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*Research Article*

# Evaluation of the Nutrient Status of Some Hydrophytes in the Water Courses of Nile Delta, Egypt

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The nutritive values of three dominant hydrophytes along the water courses in Nile Delta, Egypt (*Echinochloa stagnina*, *Eichhornia crassipes*, and *Ceratophyllum demersum*) were evaluated in terms of estimating their phytomass, organic, and inorganic chemical compositions. Shoots were collected seasonally from 25 permanent stands representing the distribution of the three species along 15 canals and 10 drains distributed in 5 localities within the Nile Delta. Living and dead parts and total phytomass were estimated. Their inorganic (Na, K, Ca, Mg, P, Cu, Mn, and Pb) and organic (carbohydrates, total nitrogen, total protein, ether extract, digestible nutrient, digestible energy, metabolized energy, and net energy) contents were estimated. The vegetative phase of *E. stagnina* extended during winter, spring, and summer, while it is flowering and fruiting during autumn . On the other hand, *E. crassipes* and *C. demersum* attained their maximum flowering during spring and maximum fruiting during summer, while maximum vegetative phase during autumn and winter. *E. stagnina* had the highest mean annual phytomass, while *C. demersum* had the lowest. The living parts of *C. demersum* had the highest concentrations of Na, Ca, and Mg, while the living parts of *E. crassipes* had the highest of K and N. *C. demersum* had the ability to accumulate more concentrations of heavy metals than the other studied species. *E. crassipes* had the highest values of total carbohydrate and total proteins, while *E. stagnina* had the highest of crude fibers, and *C. demersum* had the highest of ether extract and ash contents. The living parts of *E. crassipes* and *C. demersum* were considered as excellent forages, while the dead parts of all species and the living parts of *E. stagnina* were evaluated as poor forage.

## 1. Introduction

In Egypt, the serious problem of feed shortage, especially green summer fodder, suppresses the improvement of animal production. Therefore, dependence on improving local food and food resources for both animals and humans is necessary for a sound policy. The animal feeding system is depending on the cultivation of Egyptian clover (*Trifolium alexandrinum* L.). It produces around 4.8 million ton of starch per year and could cover the requirements of animals with surplus of 0.9 million ton of starch. However, in summer period, there will be at least a deficiency of 1.5 million ton of starch, and most animals are in fact in a starving condition receiving less than their maintenance requirements [1]. This calls for studying other nonconventional sources of feed.

Aquatic plants can cause problems with navigation, agriculture, fisheries, and public health. However, they play an important role in organic production of most inland water systems, and through photosynthesis, oxygen releases and enriches the aeration of the water system. In addition, some hydrophytes help in stabilizing the bottoms, prevent the erosion of the banks, and removing the toxic compounds through absorption of nutrients from the water and upper bottom sediments [2]. Aquatic plants also provide shelter and nourishment to fish, water fowl, and other aquatic organisms; some of them are hosts for many epiphytes and provide source for paper pulp, fiber, and bioenergy. For example, many species of *Ceratophyllum*, *Lemna* and *Potamogeton* are eaten by birds [3]. Some other roles of hydrophytes in the ecosystem are: soil stabilizers, nutrient cyclers, nutrient pump from the soil, water purifications, and as a source of food for terrestrial organisms such as birds and man [4]. Other uses of fresh water weeds are for biogas production, fuel, fertilizer, soil additives or mulch, mushroom culture, paints [5], and the reduction of water pollutants from paper-pulp mills, tanneries [6], and rubber and oil palm industries [7].

The utilization of aquatic plants as natural filters for the abatement of pollutants transported by water in rivers or lakes is considered to be an effective, low-cost, and cleanup option to ameliorate the quality of surface waters. Indeed, aquatic plants have been extensively utilized in the last decades to clean pollutant water almost all over the world [8]. Moreover, aquatic plants play an important role in sequestering large quantities of nutrients [9] and metals [10–12] from the environment by storing them in the roots and/or shoots. Aquatic plants have high remediation potential for macronutrients because of their general fast growth and high biomass production. It is therefore important to evaluate the seasonal and spatial variations in plant accumulation in wetland systems in order to assess the potential for nutrient and metal removal by plant uptake and harvesting. The present study aims at evaluating the phytomass and nutritive values of three dominant hydrophytes along the water courses in Nile Delta, Egypt (*Echinochloa stagnina, Eichhornia crassipes,* and *Ceratophyllum demersum*) in terms of estimating the seasonal variation in their organic and inorganic chemical compositions. Such study may assist in understanding the importance of these plants in animal nutrition in Egypt.

## 2. Study Area

Geologically, the area of Nile Delta had been subjected to the same geologic events that affected the northern Egypt during the pre-Miocene geologic history. The Delta is bounded on the eastern side by a major upward zone which occupies most of north central Sinai. This zone extends westwards into "Cairo-Suez Anticlinal Horst" [13] and is followed, northwards, by a major downward zone which occupies most of the Delta and its extension into northwest Sinai. Because of the thouthands of years of agricultural activities, all soils, with exception of the northern most part, are manmade and are regarded as anthropic variants of the Gleysols and Fluvisols. The low layer Delta is flat separated from the open sea by a narrow belt of Silic semistatic (and partly dynamic) Ergosols. This sand dune bar grows in the littoral of the shallow sea and gradually separates closed lagoons, which consequently turn into salty lakes and then with the gradual silting into Marshy Solonchaks [14].

Most of the Egyptian cultivated land is irrigated by the river Nile through a network of canals and is drained by a similar network of drains. Most of these canals and drains were dug in the last 200 years [15]. The total length of both networks (excluding private ditches and drains) exceeds 47000 km: > 31000 km of canals and > 16000 km of drains [16].

Soil characters of the water courses in the middle Delta region, as estimated by El-Sheikh [17], indicated that most soils were consisted of silt (Table 1). The drains were characterized by higher salinity compared with canals. On the other hand, canals were characterized by higher N, K, and Ca; but lower OM, P, Na, and Mg than drains. Comparing the water samples of canals with those of drains, it was obvious that the canal water is less saline and is characterized by lower values of the dissolved elements.

According to the map of the world distribution of arid regions [18], the northern part of the Nile Delta lies in the arid zone, and the southern part lies in the hyperarid zone. The climatic conditions are warm summer (20 to 30°C) and mild winter (10 to 20°C). Though occasional short rainstorms occur in winter, most of the days are suny. The aridity index (P/PET) is between 0.03 and 0.20 at the North of the Delta (arid region) and less than 0.03 at the south (hyperarid region), where P is the annual precipitation, and PET is the potential evapotranspiration.

## 3. Materials and Methods

Twenty-five permanent sites (quadrats of 1 m$^2$) were selected to represent the distribution of three aquatic species along 15 canals and 10 drains distributed in 5 localities within the Nile Delta region (Figure 1). These species are *Echinochloa stagnina* (C.Mast.) Solms, (emergent), *Eichhornia crassipes* (C.Mast.) Solms, (free floating), and *Ceratophyllum demersum* L. (submergent). In each quadrat, the shoots of plants were harvested, separated into living and dead parts, and weighted. The oven dry weights at 105°C were estimated for the living parts, dead parts and total phytomass (gm dry weight m$^{-2}$). Composite samples were collected from living and dead parts of the shoots of each species, cleaned, dried at 60°C, and powdered in a metal-free plastic mill. Na, K, and Ca were analyzed using flame photometer, Fe, Mg, Cu, Mn, Zn, and Pb using Atomic Absorption and P, and N by spectrophotometer. Ash content was estimated by ignition at 500°C for about 24 hours. Ether extract (total lipids) was determined by extracting the plant with ether, and crude fiber was determined by the soxhlet extraction method. All these procedures are outlined by Allen et al. [19]. Crude protein (CP) was calculated by multiplying the insoluble nitrogen by the factor of 6.25 [20].

Digestible crude protein (DCP) was calculated according to the equation of Demarquilly and Weiss [21]:

$$\text{DCP (in \% DM)} = 0.929\ \text{CP (in \%DM)} - 3.52. \qquad (1)$$

Carbohydrates (NFE) were calculated from the following equation [22]:

$$\text{NFE (in \% DM)} = 100 - (\text{CP} + \text{CF} + \text{FAT} + \text{MINS}), \qquad (2)$$

where CF is the crude fibre, and MINS is the total minerals.

Total digestible nutrients (TDNs) were estimated according to the equation applied by Naga and El- Shazly [23]:

$$\text{TDN (in \% DM)} = 0.62\ (100 + 1.25\ \text{EE}) - \text{PK}, \qquad (3)$$

where EE is the percentage of ether extract, P is the percentage of crude protein, and K is the coefficient that depends on the protein and fiber contents (0.7).

Table 1: Mean and coefficient of variation (CV) of some characters of soil (a) and water (b) samples collected from canals and drains in the Nile Delta (after El-Sheikh 1989).

(a) Soil

| Water course | Sand% | Silt% | Clay% | OM% | CaCo$_3$% | EC $\mu$mohs cm$^{-1}$ | pH | N mg 100 gm$^{-1}$ | P mg 100 gm$^{-1}$ | K mg 100 gm$^{-1}$ | Na mg 100 gm$^{-1}$ | Ca mg 100 gm$^{-1}$ | Mg mg 100 gm$^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Terrace Zone | | | | | | | | | | | | | |
| Canal | | | | | | | | | | | | | |
| Mean | 44.9 | 42.9 | 11.9 | 6.3 | 3.4 | 1523 | 7.7 | 249 | 8.2 | 111 | 274 | 1980 | 263 |
| CV | 0.2 | 0.1 | 0.6 | 0.1 | 0.5 | 0.4 | 0.0 | 0.1 | 0.2 | 0.2 | 0.1 | 0.2 | 0.1 |
| Drain | | | | | | | | | | | | | |
| Mean | 41.5 | 47.5 | 11.3 | 6.8 | 2.9 | 2479 | 7.8 | 204 | 11.8 | 84 | 340 | 1546 | 301 |
| CV | 0.1 | 0.1 | 0.9 | 0.1 | 0.4 | 0.1 | 0.0 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 |
| Slope Zone | | | | | | | | | | | | | |
| Canal | | | | | | | | | | | | | |
| Mean | 42.8 | 45.2 | 11.8 | 6.8 | 2.1 | 418 | 7.8 | 256 | 7.7 | 80 | 137 | 1572 | 257 |
| CV | 0.1 | 0.0 | 0.4 | 0.2 | 0.2 | 0.3 | 0.0 | 0.2 | 0.1 | 0.3 | 0.1 | 0.2 | 0.1 |
| Drain | | | | | | | | | | | | | |
| Mean | 40.8 | 43.2 | 15.9 | 7.7 | 2.3 | 2154 | 7.8 | 209 | 11.4 | 74 | 348 | 1518 | 322 |
| CV | 0.2 | 0.1 | 0.6 | 0.2 | 0.2 | 0.7 | 0.0 | 0.2 | 0.3 | 0.3 | 0.4 | 0.1 | 0.1 |

(b) Water

| Water course | EC $\mu$mohs cm$^{-1}$ | pH | N mg L$^{-1}$ | P mg L$^{-1}$ | K mg L$^{-1}$ | Na mg L$^{-1}$ | Ca mg L$^{-1}$ | Mg mg L$^{-1}$ | Co$_3$ mg L$^{-1}$ | HCO$_3$ mg L$^{-1}$ | Cl mg L$^{-1}$ | So$_4$ mg L$^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Canals | | | | | | | | | | | | |
| Mean | 350.0 | 7.7 | 1.6 | 0.5 | 17.3 | 80.0 | 39.5 | 9.2 | 21.0 | 183.0 | 62.0 | 334.3 |
| CV | 0.1 | 0.2 | 0.7 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.3 | 0.2 | 0.2 | 0.2 |
| Drains | | | | | | | | | | | | |
| Mean | 1385.0 | 7.6 | 1.4 | 1.0 | 19.3 | 157.9 | 57.0 | 12.3 | 31.1 | 300.1 | 232.0 | 364.5 |
| CV | 0.2 | 0.0 | 1.0 | 0.6 | 0.6 | 0.01 | 0.04 | 0.3 | 0.0 | 0.0 | 0.2 | 0.2 |

Digestible energy (DE) was estimated following this equation [24]:

$$\begin{aligned}\text{DE (Mcal kg}^{-1}\text{)} &= 0.0504\ \text{CP (\%)} + 0.077\ \text{EE (\%)}\\ &\quad + 0.02\ \text{CF (\%)} + 0.000377\ \text{NFE}^2\text{(\%)}\\ &\quad + 0.011\ \text{NFE (\%)} - 0.152.\end{aligned} \tag{4}$$

Metabolized energy (ME) is 0.82 DE [25], and net energy (NE) is 1/2 ME.

Gross energy (GE) was calculated following this equation [24]:

$$\text{GE (Kcal 100 g}^{-1}\text{)} = 5.72\ \text{CP} + 9.5\ \text{EE} + 4.79\ \text{CF} + 4.03\ \text{NFE}. \tag{5}$$

One-way ANOVA was applied to assess the significance of variations in standing crop phytomass, elements, organic components, and nutritive variables in relation to the type of water course and the season [26].

## 4. Results

Phenological behavior of the studied species indicated that the vegetative phase *E. stagnina* extended during winter, spring, and summer, it is while flowering and fruiting during autumn (Figure 2). On the other hand, *E. crassipes* and *C. demersum* attained their maximum flowering during spring and maximum fruiting during summer, while maximum vegetative phase during autumn and winter. There was no pronounced sprouting of *C. demersum*.

The seasonal variation in the living and dead parts indicated that the living parts of *E. stagnina* and *C. demersum* attained their highest phytomass (866.8 and 200.1 gm$^{-2}$, resp.) during autumn, while those of *E. crassipes* (647.6 gm$^{-2}$) in summer (Figure 3). On the other hand, the dead parts of *E. stagnina* had their highest value (223.8 gm$^{-2}$) in autumn and *E. crassipes* (208.8 gm$^{-2}$) in winter. *E. stagnina* had the highest mean annual phytomass (801.1 gm$^{-2}$), while *C. demersum* had the lowest (160.9 g m$^{-2}$).

Living parts of *C. demersum* had the highest concentrations of Na (37.5 mg g$^{-1}$), Ca (35.8 mg g$^{-1}$), Mg (25.0 mg g$^{-1}$), P (0.8 mg g$^{-1}$), and Mn (1467.0 $\mu$g g$^{-1}$) in autumn, but

Table 2: Variation in the mean concentration ± standard deviation of the different macronutrients in the living (L) and dead (D) parts of the studied species in relation to different seasons.

| Variable | | Na mg g$^{-1}$ | K mg g$^{-1}$ | Ca mg g$^{-1}$ | Mg mg g$^{-1}$ | N mg g$^{-1}$ | P mg g$^{-1}$ |
|---|---|---|---|---|---|---|---|
| | | | | *Echinochloa stagnina* | | | |
| Winter | L | 25.2 ± 1.3 | 23.4 ± 0.7 | 15.1 ± 0.4 | 8.7 ± 0.4 | 10.9 ± 0.2 | 0.3 ± 0.1 |
| | D | 16.5 ± 0.7 | 12.5 ± 0.1 | 11.4 ± 0.1 | 8.7 ± 0.1 | 7.5 ± 0.2 | 0.2 ± 0.1 |
| Spring | L | 16.1 ± 0.8 | 21.7 ± 0.6 | 12.7 ± 0.4 | 8.8 ± 0.5 | 7.0 ± 0.3 | 0.3 ± 0.1 |
| | D | 14.0 ± 0.4 | 11.5 ± 0.2 | 9.2 ± 0.1 | 7. 9 ± 0.4 | 4.2 ± 0.2 | 0.2 ± 0.1 |
| Summer | L | 21.7 ± 1.1 | 24.3 ± 0.9 | 14.2 ± 0.5 | 5.4 ± 0.3 | 8.5 ± 0.3 | 0.3 ± 0.1 |
| | D | 20.4 ± 0.8 | 12.9 ± 0.3 | 10.6 ± 0.2 | 7.8 ± 0.2 | 7.1 ± 0.3 | 0.1 ± 0.1 |
| Autumn | L | 26.0 ± 1.0 | 21.6 ± 0.7 | 14.0 ± 0.4 | 8.3 ± 0.4 | 8.3 ± 0.2 | 0.3 ± 0.1 |
| | D | 14.3 ± 0.3 | 10.0 ± 0.1 | 8.0 ± 0.1 | 9.5 ± 0.3 | 5.6 ± 0.3 | 0.2 ± 0.1 |
| Annual mean | L | 22.3 ± 4.5 | 22.8 ± 1.3 | 14.0 ± 0.9 | 7.8 ± 1.6 | 8.7 ± 1.6 | 0.3 ± 0.0 |
| | D | 16.3 ± 2.9 | 11.7 ± 1.3 | 9.8 ± 1.5 | 8.7 ± 0.9 | 6.1 ± 1.5 | 0.2 ± 0.1 |
| F-value | L | 4.35** | ns | ns | 4.50** | ns | ns |
| | D | ns | ns | ns | 4.48* | ns | Ns |
| | | | | *Eichhornea crassipes* | | | |
| Winter | L | 17.4 ± 0.8 | 27.4 ± 1.2 | 26.5 ± 0.7 | 11.3 ± 0.3 | 6.7 ± 0.1 | 0.3 ± 0.1 |
| | D | 32.8 ± 1.9 | 14.3 ± 0.5 | 20.6 ± 0.1 | 10.1 ± 0.1 | 1.6 ± 0.1 | 0.2 ± 0.1 |
| Spring | L | 21.0 ± 0.6 | 31.2 ± 1.1 | 30.0 ± 0.4 | 16.3 ± 0.2 | 12.9 ± 0.2 | 0.5 ± 0.1 |
| | D | 28.7 ± 1.2 | 17.4 ± 0.4 | 21.7 ± 0.1 | 15.3 ± 0.1 | 3.0 ± 0.1 | 0.2 ± 0.1 |
| Summer | L | 22.5 ± 1.0 | 30.4 ± 1.3 | 27.8 ± 0.4 | 13.3 ± 0.4 | 19.7 ± 0.3 | 0.4 ± 0.1 |
| | D | 36.8 ± 2.9 | 18.0 ± 1.2 | 25.8 ± 0.3 | 14.7 ± 0.2 | 3.3 ± 0.1 | 0.2 ± 0.1 |
| Autumn | L | 21.4 ± 1.0 | 38.3 ± 1.1 | 28.7 ± 0.4 | 18.3 ± 0.6 | 26.5 ± 0.8 | 0.7 ± 0.1 |
| | D | 27.1 ± 1.1 | 23.6 ± 0.3 | 19.2 ± 0.3 | 21.1 ± 1.9 | 4.0 ± 0.1 | 0.2 ± 0.1 |
| Annual mean | L | 20.6 ± 2.2 | 31.8 ± 4.6 | 28.3 ± 1.5 | 14.8 ± 3.1 | 16.5 ± 8.5 | 0.5 ± 0.2 |
| | D | 31.4 ± 4.4 | 18.3 ± 3.9 | 21.8 ± 2.8 | 15.3 ± 4.5 | 3.0 ± 1.0 | 0.2 ± 0.0 |
| F-value | L | 4.39** | 3.13* | 3.61* | 12.82*** | 20.39*** | 5.50** |
| | D | — | — | — | — | — | — |
| | | | | *Ceratophyllum demersum* | | | |
| Winter | | 28.0 ± 0.5 | 29.3 ± 0.6 | 31.5 ± 0.7 | 14.5 ± 0.5 | 20.8 ± 0.1 | 0.7 ± 0.2 |
| Spring | | 29.6 ± 0.6 | 31.5 ± 0.6 | 32.7 ± 0.6 | 17.5 ± 0.6 | 20.4 ± 0.2 | 0.6 ± 0.2 |
| Summer | | 29.7 ± 0.8 | 29.2 ± 0.7 | 33.0 ± 0.9 | 24.5 ± 1.1 | 25.4 ± 0.5 | 0.6 ± 0.2 |
| Autumn | | 37.5 ± 1.1 | 36.0 ± 0.7 | 35.8 ± 1.5 | 25.0 ± 0.9 | 24.0 ± 0.5 | 0.8 ± 0.2 |
| Annual mean | | 31.2 ± 4.3 | 31.5 ± 3.2 | 33.3 ± 1.8 | 20.4 ± 5.2 | 22.7 ± 2.4 | 0.7 ± 0.1 |
| F-value | | ns | ns | ns | ns | ns | 11.43*** |

$^{*}P < .05$, $^{**}P < .01$, $^{***}P < .001$, ns: insignificant difference ($P > .05$).

Cu and Pb (54.7 and 127.6 $\mu$g g$^{-1}$, resp.) in summer (Tables 2 and 3). On the other hand, the living parts of *E. crassipes* had the highest values of K and N (38.3 and 26.5 mg g$^{-1}$, resp.) in autumn. The living parts of *E. stagnina* had the lowest values of Mg and Cu in summer and Mn in autumn, while the dead parts had the lowest of Na in spring, P in summer, and K and Ca in autumn.

According to the organic contents in the living and dead shoot parts, the living parts of *E. crassipes* had the highest value of total carbohydrates, NFE (61.9%), but the lowest of ether extract (EE = 0.8%) in winter and the highest total protein, TP (16.6%), but the lowest crude fiber, CF (11.9%), in autumn (Table 4). On the other hand, the living parts of *C. demersum* attained their highest values of EE and ash (2.1% and 30.9%, resp.), but the lowest of NFE (31.6%) in autumn. Moreover, the dead parts of *E. stagnina* had the highest CF (29.4%), while the living parts had the lowest ash (11.6%) in autumn. *E. crassipes* had the highest values of total

Table 3: Variation in the mean concentration ± standard deviation of the different micronutrients in the living (L) and dead (D) parts of the studied species in relation to different seasons.

| Variable | | Cu $\mu$g g$^{-1}$ | Mn $\mu$g g$^{-1}$ | Pb $\mu$g g$^{-1}$ |
|---|---|---|---|---|
| | | | *Echinochloa stagnina* | |
| Winter | L | 18.6 ± 0.6 | 153.4 ± 78.0 | 51.1 ± 26.2 |
| | D | 21.2 ± 2.3 | 231.0 ± 11.3 | 52.6 ± 14.8 |
| Spring | L | 26.5 ± 0.8 | 148.0 ± 64.5 | 51.4 ± 36.8 |
| | D | 34.5 ± 6.9 | 209.6 ± 41.6 | 64.3 ± 18.6 |
| Summer | L | 12.9 ± 6.1 | 102.5 ± 61.8 | 59.7 ± 40.7 |
| | D | 44.5 ± 6.1 | 180.2 ± 44.5 | 43.3 ± 17.1 |
| Autumn | L | 16.4 ± 8.8 | 90.3 ± 12.4 | 74.6 ± 63.3 |
| | D | 20.5 ± 9.6 | 240.1 ± 98.0 | 72.8 ± 28.2 |
| Annual mean | L | 18.6 ± 5.8 | 123.6 ± 31.8 | 59.2 ± 11.0 |
| | D | 30.2 ± 11.5 | 215.2 ± 26.6 | 58.3 ± 12.9 |
| F-value | L | 3.69$^{**}$ | 7.29$^{***}$ | ns |
| | D | ns | ns | ns |
| | | | *Eichhornea crassipes* | |
| Winter | L | 24.8 ± 9.3 | 294.8 ± 114.0 | 57.7 ± 33.9 |
| | D | 17.8 ± 4.1 | 201.2 ± 44.0 | 38.9 ± 16.1 |
| Spring | L | 46.2 ± 12.6 | 294.2 ± 156.0 | 86.3 ± 48.7 |
| | D | 33.2 ± 8.1 | 231.5 ± 68.0 | 59.2 ± 26.1 |
| Summer | L | 34.5 ± 11.6 | 331.7 ± 108.0 | 50.7 ± 31.0 |
| | D | 13.7 ± 5.9 | 385.0 ± 296.0 | 33.0 ± 12.3 |
| Autumn | L | 31.3 ± 12.5 | 225.0 ± 84.0 | 62.2 ± 53.0 |
| | D | 41.9 ± 18.7 | 746.5 ± 112.0 | 55.5 ± 32.7 |
| Annual mean | L | 34.2 ± 8.9 | 286.4 ± 44.5 | 64.2 ± 15.5 |
| | D | 26.7 ± 13.2 | 391.1 ± 250.3 | 46.7 ± 12.7 |
| F-value | L | 6.15$^{**}$ | ns | ns |
| | D | — | — | — |
| | | | *Ceratophyllum demersum* | |
| Winter | | 33.4 ± 7.5 | 817.7 ± 375.9 | 99.2 ± 27.8 |
| Spring | | 39.5 ± 9.0 | 1131.2 ± 593.7 | 103.5 ± 36.2 |
| Summer | | 54.7 ± 19.9 | 1283.6 ± 576.7 | 127.6 ± 34.5 |
| Autumn | | 44.2 ± 21.5 | 1467.0 ± 920.0 | 96.6 ± 39.9 |
| Annual mean | | 42.0 ± 8.0 | 1174.9 ± 274.9 | 106.7 ± 14.2 |
| F-value | | 6.19$^{**}$ | ns | 2.81$^{*}$ |

$^{*}P < .05$, $^{**}P < .01$, $^{***}P < .001$, ns: insignificant difference ($P > .05$).

carbohydrate and total proteins, while *E. stagnina* had the highest of crude fibers, and *C. demersum* had the highest of ether extract and ash contents. Furthermore, the living parts of *C. demersum* had the highest annual mean values of total protein, ether extract, crude fiber, and ash content, while that of *E. stagnina* had the highest of total carbohydrates.

The variations in the nutritive value in the living and dead shoot parts for most of the studied species were significant in relation to the season. The highest value of digestible crude protein, DCP (11.3%), was recorded in the living parts of *E. crassipes* in autumn and *C. Demersum* in summer, while the highest of total digestible nutrients, TDN (68.1%), was recorded in the living parts of *E. stagnina* in winter (Table 5). The living parts of *E. stagnina* had the highest values of digestible energy, DE, metabolized energy, ME, and net energy, NE (2.8, 2.3, and 1.2 Mcal kg$^{-1}$, resp.), while the dead parts had the highest gross energy, GE (391.3 Kcal kg$^{-1}$), in autumn. The living parts of *C.*

Table 4: Variation in the mean organic contents in the above-ground living (L) and dead (D) parts of the studied species in relation to different seasons. NFE: total carbohydrates, TP: total protein, EE: ether extract, CF: crude fiber.

| Variable | | NFE | TP | EE | CF | Ash |
|---|---|---|---|---|---|---|
| | | | *Echinochloa stagnina* | | | |
| Winter | L | 53.1 ± 2.7 | 6.8 ± 1.3 | 1.6 ± 0.3 | 24.9 ± 1.7 | 13.6 ± 0.7 |
| | D | 56.1 ± 0.4 | 4.7 ± 0.1 | 1.6 ± 0.2 | 25.7 ± 0.8 | 11.9 ± 1.1 |
| Spring | L | 54.0 ± 3.8 | 4.4 ± 1.6 | 1.0 ± 0.4 | 27.0 ± 4.0 | 13.6 ± 1.5 |
| | D | 54.0 ± 3.2 | 2.6 ± 1.5 | 1.4 ± 0.3 | 25.5 ± 2.6 | 16.5 ± 1.2 |
| Summer | L | 53.4 ± 1.7 | 5.3 ± 2.0 | 1.2 ± 0.6 | 27.5 ± 2.2 | 12.6 ± 0.7 |
| | D | 52.2 ± 4.5 | 4.4 ± 1.7 | 1.5 ± 0.4 | 27.6 ± 3.6 | 14.3 ± 1.2 |
| Autumn | L | 57.0 ± 1.4 | 5.2 ± 1.4 | 1.2 ± 0.2 | 25.0 ± 1.7 | 11.6 ± 0.4 |
| | D | 52.5 ± 6.0 | 3.5 ± 1.7 | 1.8 ± 0.6 | 29.4 ± 5.5 | 12.8 ± 3.7 |
| Annual mean | L | 54.4 ± 1.8 | 5.4 ± 1.0 | 1.3 ± 0.3 | 26.1 ± 1.3 | 12.9 ± 0.9 |
| | D | 53.7 ± 1.8 | 3.8 ± 0.9 | 1.6 ± 0.2 | 27.1 ± 1.8 | 13.9 ± 2.0 |
| F-value | L | ns | ns | ns | ns | 4.48* |
| | D | ns | ns | ns | 4.45* | ns |
| | | | *Eichhornea crassipes* | | | |
| Winter | L | 61.9 ± 3.4 | 4.2 ± 0.5 | 0.8 ± 0.2 | 14.0 ± 1.2 | 19.1 ± 1.9 |
| | D | 58.5 ± 4.1 | 1.0 ± 0.4 | 1.2 ± 0.2 | 20.7 ± 1.3 | 18.7 ± 3.3 |
| Spring | L | 52.0 ± 3.5 | 8.1 ± 0.9 | 1.1 ± 0.3 | 17.1 ± 1.6 | 21.7 ± 2.4 |
| | D | 49.2 ± 2.8 | 1.8 ± 0.8 | 1.6 ± 0.1 | 24.5 ± 1.4 | 22.8 ± 1.6 |
| Summer | L | 50.0 ± 6.5 | 12.3 ± 2.1 | 1.2 ± 0.5 | 15.1 ± 2.8 | 21.4 ± 4.4 |
| | D | 57.2 ± 4.3 | 2.1 ± 0.9 | 1.4 ± 0.1 | 19.8 ± 3.5 | 19.5 ± 1.7 |
| Autumn | L | 50.4 ± 5.8 | 16.6 ± 5.2 | 1.8 ± 0.3 | 11.9 ± 0.9 | 19.3 ± 1.3 |
| | D | 51.3 ± 2.4 | 2.5 ± 0.6 | 1.3 ± 0.2 | 22.9 ± 2.8 | 22.0 ± 3.8 |
| Annual mean | L | 53.6 ± 5.6 | 10.3 ± 5.3 | 1.2 ± 0.4 | 14.5 ± 2.2 | 20.4 ± 1.4 |
| | D | 54.1 ± 4.5 | 1.6 ± 0.6 | 1.4 ± 0.2 | 21.9 ± 2.1 | 20.8 ± 1.9 |
| F-value | L | 8.27*** | 19.70*** | 17.58*** | 13.39*** | ns |
| | D | — | — | — | — | — |
| | | | *Ceratophyllum demersum* | | | |
| Winter | | 31.8 ± 2.3 | 13.0 ± 0.5 | 1.6 ± 0.4 | 23.1 ± 2.1 | 30.5 ± 1.9 |
| Spring | | 35.5 ± 2.5 | 12.8 ± 1.3 | 1.9 ± 0.2 | 21.7 ± 1.5 | 28.2 ± 2.7 |
| Summer | | 34.6 ± 7.3 | 15.9 ± 3.4 | 1.5 ± 0.5 | 22.9 ± 5.6 | 24.8 ± 1.7 |
| Autumn | | 31.6 ± 11.6 | 15.0 ± 3.0 | 2.1 ± 0.5 | 20.4 ± 4.1 | 30.9 ± 7.4 |
| Annual mean | | 33.4 ± 1.9 | 14.2 ± 1.5 | 1.8 ± 0.3 | 22.0 ± 1.2 | 28.6 ± 2.8 |
| F-value | | ns | ns | Ns | ns | 8.94*** |

$^{*}P < .05$, $^{**}P < .01$, $^{***}P < .001$, and ns: insignificant difference ($P > .05$).

*demersum* had the lowest values of TDN, DE, ME, NE in winter, while the dead parts of *E. crassipes* attained the lowest GE in autumn. The living parts of *E. stagnina* had the highest annual mean values of total digestible nutrients, digestible energy, and metabolized energy, while those of *C. demersum* had the highest of digestible crude protein.

## 5. Discussion

Biomass estimation is an important tool in aquatic plant research for studies such as species distribution and abundance, succession, and assessment of weed management operations [27]. *E. stagnina* and *C. demersum* attained their maximum phytomass during autumn, while *E. crassipes* during summer. A similar finding was postulated by El-Darier and Sadek [28]. These results may be interpreted as *E. stagnina* flowered and fruited during autumn, while *E. crassipes* during summer. The highest mean annual phytomass of *E. stagnina* may be due to the rhizomatus nature of this plant which is believed to be more resistant than the other life forms to trampling along the canal terraces by farmers and their grazing animals. On the other hand, the lowest phytomass of *C. demersum* may be attributed partially to the shade caused by the tall crowdy plants (e.g.

Table 5: Nutritive value of the above-ground living (L) and dead (D) parts of the studied species in relation to different seasons. DCP: digestible crude protein, TDN: total digestible nutrients, DE: digestible energy, ME: metabolized energy, NE: net energy and GE; gross energy.

| Variable | | DCP% | TDN% | DE Mcal kg$^{-1}$ | ME Mcal kg$^{-1}$ | NE Mcal kg$^{-1}$ | GE Kcal 100g$^{-1}$ |
|---|---|---|---|---|---|---|---|
| *Echinochloa stagnina* | | | | | | | |
| Winter | L | 2.8 ± 1.2 | 68.1 ± 1.1 | 2.5 ± 0.0 | 2.1 ± 0.0 | 1.1 ± 0.0 | 384.8 ± 7.5 |
| | D | 0.9 ± 0.1 | 66.7 ± 0.1 | 2.5 ± 0.0 | 2.1 ± 0.0 | 1.1 ± 0.0 | 393.0 ± 3.9 |
| Spring | L | 0.9 ± 1.1 | 64.2 ± 3.5 | 2.6 ± 0.3 | 2.1 ± 0.2 | 1.1 ± 0.1 | 381.5 ± 9.8 |
| | D | 0.1 ± 0.2 | 62.0 ± 6.4 | 2.3 ± 0.1 | 1.9 ± 0.1 | 1.0 ± 0.0 | 369.9 ± 7.5 |
| Summer | L | 1.5 ± 1.8 | 66.7 ± 1.5 | 2.5 ± 0.2 | 2.1 ± 0.1 | 1.1 ± 0.1 | 388.6 ± 3.9 |
| | D | 1.0 ± 1.0 | 63.1 ± 3.8 | 2.3 ± 0.2 | 1.9 ± 0.2 | 1.0 ± 0.1 | 385.9 ± 13.0 |
| Autumn | L | 1.4 ± 1.2 | 66.7 ± 1.2 | 2.8 ± 0.3 | 2.3 ± 0.3 | 1.2 ± 0.1 | 386.3 ± 6.4 |
| | D | 0.6 ± 0.8 | 61. ± 6.7 | 2.4 ± 0.1 | 2.0 ± 0.1 | 1.0 ± 0.1 | 391.3 ± 20.7 |
| Annual mean | L | 1.7 ± 0.8 | 66.4 ± 1.6 | 2.6 ± 0.1 | 2.2 ± 0.1 | 1.1 ± 0.1 | 385.3 ± 2.9 |
| | D | 0.7 ± 0.4 | 63.4 ± 2.3 | 2.4 ± 0.1 | 2.0 ± 0.1 | 1.0 ± 0.1 | 385.0 ± 10.5 |
| F-value | L | ns | ns | ns | ns | ns | ns |
| | D | ns | ns | ns | ns | ns | ns |
| *Eichhornea crassipes* | | | | | | | |
| Winter | L | 0.4 ± 0.4 | 51.4 ± 1.4 | 2.4 ± 0.1 | 2.0 ± 0.1 | 1.0 ± 0.0 | 345.5 ± 8.0 |
| | D | 0.0 ± 0.0 | 51.5 ± 2.0 | 2.4 ± 0.2 | 2.0 ± 0.2 | 1.0 ± 0.1 | 357.0 ± 12.7 |
| Spring | L | 3.7 ± 0.9 | 50.3 ± 1.5 | 2.5 ± 0.4 | 2.1 ± 0.5 | 1.1 ± 0.2 | 347.4 ± 7.3 |
| | D | 0.0 ± 0.0 | 64.3 ± 0.5 | 2.1 ± 0.1 | 1.7 ± 0.1 | 0.9 ± 0.0 | 346.4 ± 6.0 |
| Summer | L | 8.0 ± 2.0 | 57.5 ± 5.8 | 2.4 ± 0.3 | 2.0 ± 0.2 | 1.0 ± 0.1 | 356.8 ± 18.0 |
| | D | 0.0 ± 0.0 | 55.9 ± 7.5 | 2.3 ± 0.2 | 1.9 ± 0.1 | 1.0 ± 0.1 | 355.5 ± 5.4 |
| Autumn | L | 11.3 ± 4.7 | 57.7 ± 8.0 | 2.6 ± 0.1 | 2.1 ± 0.1 | 1.1 ± 0.1 | 387.0 ± 29.0 |
| | D | 0.0 ± 0.0 | 60.7 ± 8.2 | 2.2 ± 0.2 | 1.8 ± 0.1 | 0.9 ± 0.1 | 324.7 ± 42.0 |
| Annual mean | L | 5.9 ± 4.8 | 54.2 ± 3.9 | 2.5 ± 0.1 | 2.1 ± 0.1 | 1.1 ± 0.1 | 359.2 ± 19.2 |
| | D | 0.0 ± 0.0 | 58.1 ± 5.6 | 2.3 ± 0.1 | 1.9 ± 0.1 | 1.0 ± 0.1 | 345.9 ± 14.9 |
| F-value | L | 15.07*** | 4.86* | ns | ns | ns | ns |
| | D | — | — | — | — | — | — |
| *Ceratophyllum demersum* | | | | | | | |
| Winter | | 8.7 ± 0.5 | 45.4 ± 4.8 | 1.8 ± 0.1 | 1.5 ± 0.1 | 0.8 ± 0.0 | 330.2 ± 10.4 |
| Spring | | 8.4 ± 1.2 | 49.4 ± 4.8 | 1.9 ± 0.1 | 1.6 ± 0.1 | 0.8 ± 0.0 | 339.9 ± 16.6 |
| Summer | | 11.3 ± 3.2 | 49.6 ± 5.6 | 2.1 ± 0.1 | 1.7 ± 0.1 | 0.9 ± 0.1 | 357.0 ± 10.2 |
| Autumn | | 10.5 ± 2.8 | 49.9 ± 8.0 | 2.0 ± 0.2 | 1.6 ± 0.2 | 0.8 ± 0.1 | 333.2 ± 33.4 |
| Annual mean | | 9.7 ± 1.4 | 48.6 ± 2.1 | 2.0 ± 0.1 | 1.6 ± 0.1 | 0.8 ± 0.1 | 340.1 ± 11.9 |
| F-value | | ns | ns | 5.42* | 5.38* | 5.47* | ns |

$^{*}P < .05$, $^{**}P < .01$, $^{***}P < .001$, and ns: insignificant difference ($P > .05$).

*Phragmites australis*), which may influence the growth of some associated aquatic plants. This may also interpreted the view that plants under water will have lower availability of atmospheric oxygen and carbon dioxide [29]. The phytomass of *E. crassipes* in the present study is lower than that recorded by El-Fiky [30] along a drainage ditch in Giza and Reddy et al. [31] in some natural stands in Florida. On the other hand, the phytomass of *E. stagnina* and *C. demersum* is higher than that recorded by El-Fiky [30].

The successful living of aquatic macrophytes in polluted areas is usually due to its ability to accumulate larger metal concentrations than in the surrounding water [32]. Comparing the three studied species with *Pistia stratiotes* [33], it is clear that Na, Mg, Fe, Zn, and Cu are higher in the tissues of the three species than in *P. stratiotes*. In general, this comparison indicated that the studied plants had the ability to absorb heavy metals from the water courses and act as biofilter for these elements. It was obvious that Mg and Mn concentrations in *C. demersum* exceed the maximum values, while Ca and P approach the minimum, but Na exceeds the maximum in all plants [34]. Mjelde and Faafen [35] in their study on small Norwegian lakes observed that

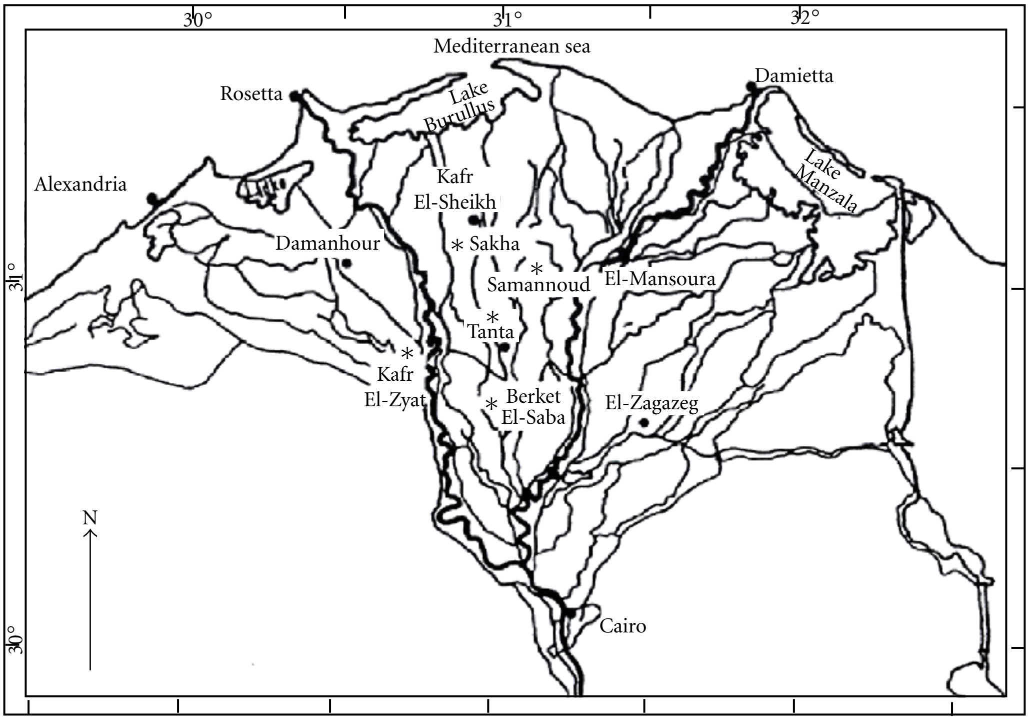

Figure 1: Map of the Nile Delta region of Egypt.∗ indicates the study area.

most macrophytes-dominated lakes with P concentration above $30\,\mathrm{mg\ m^{-3}}$ were dominated by *C. demersum*. *C. demersum* is a useful indicator of water pollution; it can trap macro- and microelements and accelerate the removal and biotransformation of herbicides from contaminated water [36]. Yaowakhan et al. [37] observed that, at high Pb concentration, *C. demersum* showed substantial accumulation, that is, 1621 mg/kg at 1 mg/L Pb after 6 days and 6982 mg/kg at 10 mg/L Pb after 9 days. The relative growth of plants generally decreased with increase in Pb concentration. Keskinkan et al. [38] reported that *M. spicatum* has a better adsorption capacity than *C. demersum* for Zn, Cu, and Pb.

Ministry of Agriculture, Fisheries and Food in England (Anonymous [39]) reported that minimum protein in the animal diet ranges between 6 to 12% depending on the animal species. NRC [40] indicated that sheep are known to require 8.9% protein for maintenance. The average annual protein contents in the living part of *E. stagnina* and the dead parts of all species are far too low than the proper level, while those of *C. demersum* exceed the maintenance requirement. Comparing with the other fodder plants, the protein content in the living and dead parts of all species were lower than those of *T. alexandrinum* (16.2%: [41]). The protein contents of the living and dead parts of all species agree with the scale of the protein content of some rough fodder materials (2.7%–13.4%: [42]) except *E. stagnina*. The same is true regarding ash content (1.3%–23.1%) except for *C. demersum* where their values exceed the upper limit of the range. The importance of lipids (i.e., ether extract) to plants, in terms of structure and use in metabolism, is well known. However, Chapin et al. [43] indicated that lipids are clearly unimportant as an energy source in some plants. Lipids of the living and dead parts of all species lay within the scale of some rough fodder materials (0.5%–3.1%: [42]), but lower than those of *T. alexandrinum* (2.9%: [41]). Total carbohydrates in the living and dead parts of all species lay with the range of some rough fodder material (27.8–51.9%: [42]), but lower than those of *T. alexandrinum* (43.4%: [41]). In addition, the crude fibers of all species were higher than that of *T. alexandrinum* (21.5%: [41]) except those of *E. crassipes* which are relatively low.

DCP attained its maximum values (11.3%) in the living parts of *C. demersum*. The value required for the diet of sheep is about 6.1% (NRC [34]). In general, straw and chaff of grasses have very low and often zero DCP [21]. DCP in Egyptian clover hay is about 9.0% [42]. It seems that the nutritive values of the living parts of the studied species are within the range of nutritive value of sheep [34], goat [44], dairy cattle [45], and beef cattle [24].

*E. stagnina* had the highest TDN in the living and dead parts, while *C. demersum* had the lowest. In comparison, Heneidy and Bidak [46] recorded a TDN average of 68.8% in *P. australis*, and El-Beheiry and El-Kady [47] reported a TDN of 50% in some *Tamarix* species. Abdel-Razik et al. [48] reported an annual range of 66.0%–75.0% in the Mediterranean coastal region of Egypt. Chauhan et al. [41] reported a value of 66.7% for Egyptian clover, while Shoukry [42] reported a range of 34.0%–48.0 % for some rough fodder materials. The living parts of *E. stagnina* had the

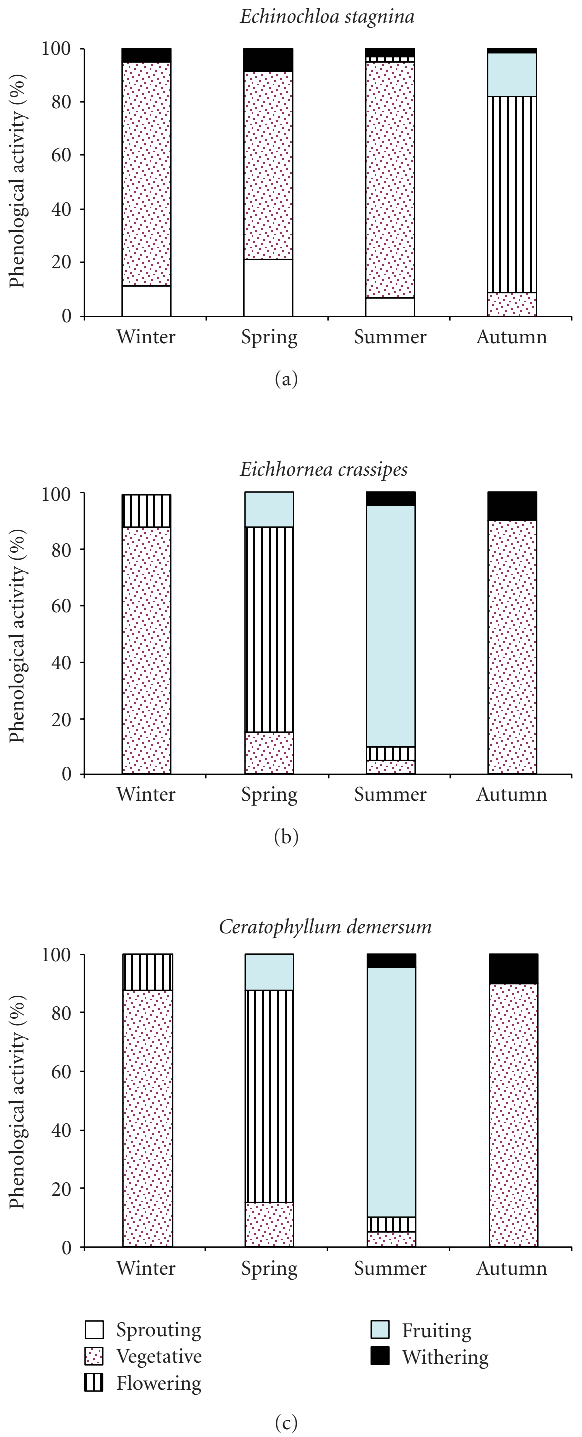

FIGURE 2: Phenological activity (%) of the 3 studied species in the four seasons along the canals and drains in Nile Delta.

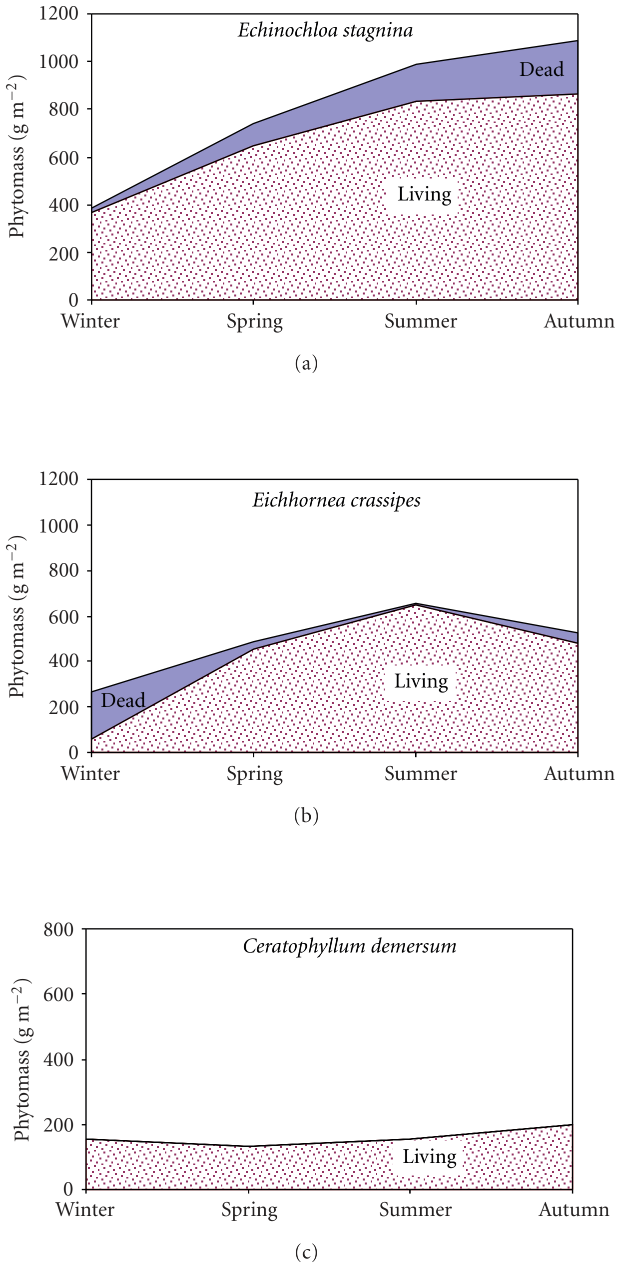

FIGURE 3: Phytomass of living (L) and dead (D) parts of the studied species in relation to the different seasons. T: total phytomass.

highest value of DE (2.8 Mcal kg$^{-1}$), while C. *demersum* had the lowest. In comparison, cheeps are known to require 2.7 Mcal kg$^{-1}$ for diet [34]. Heneidy and Bidak [46] reported 3.04 Mcal kg$^{-1}$ for *P. australis,* while El-Kady [49] reported 2.4 Mcal kg$^{-1}$ and 2.2 Mcal kg$^{-1}$ for the living and dead parts, respectively. Moreover, Chauhan et al. [41] reported 2.9 Mcal kg$^{-1}$ for *T. alexandrinum*. The maximum ME was 2.3 Mcal kg$^{-1}$ in the living parts of *E. stagnina,* while the minimum (1.5 Mcal kg$^{-1}$) was in those of C. *demersum*. In comparable studies, *P. australis* had a value of 2.62 Mcal kg$^{-1}$ [46] and *T. alexandrinum* had a value of 2.46 Mcal kg$^{-1}$ [41]. The cheep and breeding cattle require 2.23 and 2.1 Mcal kg$^{-1}$, respectively, [24, 34]). Using the scale suggested by Boudet and Riviere [50], the living parts of *E. crassipes* and *C. demersum* were considered as excellent forages, while the dead parts of all species and the living parts of *E. stagnina* were evaluated as poor forage.

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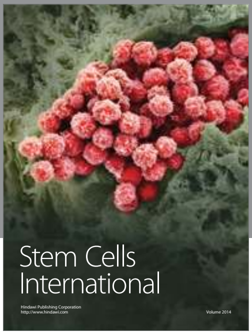
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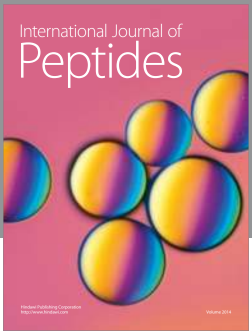
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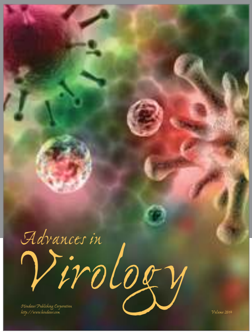
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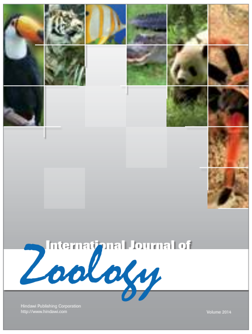
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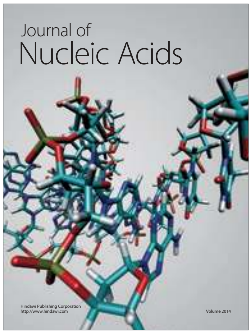
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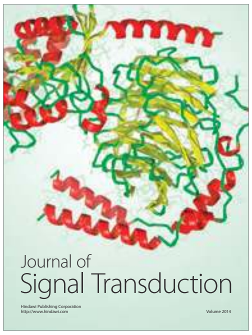
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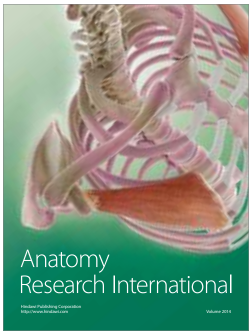
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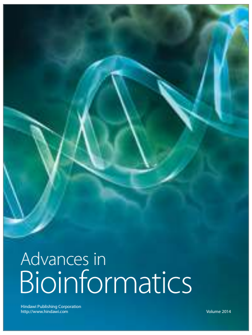
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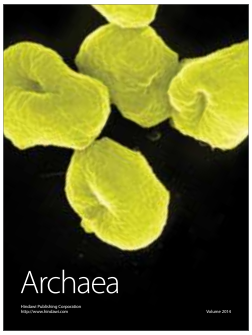
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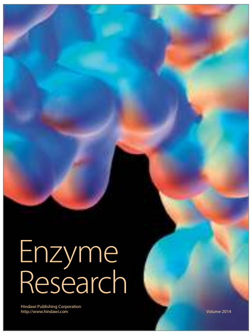
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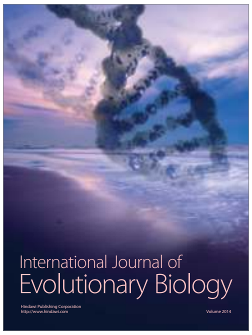
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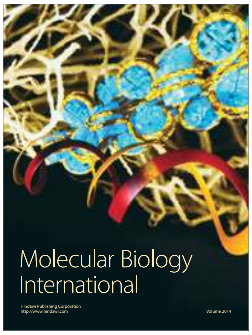
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