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Effect of Seaweed Extract on Productivity and Quality Attributes of Four Onion Cultivars

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Abstract: The excessive use of chemicals and inorganic fertilizers by farmers to increase crop yield is detrimental to the environment and human health. Application of biostimulants such as seaweed extract (SWE) in agriculture could be an effective and eco-friendly alternative to inorganic fertilizers. Biostimulants are natural organic degradable substances. Their application serves as a source of nutrition for crops, possibly improving growth and productivity when applied in combination with the fertilizers. The current study was conducted to evaluate the vegetative growth, reproductive behavior and quality attributes of four onion cultivars, 'Lambada', 'Red Bone', 'Nasarpuri', and 'Phulkara', in response to different concentrations of commercial SWE. Four levels of SWE extract were used, 0% (control), 0.5%, 1%, 2%, and 3%, which were applied as a foliar spray to each cultivar. The application of 0.5% SWE caused a significant increase in total soluble solids, mineral content (N, P, and K), bulb weight and yield. Application at 3% SWE increased ascorbic acid as compared to control. The cultivars responded in different ways regarding bulb dry weight and bulb and neck diameter. Among all cultivars, 'Lambada' showed the maximum bulb dry matter, 'Phulkara' showed enhanced neck diameter whereas 'Red Bone' showed maximum leaf length. It is concluded that 0.5% SWE increased the yield, nutrient contents, and total soluble solids (TSS) of the four onion cultivars whereas 3% SWE, the highest concentration, increased ascorbic acid in different onion cultivars.

Keywords: ascorbic acid; biostimulants; *Allium cepa*; Phulkara; Nasarpuri; Lambada and Red Bone

1. Introduction

Onion (*Allium cepa* L.) belongs to the family Amaryllidaceae. It originated in the Mediterranean region of southwest Asia. More than 800 species of onion are cultivated in the tropical, temperate, and sub-temperate zones of the world [1,2]. Onion is cultivated worldwide due to its economic importance, taste and health-supporting attributes [3]. In the recent past, China, India, the USA, and Turkey were the leading onion producing countries [4]. In Pakistan, onion is grown over an area of 147 thousand acres with an annual production of 1981 thousand tons [5].

Onion has an unbranched root system; it requires a high amount of fertilizers for optimum yield [6]. Chemical fertilizers are commonly used by farmers because of the high concentration of nutrients. Frequent use of chemical fertilizers is a risks to human health and is also a threat to the environment [7]. Increased water eutrophication, nitrate accumulation, heavy metal accumulation and toxicity, and release of nitrogen and sulfur oxides in the air are major environmental concerns. In recent years, rapid emission of greenhouse gases from fertilizers has become a major concern [8]. Application of organic amendments is an environmentally friendly approach to improve crop production and soil sustainability [9]. However there is also some risk of xenobiotic contaminated in manure used to fertilize agricultural soils [10–12].

Biostimulants are emerging as safe alternatives to some chemical fertilizers due to their modulating hormonal, i.e., 'auxin-like, gibberellin-like', effects. They are available in a variety of formulations with varying ingredients. Biostimulants are usually classified into three major groups that includes humic substances (HS), hormone-containing products (HCP), and amino acid-containing products (AACP). Seaweed extracts belong to HCP, contain prominent amounts of active plant growth substances such as auxins, cytokinins, and their derivatives [13]. These growth hormones interact with the biochemical and physiological mechanisms of plants, thus improving crop productivity [14,15].

Moreover, the use of biostimulants may also decrease the fertilizer requirement by enhancing the assimilation of micro- and macro-nutrients [16,17]. Biostimulant benefits have been mainly attributed to the presence of phytohormones and organic molecules [18] such as betaines [18,19]. Such organic compounds are rich in carbohydrates and amino acids and vitamins that increase phenolic compounds [19–21]. Significant improvement in phenolic content approximates the antioxidant activity which decreases reactive oxygen species thus, increase growth and productivity of crops [19,22].

Among biostimulants, seaweed extract (SWE) collected from *Ulva lactuca, Caulerpa sertularioides, Padina gymnospora,* and *Sargassum liebmannii* is the most commonly used amendment [15]. It is mainly comprised of algal extract, glycine betaines, amino acids, and protein hydrolysates. These compounds are very efficient in terms of improving plant growth and productivity [13]. SWE derived from sources like *Ascophyllum nodosum*, *Ecklonia maxima*, *Macrocystis pyrifer,a* and *Durvillea potatorum* are also used [20]. SWE extract based on *Ascophyllum nodosum* is enriched in phytohormones, i.e., auxins, gibberellins, cytokinins, abscisic acid, and brassinosteroids [23]. These growth regulators improve growth of plants and enrich overall quality attributes of crops [24]. Generally, all of these could cause a synergistic effect on plant growth via affecting internal metabolic activity although activity and mode of action of these molecules [25,26].

Seaweed extract derived from *Ascophyllum nodosum* along with its co-products is being increasingly utilized to enhance growth and productivity of plants [27] via enhancing seed germination, contributing to vegetative growth and modulating reproductive behavior in tomato [28].

Ascophyllum nodosum extract is comprised of different active substances, i.e., 15–25%, 15–30% alginic acid, 0–10% laminaran, 5–10% mannitol, 4–10% fucoidan, 5–10% protein, 2–7% fats, 2–10% tannins, 0.5–0.9% magnesium, 0.01–1.0% iodine, 2–3% potassium, 3–4% sodium, 0.002–0.006% glycine betaine, and 70–85% water [29]. Betaines and mannitol in seaweed extract helps plants to survive under stress conditions by improving osmotic adaptability [18,30]. However, the variable and multifaceted constituent of these mixtures have made it very effective in promoting growth, yield, and quality attributes of barley (*Hordeum vulgare*) seedlings [31], soybean (*Glycine max*) [32], and cotton (*Gossypium hirsutum*) [33] etc.

The current study was designed to examine the effect of SWE on productivity and quality of onion cultivars. There are few reports on the influence of SWE on onion cultivars, the present study aimed to explore the effective application rate of SWE for onion. We hypothesized that seaweed extract could be an effective biostimulant to improve productivity and quality of onion.

2. Materials and Methods

2.1. Plant Material and Culture Conditions

A field research trial was conducted for one year at the vegetable research farm, Institute of Horticultural Sciences (31.4303° N, 73.0672° E), University of Agriculture, Faisalabad, Pakistan. The physico-chemical characteristics of the sandy loam soil of the planting site are given in Table 1; varies with the land use [34–36]. The field was thoroughly ploughed and harrowed to make ridges and furrows at a 60 cm spacing on finely pulverized soil. Healthy and disease-free seeds of four onion cultivars, 'Phulkara', 'Nasarpuri', 'Lambada', and 'Red Bone' were sown on raised beds in rows 10.2–12.7 cm apart and were lightly covered with soil. To attain uniform seedling growth, necessary cultural and agronomic practices (weeding, irrigation, nutrition and pest management) were used for 45 days until seedling maturity (emergence of 3 to 4 true leaves). The seedling bed was irrigated one day before uprooting and transplanting of seedlings. This helps in proper uprooting with minimal damage and better establishment of seedlings in the field. Seedlings were transplanted at the a spacing of 10 cm in row by 25 cm between rows. Seedling establishment was observed regularly with re-transplanting in case of any dead, weak/injured seedlings.

Table 1. Pre-experiment soil and water characteristics.

Soil	Units	Value	Water	Units	Value
Texture	Loam		pH	-	7.25
pH	-	8.12	Conductivity	$\mu S \cdot cm^{-1}$	941
EC*e*	$dS \cdot m^{-1}$	2.19	Carbonates	$meq \cdot L^{-1}$	0.00
Organic matter	%	0.70	Bicarbonates	$meq \cdot L^{-1}$	0.75
Organic N	%	0.035	Chlorides	$meq \cdot L^{-1}$	1.55
Available P	$mg \cdot kg^{-1}$	6.79	Ca + Mg	$meq \cdot L^{-1}$	9.10
Extractable K	$mg \cdot kg^{-1}$	135	SAR	-	1.51

Abbreviations: EC*e* = Electrical Conductivity of soil extract; TSS = Total Soluble Solids; SAR = Sodium Absorption Ratio; Max = Maximum; Min = Minimum; meq = milliequivalent.

2.2. Collection and Application of Seaweed Extract

The SWE Wokozim (Jaffer Agro Services Private Ltd.) was acquired and, based on preliminary work identifying the optimum concentrations, diluted in water and applied at 0% (control or water only), 0.5%, 1%, 2% and 3% on onion plants. The *Ascophyllum nodosum* extract was characterized as a mixture of cytokinins, auxins, and betaines. As per the company description, the product can be applied as a foliar spray on all parts of plants or can be applied in irrigation water. Three foliar sprays were applied at two-week intervals starting after seedling growth indicated they were established. Each plant receiving approximately 20 mL of solution. The spray was applied to the abaxial and adaxial surface of leaves with complete coverage of plant with a commercial hand-held sprayer.

2.3. Fertilizer and Irrigation

As per production recommendations of the Punjab Agriculture Department, N, P, and K were applied at the rate of 125: 87.5: 87.5 kg ha^{-1}. The first three irrigations of 2.5 cm were applied at 8 days interval. Afterwards, the onion crop was irrigated as required [37].

2.4. Harvesting and Data Collection

Plants were harvested at the time of maturity (>75% of bulb necks fall over). Vegetative growth attributes were immediately measured including, plant height, leaf (consist of a sheath at the bottom which attaches around the stem at a node) and blade length (top of the sheath to blade tip), width and fresh biomass, root length, and total fresh biomass. Among reproductive parameters, bulb weight, bulb and neck diameter (at the narrowest point), total plant dry biomass (tissues were held for 24 h in an oven at 100 °C), and fresh bulb yield hectare^{-1} was calculated. Neck was separated at 2 cm height from the bulb. For moisture determination drying was done in the oven at 100 °C. The difference between fresh and dry weight was used to calculate percent moisture.

2.5. Total Soluble Solids (°Brix)

The total soluble solids (TSS) (°Brix) of bulb tissue was determined with a digital refractometer (ATAGO, RX-5000 Japan).

2.6. Mineral Nutrient and Ascorbic Acid Analyses

Nitrogen, phosphorus, and potassium contents of bulbs were determined according to Chapman and Parker [38]. For N analyses, dry onions were digested with sulfuric acid followed by Kjeldahl distillation. For P and K determination, samples were digested with a di-acid ($HClO_4$:HNO_3 at a 2:1 ratio) mixture. Finally, a colorimetric method was used and concentrations were assessed at 430 nm using a spectrophotometer for P analysis. For the development of yellow color for P quantification, ammonium molybdate and ammonium metavanadate chemicals were used. For K determination, digested samples were run on a flame photometer after filtration [38]. For ascorbic acid quantification, the dichlorophenolindophenol (DCPIP) method was used. Initially, 10 g onion sample was taken and its juice was taken with 2.5 mL of 20% metaphosphoric acid and diluted with distilled water to 100 mL which developed blue color as per presence of ascorbic acid. Finally, 10 mL of prepared extract was titrated with 0.1% DCPIP until the blue color disappeared and the solution became colorless [39].

2.7. Statistical Analysis

The experiment was laid out in a Randomized Complete Block Design (RCBD) with nine replications of each cultivar by SWE concentration. Statistix 8.1 computer software was used to analyze the data. Data pass the test for homogeneity and then analysis of variance (ANOVA) was used to determine the overall significance of data at $p \leq 0.05$. Treatments were compared using Fisher's least significant difference (LSD) test at $p \leq 0.05$ [40].

3. Results

3.1. Leaf-Blade Length and Plant Height

SWE application had significant ($p \leq 0.05$) effects on leaf blade length of the different onion cultivars. A maximum increase of 65% was observed for 'Phulkara', 35.7% for 'Red Bone', 25.0% for 'Lambada' and 17% for 'Nasar puri' at 0.5% SWE as compared to the control (Figure 1A). Application of 0.5 and 1% SWE significantly increased leaf blade length in all cultivars. However, application of 3% SWE increased leaf blade length in 'Phulkara' and 'Red Bone' but decreased leaf blade length in 'Nasar puri' and 'Lambada' as compared to the control.

Treatment with 0.5% SWE resulted in the most increase in plant height of all four cultivars. The increase in plant height was 29.7% in 'Phulkara', 25.4% in 'Lambada', 19.9% in 'Red Bone', and 17.9% in 'Nasar puri' as compared to control (Figure 1B). Generally, no significant change in plant height was noted when SWE concentration was increased from 0.5% and 1%. SWE at 2% also significantly enhanced plant height in 'Lambada' and 'Phulkara' but did not affect 'Nasar puri' and 'Red Bone' as compared to control (Figure 1B).

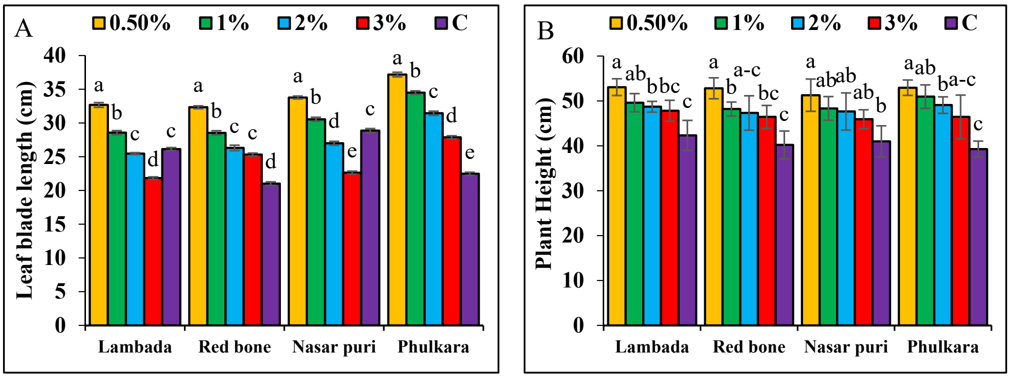

Figure 1. Leaf-blade length (**A**) and plant height (**B**) of onion cultivars as affected by foliar application of 0 (C = control), 0.5, 1, 2, or 3% seaweed extract. Values are means of nine replicates ± standard error. Means with different letters are significantly different from each other compared by least significant difference (LSD) at $p \leq 0.05$.

3.2. Leaf Length and Width

Application of SWE significantly ($p \leq 0.05$) improved leaf length and width of onion cultivars. A maximum increase of 38.6% in 'Nasar puri', 25.1% in 'Lambada', 14.3% in 'Red Bone', 13.3% in 'Phulkara' was noted in leaf length at 2% SWE over the control (Figure 2A). In 'Lambada', 1% and 3% SWE showed similar effects with each other and were both greater than the control. In 'Red Bone', 1% and 3% were similar to the control. However, 0.5% SWE caused a significant reduction in leaf length of 'Red Bone'. For 'Nasar puri', both 1 and 3% SWE also significantly improved leaf length, but 0.5% SWE did not differ from the control. Application of 3% SWE significantly enhanced but 0.5 and 1% cause a reduction in leaf length of 'Phulkara'.

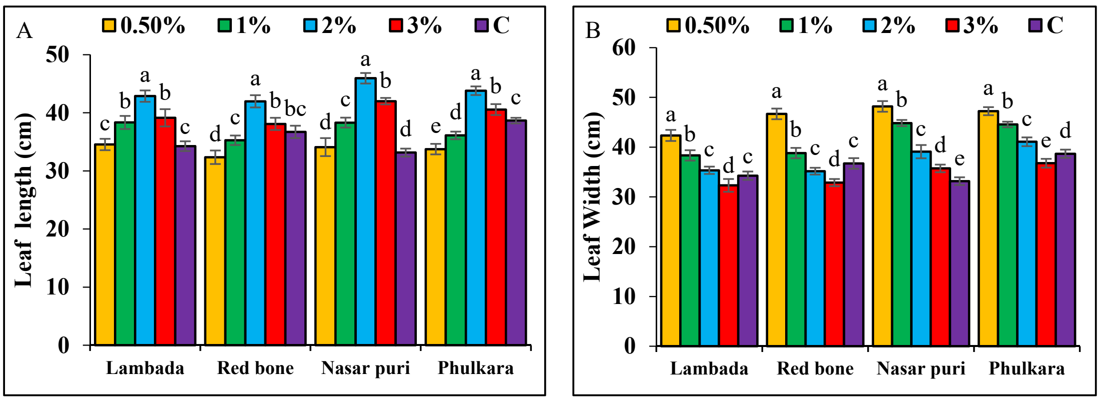

Figure 2. Leaf length (**A**) and width (**B**) in onion cultivars as affected by foliar application of 0 (C = control), 0.5, 1, 2, or 3% seaweed extract. Values are means of nine replicates ± standard error. Means with different letters are significantly different from each other compared by LSD at $p \leq 0.05$.

Leaf width showed a maximum increase of 38.6% in 'Nasar puri', 35.2% in 'Nasar puri', 15.2% in 'Phulkara' and 11.9% in 'Lambada' at 0.5% SWE as compared to the control. Application of 0.5% and 1% SWE both increased leaf width in the four cultivars (Figure 2B). SWE at 2% did not differ significantly from the control in 'Red Bone' and 'Lambada' but remained significantly greater in 'Phulkara' and 'Nasar puri'. SWE at 3% caused a significant reduction in leaf width of 'Phulkara', 'Red Bone' and 'Lambada' but increased leaf width in 'Nasar puri' over control.

3.3. Root Length and Weight

Application of SWE significantly ($p \leq 0.05$) affected onion root length and weight. A maximum increase of 81.0% in 'Phulkara', 70.0% in 'Nasar puri', 40.3% in 'Red Bone' and 9.2% in 'Lambada' root length at 0.5% SWE were observed (Figure 3A). In 'Lambada', 0.5% and 1%, SWE significantly increased root length, but 2% and 3% SWE decreased it. Application of 0.5%, 1% and 2% SWE remained statistically alike but 3% decreased root length over control in 'Red Bone'. In 'Nasar puri', all SWE rates enhanced root length as compared to the control. However, 0.5%, 1% and 2% SWE significantly improved but 3% SWE did not affect root length in 'Phulkara'.

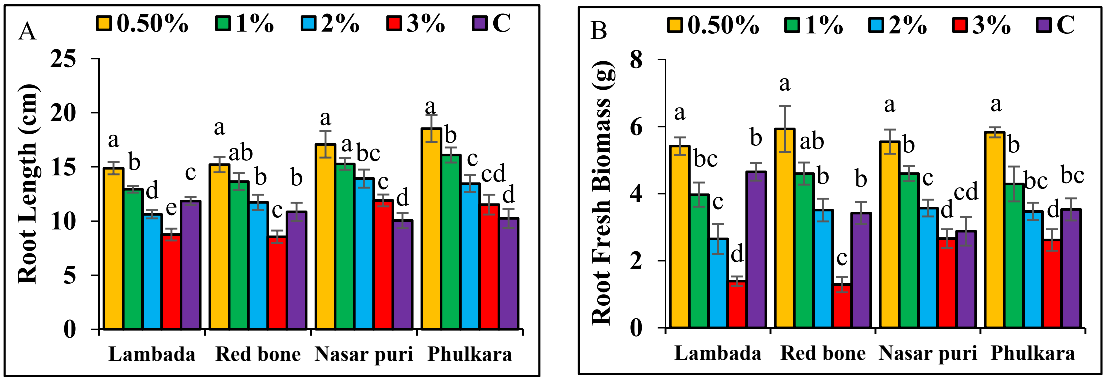

Figure 3. Root length (**A**) and fresh biomass (**B**) in onion cultivars as affected by foliar application of 0 (C = control), 0.5, 1, 2, or 3% seaweed extract. Values are means of nine replicates ± standard error. Means with different letters are significantly different from each other compared by LSD at $p \leq 0.05$.

A maximum increase of 92.7% in 'Nasar puri', 73.4% in 'Red Bone', 65.2% in 'Phulkara' and 16.6% in 'Lambada' root weight at 0.5% SWE was observed as compared to the control (Figure 3B). In 'Lambada', no significant change in root weight was observed at 1% SWE. However, 2% and 3% SWE decreased root weight in 'Lambada'. For root weight in 'Red Bone', 1% and 2% SWE were statistically alike but 3% caused a significant reduction as compared to the control. Application of 1% SWE in 'Nasar puri' significantly enhanced root weight from control but 2% and 3% SWE did not differ from the control. No significant change was observed with 1% or 2% SWE. However, 0.5% SWE significantly increased root weight, while 3% SWE decreased root weight from control in 'Phulkara'.

3.4. Bulb and Neck Diameter

Application of SWE significantly ($p \leq 0.05$) affected bulb diameter and neck diameter of the onion cultivars (Figure 4A). Bulb diameter showed a maximum increase of 23.9%, 9.0% and 18.3% in bulb diameter in 'Lambada', 'Nasar puri', and 'Red Bone' respectively as compared to the control at 0.5% SWE. However, in 'Phulkara' a maximum increase of bulb diameter of 13.2% was noted where 3% SWE was applied. In 'Lambada' all levels of SWE 0.5, 1%, 2%, and 3% caused significant improvement in bulb diameter as compared to the control. Application of 0.5 and 1% SWE were statistically alike but only 0.5% SWE caused a significant increase in 'Red Bone' bulb diameter. However, 3% of SWE caused a significant reduction in bulb diameter of 'Red Bone'. In 'Nasar puri', 0.5 and 3% SWE showed significant positive increases but 2% SWE did not differ from the control. Furthermore, the application of 1% SWE negatively affected bulb diameter in 'Nasar puri'. In 'Phulkara', except for 3% SWE, no application rate improved bulb diameter. However, 0.5 and 1% SWE significantly decreased bulb diameter weight in 'Phulkara'.

Maximum increases of 71.8%, 62.9%, 48.0%, 38.9% were noted in neck diameter of 'Red Bone', 'Red Bone', 'Lambada' 'Nasar puri', and 'Phulkara' at 0.5% SWE as compared to the control (Figure 4B). All application rates of SWE significant improved neck diameter of 'Lambada' and 'Red Bone'. In 'Nasar puri' and 'Phulkara', 0.5% and 1% SWE caused a significant increase, 1% SWE did not differ from the control, and 3% SWE decreased neck diameter.

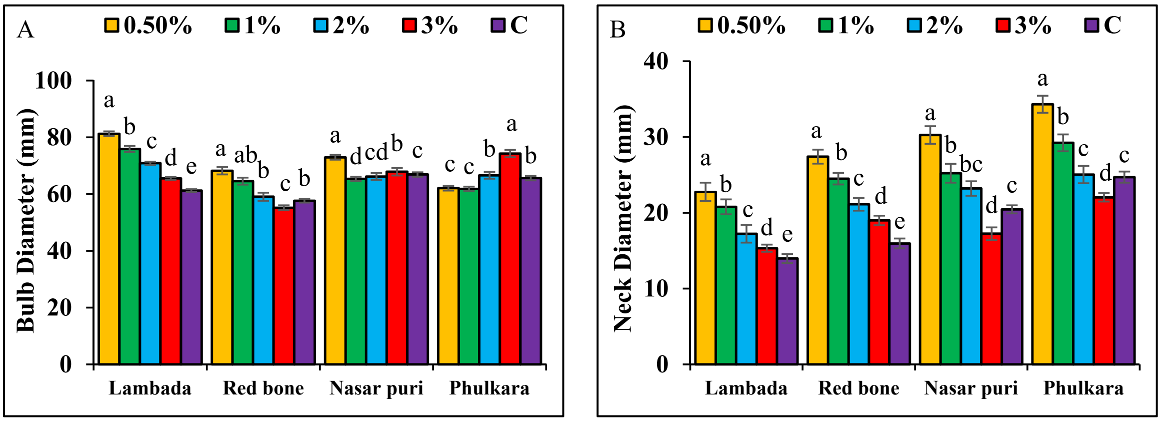

Figure 4. Bulb diameter (**A**) and neck diameter (**B**) in onion cultivars as affected by foliar application of 0 (C = control), 0.5, 1, 2, or 3% seaweed extract. Values are means of nine replicates ± standard error. Means with different letters are significantly different from each other compared by LSD at $p \leq 0.05$.

3.5. Bulb Dry Weight and Moisture Content

Application of SWE significantly ($p \leq 0.05$) affected bulb dry matter and neck moisture of different onion cultivars (Figure 5A). A maximum increase in bulb dry matter of 59.3% in 'Red Bone', 49.4% in 'Phulkara', 21.8% in 'Lambada' and 17.2% in 'Nasar puri' was noted at 0.5% SWE. Application of 0.5% and 1% SWE resulted in significant improvement in bulb dry matter of 'Lambada', 'Red Bone', 'Nasar puri' and 'Phulkara'. SWE at 2% did not differ from the control but 3% SWE caused a significant decrease in bulb dry matter of 'Lambada', 'Red Bone', 'Nasar puri' and 'Phulkara'.

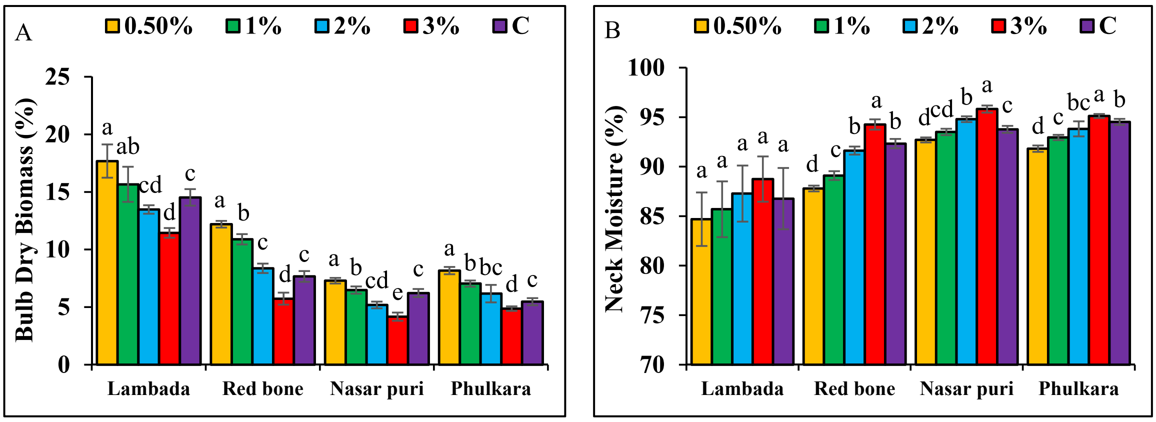

Figure 5. Bulb dry biomass (**A**) and neck moisture (**B**) in onion cultivars as affected by foliar application of 0 (C = control), 0.5, 1, 2, or 3% seaweed extract. Values are means of nine replicates ± standard error. Means with different letters are significantly different from each other compared by LSD at $p \leq 0.05$.

A maximum increase of 2.19%, 2.09% and 0.63% in neck moisture was noted in 'Nasar puri', 'Red Bone' and 'Phulkara' at 3% SWE as compared to the control (Figure 5B). No application rate of SWE differed from the control for 'Lambada' neck moisture. It was noted that 1% SWE did not differ from the control in 'Red Bone' and 'Phulkara' but was significantly different in 'Nasar puri'. Application of 2–3% SWE significantly decreased neck moisture in 'Red Bone' and 'Phulkara' but only 3% caused a reduction in 'Nasar puri'.

3.6. Bulb Weight and Yield

Application of SWE significantly ($p \leq 0.05$) affected bulb weight and yield of the onion cultivars (Figure 6A). A maximum increase in bulb weight of 5.8, 5.4, 2.4, and 2.0% in 'Lambada', 'Red Bone', 'Phulkara', and 'Nasar puri' at 0.5% SWE was observed, respectively. SWE at 0.5 and 1% significantly enhanced bulb weight, 2% SWE had no effect but 3% SWE caused a reduction of 'Lambada'. In 'Red Bone', 0.5% SWE caused a significant improvement in bulb weight but 1%, 2%, 3% SWE did not differ significantly from the control. In 'Nasar puri' and 'Phulkara', 0.5% SWE significantly improved bulb weight, 1 and 2% had no effect but 3% SWE caused a significant reduction in bulb weight.

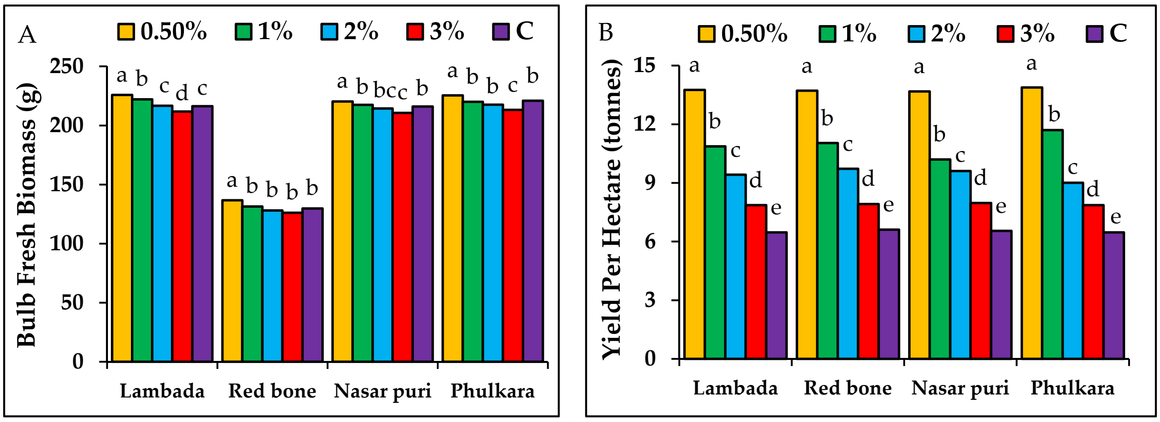

Figure 6. Bulb fresh biomass (**A**) and yield per hectare (**B**) in onion cultivars as affected by foliar application of 0 (C = control), 0.5, 1, 2, or 3% seaweed extract. Values are means of nine replicates ± standard error. Means with different letters are significantly different from each other compared by LSD at $p \leq 0.05$.

Regarding yield per hectare, application of 0.5%, 1%, 2%, and 3% SWE caused significant increases 'Lambada', 'Red Bone', 'Phulkara', and 'Nasar puri' (Figure 6B).

3.7. Total Soluble Solids

Total soluble solids and ascorbic acid showed significant ($p \leq 0.05$) positive responses to SWE application (Figure 7A). SWE at 0.5% gave a maximum increase in TSS of 175% in 'Lambada', 137% in 'Red Bone', 111% in 'Phulkara' and 30% in 'Nasar puri' over the control. On average, all application rates of SWE showed significant improvements in TSS of 'Lambada', 'Red Bone' and 'Phulkara'. However, in 'Nasar puri', 2 and 3% SWE caused significant reductions in TSS. For all onion cultivars, increasing application rates of SWE also enhanced ascorbic acid content (Figure 7B). Maximum increases of 58.8%, 52.9%, 58.8% and 58.3% in 'Lambada', 'Red Bone', 'Nasar puri', and 'Phulkara', respectively, were observed.

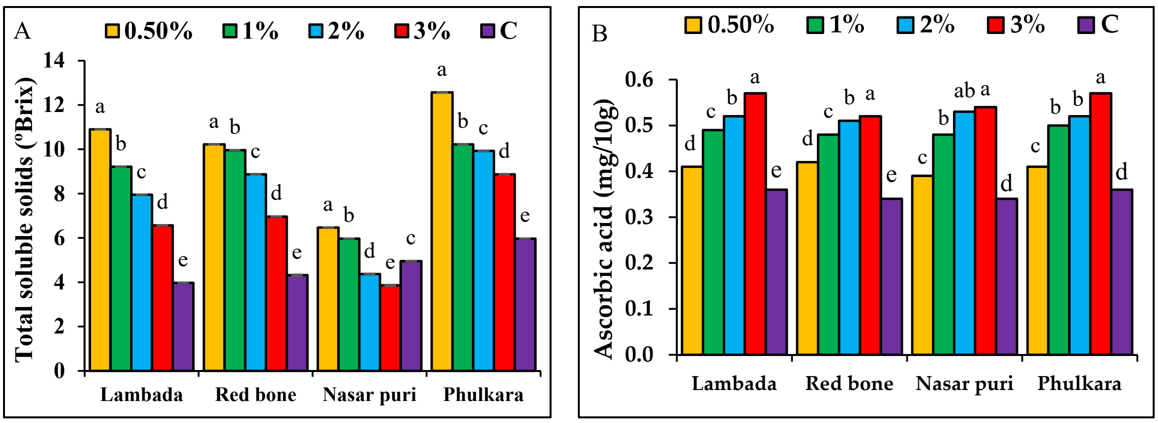

Figure 7. Total soluble solids (**A**) and ascorbic acid (**B**) in onion cultivars as affected by foliar application of 0 (C = control), 0.5, 1, 2, or 3% seaweed extract. Values are means of nine replicates ± standard error. Means with different letters are significantly different from each other compared by LSD at $p \leq 0.05$.

3.8. Nitrogen, Phosphorus and Potassium Contents

Application of SWE significantly ($p \leq 0.05$) affected N, P and K contents of the onion cultivars (Figure 8A). SWE at 0.5% resulted in a maximum increase of 83%, 127%, and 150% in N content of 'Lambada', 'Red Bone', and 'Phulkara', respectively, over the control. However, in 'Nasar puri', a greater increase in N content was observed at 3% SWE. All other application rates of SWE also significantly increased N content of the onion cultivars. For P content, again 0.5% SWE resulted in the greatest improvement of 57.6% in 'Lambada', 57.5% in 'Phulkara' and 47.3% in 'Red Bone' as compared to the control (Figure 8B). However, 1% SWE also caused a 38.3% increase in P content of 'Nasar puri'. Increasing levels of SWE gave decreasing trends in P content of all onion cultivars. For K content, 0.5% SWE showed a maximum increase of 26.3% in 'Red Bone', 57.6% in 'Lambada', 29.4% in 'Nasar puri' and 42.8% in 'Phulkara' compared to the control (Figure 8C). Application of 1% SWE also improved P content, but 2% SWE had no effect on K content of any onion cultivar (Figure 8C). However, 3% SWE caused a significant reduction in K content of 'Lambada', 'Red Bone', and 'Phulkara'.

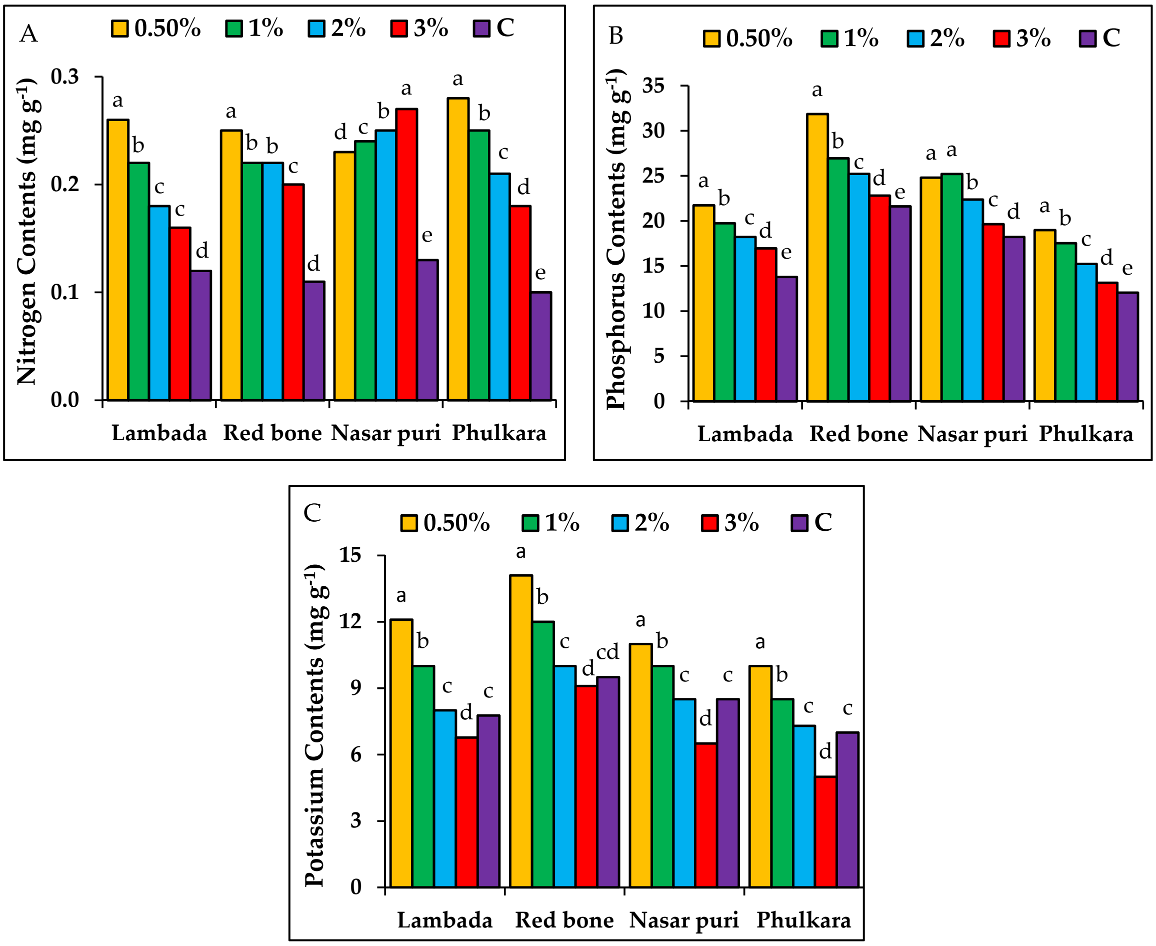

Figure 8. Nitrogen (**A**), phosphorus (**B**) and potassium (**C**) contents per g dry biomass in onion cultivars as affected by foliar application of 0 (C = control), 0.5, 1, 2, or 3% seaweed extract. Values are means of nine replicates ± standard error. Means with different letters are significantly different from each other compared by LSD at $p \leq 0.05$.

4. Discussion

In the present study, the results showed that foliar application of seaweed extract significantly enhanced different vegetative characters, i.e., leaf length, blade width, and plant height. This increment in leaf length and blade width could be ascribed to the role of seaweed enriched in auxin and cytokinins. These hormones affect metabolic activities predominantly through cell division and elongation [41].

Moreover, seaweed extract comprised of carbohydrates, mainly oligosaccharides, may control plant growth by affecting N assimilation and basal metabolism [42] by altering gene expression [43] whereas the number of leaves per plant may be influenced by prevailing climatic conditions, internal factors, and the interaction of both [44]. Vigor and health of leaves are chiefly chlorophyll dependent, as under stress conditions degradation of chlorophyll can lead to senescence of leaves [45]. SWE may prevent this chlorophyll degradation [46] due to the presence of betaines that protect the thylakoid membrane by regulating osmotic adjustment and enhancing ion homeostasis [47].

The present results also indicated that SWE application led to an increase in root length which can be ascribed to alginate oligosaccharide-induced expression of an auxin-related gene leading to higher auxin concentrations, thus promoting root formation and elongation [48]. Moreover, it could also be associated with SWE-modified absorption and localization of auxin and cytokinins that initiates lateral and adventitious root development along with heavier root biomass [49]. However, increased root growth could also be due to SWE- induced uptake and utilization of mineral nutrients [50], particularly N and S content [51]. SWE enriched in vitamins A, B and E [52] may help to enhance reproductive characters of onion as vitamin E is known to have a significant effect on bulb and neck diameter, and fresh and dry weight [53].

The present results also showed that all concentrations of seaweed exhibited higher bulb weight. This could be ascribed to auxin supplied by the seaweed which in turn enhanced cell division, elongation, and differentiation in addition to enhanced uptake of higher proteins and nucleic acid reserves eventually ensuring higher bulb weight [54]. Nutritional contents of onion were improved in SWE-applied treatments as the presence of glycine betaine, a constituent of SWE, could have led to enhanced phenolic compound synthesis [55] that has also been correlated to a positive relation between TSS, sweetness and ascorbic acid contents of fruits [56]. Total soluble solids depend upon transported ions and organic solutes which are converted into glucose inside fruit [57] where SWE application enhances glucose biosynthesis contributing to improved TSS content.

SWE extract application led to enhanced uptake and retention of nutrients in all onion cultivars. Jannin et al. [51] also concluded that SWE extracts positively led to the increment of root growth that ultimately enhanced the uptake and accumulation of elemental N content in bulbs. Similar results were reported by Halpern et al. [50] where seaweed extract significantly increased the uptake of N, P, and K. Also, SWE extract containing oligosaccharides resulted in increased photosynthesis, basal metabolism, cell division and altered metabolic pathways for increased uptake and better assimilation of nitrogen [58].

5. Conclusions

Foliar application of SWE positively influenced growth, yield, and quality attributes of in four onion cultivars. In general, the lowest rate used, 0.5% of SWE, had a significant impact on the onion cultivars nutrient content, yield, and TSS. However, the application of the highest rate of 3% SWE was not efficacious for promoting growth and yield attributes other than increased ascorbic acid. More investigations are suggested under different soil and climatic conditions to determine the best application rate of seaweed extract in field production of onions.

Author Contributions: M.A. designed and supervised experiment and wrote manuscript. J.A. conducted research, collected data and wrote manuscript. M.Z.-u.-H. and A.A.R. assisted in methodology validation and manuscript writing. R.I.K. and M.S. assisted in preparation of manuscript. S.D. and R.D. conducted statistical analyses, reviewed manuscript. All authors have read and agreed to the published version of the manuscript.

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