 a | 823.2 ± 16.0 a | 25.1 ± 0.3 (24.9–25.4) | 0.097 ± 0.002 (0.095–0.098) | 27.6 ± 1.8 b (25.5–28.8) | 136.9 ± 22.9 (121.4–163.2) |

m = meters, mg = Milligram, kg = Kilogram, Na = Sodium, K = Potassium, Ca = Calcium, Mg = Magnesium, N = Nitrogen, P = Phosphorus, S = Sulfur, dS = Decisiemens. Values within the parentheses indicate the range. Values in a column having different superscripts in different treatments are significantly different (p < 0.05).

3.3. Growth and Production of the Grass

At the end of the study period in October 2019, the total length (m) of the Asian watergrass was found significantly higher (p < 0.05) in ACC (2.78 ± 0.05 m) in comparison with CWL (2.36 ± 0.07 m) and URP (2.22 ± 0.1 m) (Table 3 and Figure 2). The total production of the grass was also found significantly higher (p < 0.05) in ACC (386.86 ± 37.86 metric tons ha⁻¹) followed by CWL (256.67 ± 30.55 metric tons ha⁻¹) and URP (137.10 ± 30.55 metric tons ha⁻¹) (Figure 3).

![Figure 2](image-url)  
**Figure 2.** Growth increments of the Asian watergrass in different treatments.
The proximate compositions of leaves, roots and stems of Asian watergrass are presented in Table 4. The crude protein was found comparatively higher in leaves (17.49% ± 0.21%) followed by roots (12.17% ± 0.65%) and stems (9.39% ± 0.23%). The lipid content was also found higher in leaves (2.15% ± 0.02%), followed by stems (2.07% ± 0.09%) and roots (1.07% ± 0.02%). Carbohydrate content was high in all body parts of the grass, the highest was in roots (56.97% ± 0.97%) followed by the stems (53.33% ± 0.61%) and leaves (50.96% ± 0.65%). Both mineral (ash) and crude fiber content were found highest in stems (25.68% ± 0.84% and 9.53% ± 0.11%) than those in leaves and roots.
Table 4. Proximate compositions (mean ± SD; n = 3) of leaves, roots and stems of Asian watergrass.

| Proximate Composition (%) | Leaves     | Roots      | Stems      |
|---------------------------|------------|------------|------------|
| Moisture                  | 11.49 ± 0.18 | 9.28 ± 0.24 | 10.44 ± 0.23 |
| Crude protein             | 17.49 ± 0.21 | 12.17 ± 0.65 | 9.39 ± 0.23  |
| Crude lipid               | 2.15 ± 0.02  | 1.07 ± 0.02  | 2.07 ± 0.09  |
| Crude fiber               | 8.47 ± 0.07  | 7.85 ± 0.12  | 9.53 ± 0.11  |
| Carbohydrate              | 50.96 ± 0.65 | 56.97 ± 0.97 | 53.33 ± 0.61 |
| Ash                       | 20.93 ± 0.47 | 21.95 ± 0.33 | 25.68 ± 0.84 |

SD = standard deviation, n = number, % = percentage.

4. Discussion

4.1. Ecology and Growth Performance of the Asian Watergrass

The growth and production of Asian watergrass (*Hygropyza aristata*) were significantly higher in ACC. Considerable increase in production of this grass would be possible through periodic partial harvesting during each production cycle. Most probably, the water depth has greatly influenced the growth and production of this grass as the depth was 0.6 to 0.7 m higher in ACC in comparison with CWL and URP. Edwards [28] reported 200 tons/ha/year productions of aquatic macrophytes in eutrophic waters in the tropics. About 750 tons/ha/year production of water hyacinth in irrigation canals was reported in China [29]. Reddy and De Busk [30] reported the biomass yield of water lettuce of 72 tons/ha/year in nutrient non-limiting waters in central Florida, USA. Our present findings on the growth and production of Asian watergrass are logical considering the production of different aquatic floating and submerged plants reported by the above authors.

The growth and production of aquatic grass are greatly influenced and controlled by different water quality parameters. The growth performance of Asian watergrass was found to be increased with the increase of water temperature from March to October in all treatments (Supplementary Figure S1a), and most probably, this period is the best season for higher growth of this grass in the coastal wetlands of Bangladesh. The photosynthetic efficiency of aquatic plant biomass is much higher than the average photosynthetic efficiency of terrestrial biomass [31], which is also related to the higher growth and production of Asian watergrass. The aquatic plant giant salvinia (*Salvinia molesta* Mitchell) is reported to survive and grow in a wide range of temperatures, of –3 to 43 °C [32], but optimal growth occurs at 24 to 28 °C [33,34]. Imaoka and Teranishi [35] reported that the growth rate of water hyacinth increased with the increase of the ambient temperatures from 14 to 29 °C.

In the present study, the temperature and the water level were found to be increased in all treatments with culture period due to seasonal influence. In our previous study, during culture of fish using this Asian watergrass, we observed higher growth of the plant during summer and monsoon months when both temperature and water level were high [1]. The salinity is another water quality parameter for the growth and survival of some aquatic plants in the coastal region. The growth and production performance of Asian watergrass were found significantly higher in ACC and CWL, where salinity was found to be 1–2%. Better growth of water hyacinth (*Eichhornia crassipes*) was found in water having salinity less than 1% [36], and it was unable to survive at salinities above 2% [37]. We also assume that 1–2% salinity is required for the higher growth of Asian watergrass in the coastal region [1,10]. Approximately neutral water pH (7.0 ± 0.2 in ACC and 7.1 ± 0.1 in CWL) and slightly acidic soil pH (6.0 ± 0.3 and 5.9 ± 0.6) were found in ACC and CWL that might have helped in higher growth and production of Asian watergrass in comparison with URP (water pH 7.9 ± 0.2 and soil pH 7.3 ± 0.2). In our previous study, we found good growth of the grass in the coastal wetlands, where pH ranged between 6.6 and 7.3 [1].

The pH range between 6.9 and 7.8 was found suitable for the higher growth of *Lemna perpusilla* [38]. The aquatic floating macrophytes, especially duckweeds, can tolerate a wide range of pH (5 to 9), but optimum growth occurs in a medium range of pH 5.0–7.0 [39], which strongly supported our findings. The nitrate-nitrogen was found more or less similar in quantities (0.01–0.10 mg L⁻¹) in all treatments during the study period (Table 1) that
might be sufficient for the growth of this grass in the coastal wetlands. On the other hand, phosphate-phosphorus was found at higher quantities in ACC (0.34 ± 0.11) and CWL (0.28 ± 0.07) in comparison with URP (0.19 ± 0.09). The total alkalinity was found significantly higher in URP in comparison with CWL and ACC, but the growth and production of Asian watergrass was found significantly lower in URP which indicates that the total alkalinity had no strong effect on the growth and production of the grass in the coastal wetlands.

In natural waterbodies, the essential nutrients required for aquatic plant growth generally come to water from the soil. Slightly acidic soil pH was found in ACC (6.0 ± 0.3) and CWL (5.9 ± 0.6) that might have influenced the growth and production of Asian watergrass in ACC and CWL in comparison with the slightly alkaline soil pH in URP (7.3 ± 0.2). Most of the nutrients become available for plant use within the pH range between 5.6 and 7.5. The optimum pH range for most plants is between 5.5 and 7.0. Islam and Khondker [40] reported that the *Spirodela polyrrHiza* grow best at a pH between 6.5 and 7.5. Generally, the quantitative requirement of phosphorus for maximum growth of aquatic plants is low, but it is necessary for plant growth and after nitrogen it is the major limiting nutrient. The available soil nitrogen was found more or less similar in quantities in all treatments (0.076–0.098 mg kg$^{-1}$) that were within the suitable range for higher growth and production of Asian watergrass. Availability of different nutrients in the water column and in the bottom mud generally affects the community composition of submerged plants. Ecological factors such as bottom mud and water velocity can modify the availability of nutrients for plants [41,42]. Barko and Smart [43] reported that the sediment appears to be a nutrient source for rooted plants mainly when nutrients are not sufficiently available in the water. In stream and river systems, the majority of nutrients flow on as particles or in dissolved condition in the water. Aquatic plant species have different trophic requirements and respond differently to sediment nutrient supply [44], and when little sediment nutrients are available, plants uptake water nutrients [45,46]. Agami and Waisel [47] reported that both roots and shoots of aquatic plants are able to obtain nutrients from water and soil. Available soil phosphorus was found significantly higher in CWL followed by ACC and URP (Table 2), which indicated that the phosphorus influenced the growth and production of Asian watergrass in the submerged low-lying coastal wetlands (Supplementary Figure S1h). According to Wilson et al. [48], the quantitative presence of available nitrogen and phosphorous are the most important limiting factors for the growth of aquatic macrophytes. Wilson et al. [49] reported that nitrogen becomes limiting when the total nitrogen concentration is less than seven times that of the phosphorus concentration. Moreover, other observed soil quality parameters, particularly electric conductivity (EC), exchangeable sodium (ENa), exchangeable potassium (EK), exchangeable calcium (Eca), exchangeable magnesium (EMg) and available sulfur (AS), were in suitable range in all treatments for growth and production of Asian watergrass in the coastal region of Bangladesh.

### 4.2. Nutrient Compositions of the Asian Watergrass

Comparatively higher amounts of protein, minerals and carbohydrate were found in the leaves and roots of Asian watergrass (Table 4). Particularly, crude protein content found in the leaves of this grass (17.49% ± 0.21%) is higher in comparison with many other aquatic plants that are used as fish feed, such as oxygen weed (14.6%), water milfoil (13.7%), hornwort (17%), water hyacinth (9.37%), sedge/water chestnut (5%), water lettuce-pistia (11.4%), water fern (11.6%) and seaweed (3%) [50–55]. The proximate composition of Asian watergrass found in the present study is supported to be used as an ingredient of commercial fish feed. Freshly harvested aquatic plants contain huge amounts of minerals depending on the type of plant. Rath [56] reported that phosphorus, magnesium, copper, zinc and manganese are present in similar concentrations as they are present in terrestrial forages, but sodium is 10–100 times, iron 4–19 times and potassium 3–6 times higher in aquatic plants than the terrestrial plants. Aquatic macroalgae are considered to be a high-quality source of protein, with the majority of species having equivalent, or higher,
total essential amino acids as a proportion of total amino acids than traditional agricultural crops and fish meal [57–60].

4.3. The Asian Watergrass Used as Direct Fish Feed

Utilization of plant protein ingredients in the fish feeds can reduce their wastage, minimize cost of production and provide adequate nourishment to fish without affecting the environment [61]. Aquatic plants are considered important nutritional sources for herbivorous-omnivorous fish and utilization of plant leaves in the diet of fish due to high nutrient content is well documented [2–6]. The water bodies where the grasses are grown can be used for fish culture and the grasses can be converted into useful feed ingredients. According to Edwards et al. [62], the floating and submerged aquatic plants that grow in the water body and are used directly as feed by the fish can be transformed into suitable fish feed ingredients. Submerged aquatic macrophytes are soft in nature, moderately rich in protein and are preferred by different herbivorous fish [5]. Asian watergrass was used directly for grass carp (Ctenopharyngodon idella) culture and obtained satisfactory production, and reduced fish production cost 2.95-folds in comparison with commercial feed [1]. The polycluture of grass carp with other co-species using the Asian watergrass was done, where grass carp consumed the grass and their feces served directly as fertilizer to grow plankton and indirectly invertebrates, which are used as food for other fish [10]. The whole body of the Asian watergrass is very soft and is the preferred food of grass carp, and the root of this grass is a preferred food of tilapia and silver barb. Pipalov [63] reported that the grass carp prefers soft-tissue aquatic plants, filamentous algae and duckweeds, and consumes all parts of preferred plants. Silver barb is a herbivorous species and grows well on low-protein diets, feeding mainly on aquatic plants, grasses and algae [64,65]. The tilapia is an omnivorous fish and consumes large quantities of plant materials [66–68]. Considering the growth increment, production performance, nutrient compositions and preference as feed of the fish, the Asian watergrass could be used as direct fish feed in aquaculture.

4.4. Use of Asian Watergrass in the Formulation of Aqua Feeds

The price of fish meal has been increased in recent years throughout the world due to a decline world capture fisheries that had been used in the formulation of aqua feed [69]. The average annual price of fish meal was the lowest in 1994 and 1999 at 403 and 433 US$/ton respectively, and it had continued to increase, reaching 1230 US$/ton in 2009 and thereafter with 1687 US$/ton in 2010 and a peak of 1747 US$/ton in 2013 [2]. Fish meal is the main protein source in aqua feed industries due to its balanced amino acid profiles and good source of essential fatty acids [70], but due to its high cost, variable quality as well as uncertain availability, emphasis has been given to the development of a cost-effective replacement of fish meal [71]. To make aquaculture more profitable, there is an urgent need to identify and incorporate the qualitative and quantitative requirements of dietary protein among the various ingredients used for the preparation of fish feeds. Aquatic plants are an excellent source of nutrients that can potentially be used in the formulation of fish feed [72]. Use of plant protein sources in the feed industry is sustainable, environment-friendly and cost-effective [8,9,73]. Plant proteins are almost similar to fish meal in terms of the protein content and protein and amino acid digestibility [74], and nutrition research has concentrated on the replacement of animal protein by plant proteins [75]. Hidalgo et al. [76] reported that inclusion of feedstuffs with relatively high levels of carbohydrate in formulated fish feed is preferred in view of its protein-sparing action that makes the diet more cost-effective. Use of plant protein in fish feed has been tried for various commercial fish cultures not only for its easy availability and economic benefits, but also, these plant products have lower amounts of phosphate and nitrogen than animal protein which reduce the chances of eutrophication [9]. Iskandar et al. [77] reported that 40% of fermented Lemna spp. used in artificial feed produced the highest growth of Nilem carp. Incorporation of 20% water lettuce in the formulation of a low-cost non-conventional diet of Labeo rohita
gave better growth performance in comparison with a control diet [78]. Yousif et al. [79] reported that 20% of water spinach (Ipomoea aquatica) substituted to fish meal in the diet of Nile tilapia fry was given the highest productivity and reduced the production costs. Rath and Dutta [80] reported that a 50% inclusion level of leaf meal of water hyacinth in the diet of Heteropneustes fossilis resulted in 150% more weight gain, and a 25% inclusion level in fingerlings of magur (Clarias batrachus) resulted in higher growth rate and better FCR. Indian major carps (rohu, catla and mrigal) fed a diet containing 25–35% water hyacinth leaf meal also showed encouraging results, both in the laboratory and under field conditions [81]. Utilization of local ingredients and identification of alternative raw materials for fish feed components in the formulation of aqua feeds have become necessary due to increases in the cost of fish meal throughout the world. Considering the nutrient compositions and growth performance of cultured fish in monoculture and polyculture, the Asian watergrass may be an important potential source of a plant protein ingredient that may be used in the formulation of aqua feeds throughout the world.

5. Conclusions

In the present study, we investigated the ecology and growth performance of the Asian watergrass as well as its proximate composition. The findings indicate that the aquatic environment and available nutrients in water and soil are suitable for higher growth and production of Asian watergrass in the inundated low-lying coastal wetlands of Bangladesh. The proximate composition of this grass was found at a satisfactory level, which is hopefully important for future aquaculture and in the formulation of aqua feed development throughout the world. However, further studies are necessary to investigate the presence of different amino acids and fatty acids components and find out whether there are any anti-nutritional factors or not in the Asian watergrass.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/su13126559/s1, Figure S1: Relationship between water quality parameters and growth performance (length in m) of H. aristata among the treatments: (a) Temperature, (b) Salinity, (c) Dissolved oxygen, (d) pH, (e) Total alkalinity, (f) Nitrate-nitrogen, (g) Nitrite-nitrogen and (h) Phosphate-phosphorus. Figure S2: Photograph of the grass in different treatments: (a) CWL, (b) ACC and (c) URP.

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