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Effects of Compound Salt Concentration on Growth, Physiological and Nutritional Value of Hydroponic Forage Wheat

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Abstract: (1) Background: Hydroponic forage plays an increasingly important role in animal breeding during winter and spring in arid and cold regions due to its rich nutrient and good palatability. In the present study, the profiles of growth, physiological indexes, nutritional value and in vitro degradation of hydroponic forage cultivated with different salt concentration were evaluated. (2) Methods: The compound salt was extracted from soil surrounding the Tarim River Basin, and five compound salt solution treatment groups (three replicates each) with concentrations of 0%, 0.4%, 0.8%, 1.2% and 1.6% were prepared. Winter wheat seeds were selected as hydroponic forage for germination experiments, and the germination, physiological indicators, nutritional value and in vitro fermentation degradation rate were analyzed. (3) Results: The results showed that the germination and growth of hydroponic herbage were significantly ($p < 0.05$) inhibited by compound salt concentration higher than 0.8% from the third day. Compared with the 0% concentration group, the chlorophyll content in the 0.4% concentration group was significantly increased ($p < 0.05$), and contents of chlorophyll a, chlorophyll b and total chlorophyll were 729.71 mg·g⁻¹, 223.19 mg·g⁻¹ and 952.9 mg·g⁻¹, respectively. The total chlorophyll content in the 0.8% and 1.2% concentration groups were significantly lower than those in the 0% and 0.4% concentration groups ($p < 0.05$), and in the 1.6% concentration group, the content undetected. With the increase in compound salt concentration, the contents of soluble sugar and proline were significantly increased ($p < 0.05$). The nutrient compositions were significantly increased ($p < 0.05$) under the 0.4% and 0.8% concentration groups, in which the content of crude protein in 0.4% concentration group was 15.23%. The results of gas production and fermentation parameters suggested that the 0.8% concentration group could enhance rumen fermentation characteristics. (4) Conclusions: In summary, 0.8% as the upper limit concentration and 0% to 0.4% as the optimal concentration range of compound salt can be considered for cultivating hydroponic forage wheat.

Keywords: salt concentration; hydroponic wheat; physiological characteristics; nutritional characteristics; gas production

1. Introduction

Rapid development of husbandry in many developing countries and the shortage of high-quality forages because of arid climate and saline-alkali soil have limited the sustainable development of the ruminant industry [1,2]. Southern Xinjiang, located in the south of the Xinjiang Uygur Autonomous Region of China, covers 60% of the total area of...
Xinjiang and 11% of the total area of China [3]. The capacity to provide feed to ruminants from natural grassland has decreased sharply in recent years in Southern Xinjiang areas because of the existence of the Taklimakan Desert [4], excessive cultivation, water shortage, soil salinization [5] and the continuously increasing amount of animal breeding. High-quality forages are often purchased from northern Xinjiang or outside of Xinjiang, which lead to an increase in fodder cost. Consequently, it is essential to develop and utilize feed resources reasonably to make sure the sustainable development of the livestock industry in Southern Xinjiang.

Winter and spring are the seasons for lambing and lactation of female animals, requiring a large amount of feed with good adaptability and high nutritional value [6]. However, the shortage of green forage during the dry and cold autumn and winter seasons is a common phenomenon, which in turn causes livestock to lose weight, pregnant animals to miscarry and newborn animals to die. Providing livestock with green and juicy forage during the autumn and winter is very important.

Hydroponics has been used to produce vegetables and food crops for many years. Recently, the practice of hydroponically sprouting grain seeds has been developed for feeding animals [7]. Hydroponic sprouts have the advantages of rapid production and high biomass production, in an average of 6–8 days, which means they can be used as a quick renewable resource of forage [8]. Hydroponic forage can be generally cultivated in non-agricultural land using water extracted from groundwater. Alan et al. [9] reported that milk quality improved with high fat and mineral elements by feeding hydroponic forage to dairy cows. Ren et al. [10] found that hydroponic barley seedlings replaced 25% of oats and had no significant effect on the feed intake and digestibility of Holstein cows. The study of Brake et al. [11] showed that wheat seedlings are rich in protein, amino acids and vitamins. Wheat seedling has good palatability and digestibility and can be mixed with straw feed and other feed stuffs to make diets to improve the feed intake of livestock. However, salinity is one of the major factors limiting wheat production worldwide. Wang et al. [12] investigated the groundwater resources of the Tarim River Basin and discovered that the water–salt accumulation area relatively increased with high soil salinization and mineralization. The development and utilization of salty water is of strategic importance for water security in the region. Wang et al. [13] confirmed that halogeton glomeratus achieved maximum growth when irrigated with a 100 mmol·L$^{-1}$ NaCl solution. Feng et al. [14] compared two types of forage grasses and found that salt stress increased the dry matter content of forage grasses. Jang et al. [15] found that the secondary metabolites of L. tetragonum were optimal at 75 mmol·L$^{-1}$.

Most previous studies focused on the effects of single salt on the performance of plant growth. In fact, groundwater containing compound salts is often widely used for the production of hydroponic forage. It is necessary to study the effects of compound salts on the growth characteristics of hydroponic forage. We hypothesize that under hydroponic conditions, the germination, growth and nutritional value of winter wheat decrease with the increase in compound salt concentration. Therefore, the present research aimed at exploring the effects of compound salt concentration on the growth, physiological indexes and nutritional value of winter wheat seedlings. The results of current study will be beneficial for alleviating the shortage of green forage in animal farming in arid areas.

2. Materials and Methods

2.1. Materials

Soil samples taken from the vicinity of the Tarim River Basin were mixed with distilled water at a volume ratio of 1:5 and stirred for 5 min [16]. After the supernatant fluid was evaporated by the boiling method, the residue defined as compound salt was obtained for the preparation of the hydroponic culture solution. The content of soil salt-based ions and composition of compound salts [17] are presented in Table 1. Compound salt concentrations were set at 0%, 0.4%, 0.8%, 1.2% and 1.6% for hydroponic winter wheat cultivation. Wheat seeds (Xindong 22) were obtained from the College of Agriculture, Tarim University.
Table 1. The content of soil salt-based ions and the composition of compound salt extracted from soil around Tarim River Basin.

<table>
<thead>
<tr>
<th>Items</th>
<th>Cl$^{-}$</th>
<th>CO$_3^{2-}$</th>
<th>HCO$_3^{-}$</th>
<th>SO$_4^{2-}$</th>
<th>Ca$^{2+}$</th>
<th>Mg$^{2+}$</th>
<th>K$^+$</th>
<th>Na$^+$</th>
<th>Total Soluble Salts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil salt-based ions (g·kg$^{-1}$)</td>
<td>3.07</td>
<td>-</td>
<td>0.11</td>
<td>1.2</td>
<td>1.4</td>
<td>0.45</td>
<td>6.69</td>
<td>7.62</td>
<td>20.53</td>
</tr>
<tr>
<td>Compound salt composition (%)</td>
<td>14.95</td>
<td>-</td>
<td>0.54</td>
<td>5.85</td>
<td>6.82</td>
<td>2.19</td>
<td>32.59</td>
<td>37.12</td>
<td>100</td>
</tr>
</tbody>
</table>

2.2. Hydroponic Wheat Seedling Production

Wheat seeds were disinfected with 0.3% potassium permanganate solution for 15 min, rinsed 5 times to remove the disinfection, and finally, they were soaked in cold water overnight. The following morning, the seeds were evenly placed in a Petri dish lined with two filter paper layers with forceps, and the compound salt concentration solutions were added to the corresponding dishes. Treatments were divided into five groups according to the five different compound salt concentrations with three replicates in each group of 50 seeds in one Petri dish. The Petri dishes were placed in the light incubator for culturing. The incubator’s temperature was set to 26°C/16°C for day and night, respectively; dark treatment was carried out first for 24 h to increase the amount of germination, followed by exposure light time for 24 h, replenishing the missing water twice a day to keep the humidity at about 70–90%. The experimental period for hydroponic wheat seedlings was seven days.

2.3. Determination of Plant Growth Parameters

Plants were randomly chosen from each treatment to estimate shoot length, root length and other relevant growth indicators during the 7 days of the hydroponics period. The length of wheat seedling was manually measured using a measuring scale. The number of seed germination was counted, and the bud length was measured over 2–4 days. Bud length refers to the length of stem and leaves after germination of wheat seed. From the fifth day, the wheat seedling began to appear lobulated, so the bud length was no longer counted. The height of wheat seedling (plant length) was measured over 5–7 days.

2.4. Determination of Physiological Indicators

The proline content was measured by ninhydrin staining of Shen et al. [18] and calculated using a proline standard curve (0–50 mg·mL$^{-1}$) identically. A previous method was used for the determination of photosynthetic pigments (total chlorophyll, chlorophyll a and chlorophyll b), and total chlorophyll was calculated as chlorophyll a + chlorophyll b [19]. The absorbance of the extract was measured at 470, 663 and 645 nm using a spectrophotometer (TU-1810, Puxi General Instrument Co., Ltd., Beijing, China). The malondialdehyde (MDA) was measured with the thiobarbiturate method and expressed as µmol·g$^{-1}$ using the following formula 6.45 (A532–A600)−0.56A450 [20]. The soluble sugars were also measured by the same method at 450 nm using a TU-1810 spectrophotometer.

2.5. Nutritional Compositions of Hydroponic Wheat Seedlings

The dry matter (DM) contents of samples were determined in triplicate after drying approximately 3 g of each sample at 103°C (DHG-9240A, Shanzhi Instrument Equipment Co., Ltd., Shanghai, China) for 4 h. Ether extract (EE), crude protein (CP) and crude ash (Ash) were analyzed according to AOAC methods [21]. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined according to Van Soest et al. [22].

2.6. In Vitro Fermentation and Gas Parameters

A sample of 0.22 g was weighed into a 100 mL glass syringe, and rumen buffer was prepared according to the method of Menke et al. [23]. Before morning feeding, the ruminal fluid obtained from three Duo Lang sheep fitted with a fistula was immediately taken to the laboratory, filtered through four layers of gauze, kept at 39°C in a water bath and blended
with buffer solution (1:2, v/v) under a continuous flush of CO₂, and several drops of 0.1% resazurin solution were added. The samples were added into each glass syringe with 30 mL of mixed solution. After adding the liquid, it was placed in an artificial rumen incubator in a 39 °C water bath. The amount of gas generated after 0, 1, 2, 4, 8, 12, 24, 36, 48, 60 and 72 h was recorded, and the gas production (GPₜ) was calculated as Pₜ = (Pₜ - P₀)/W.

GPₜ: samples in t time of gas production (mL·g⁻¹ DM); Pₜ: Volume read in time period t (mL); P₀: Volume of blank sample read in time period t (mL); W: weight of sample used in fermentation.

After 72 h of in vitro fermentation, the pH of the fermentation broth was measured with a pH meter (Hanna Instruments Italia Srl, Villafranca Padovana, Italy) and placed in ice water to terminate the fermentation.

Ammoniacal nitrogen (NH₃-N) concentration referred to the method of Chaney et al. [24]. The in vitro dry matter degradation (IVDMD) was calculated by the difference of the DM content before and after fermentation [25].

2.7. Statistical Analysis

Statistical analysis was conducted using one-way analysis of variance (ANOVA) with SPSS software (version 26.0). The resultant data were shown as means ± standard errors (n = 3), and Duncan’s multiple test was applied to detect differences between means (p < 0.05). Nonlinear regression in SPSS software was adopted for the calculation of degradation parameters a, b and c.

3. Results

3.1. Plant Growth

Table 2. Germination of Xindong 22 under different compound salt concentrations.

<table>
<thead>
<tr>
<th>Items</th>
<th>Treatment</th>
<th>Days</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Germination</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(piece)</td>
<td>0%</td>
<td>24.0 ± 2.0</td>
<td>30.3 ± 4.0</td>
<td>34.0 ± 2.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.4%</td>
<td>19.0 ± 1.0</td>
<td>20.0 ± 2.7</td>
<td>23.0 ± 1.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.8%</td>
<td>14.0 ± 2.0</td>
<td>17.0 ± 2.0 b</td>
<td>19.0 ± 1.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.2%</td>
<td>11.0 ± 3.0</td>
<td>12.0 ± 3.0 c</td>
<td>13.0 ± 2.0 d</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.6%</td>
<td>5.0 ± 2.0 d</td>
<td>6.0 ± 2.0 d</td>
<td>7.0 ± 1.7 e</td>
<td></td>
</tr>
<tr>
<td>Bud length (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0%</td>
<td>1.1–2.6</td>
<td>1.7–6</td>
<td>1.3–8.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.4%</td>
<td>0.9–2.4</td>
<td>1.4–4.3</td>
<td>1.5–5.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.8%</td>
<td>0.5–1.5</td>
<td>0.9–1.6</td>
<td>0.9–1.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.2%</td>
<td>0.5–1.3</td>
<td>0.6–1.3</td>
<td>0.6–1.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.6%</td>
<td>0.5–0.7</td>
<td>0.7–1.3</td>
<td>0.7–1.4</td>
<td></td>
</tr>
</tbody>
</table>

Different lowercase letters in the same column indicate significant differences between the different treatments of the same index (p < 0.05).

As shown in Table 3, the plant height of each treatment group was significantly lower than that of the 0% concentration group at any period (p < 0.05). Under the treatment of compound salts, the plant height was significantly higher in the 0.4% concentration group.
than that in the other three groups, and the plant height was only 0.53 cm on the fifth day with a compound salt concentration of 1.6%. On day 5, the seedling root length of the 0.4% concentration group was significantly higher than that of the other four groups (p < 0.05). On days 6 and 7, the root length of 1.6% compound salt concentration had the significantly lowest value compared with other groups (p < 0.05).

Table 3. Growth of Xindong 22 seedlings under different compound salt concentrations.

<table>
<thead>
<tr>
<th>Items</th>
<th>Days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Plant Height (cm)</td>
</tr>
<tr>
<td>0%</td>
<td>11.43 ± 0.76 a</td>
</tr>
<tr>
<td>0.4%</td>
<td>6.77 ± 1.51 b</td>
</tr>
<tr>
<td>0.8%</td>
<td>3.10 ± 0.30 c</td>
</tr>
<tr>
<td>1.2%</td>
<td>1.27 ± 0.47 d</td>
</tr>
<tr>
<td>1.6%</td>
<td>0.53 ± 0.35 d</td>
</tr>
</tbody>
</table>

Different lowercase letters in the same column indicate significant differences between the different treatments of the same index (p < 0.05).

3.2. Physiological Indexes

The influence of physiological indexes of the wheat seedling is shown in Table 4. In general, chlorophyll contents increased first and then decreased with the increase in the compound salt concentration. When the compound salt concentration was 0.4%, chlorophyll contents in seedlings were significantly higher than those in the 0%, 0.8%, 1.2% and 1.6% concentration groups (p < 0.05), and no chlorophyll content was detected in the 1.6% concentration group. The lowest MDA content in the 1.6% concentration group was 0.005 µmol·g⁻¹, which was significantly lower than that in the other experimental groups (p < 0.05). The soluble sugar content in the 1.6% concentration group was significantly higher than that in the other concentration groups (p < 0.05). The proline content in the 0.4% concentration group was significantly lower than that in the 0%, 1.2%, and 1.6% concentration groups (p < 0.05).

Table 4. Effects of different compound salt concentrations on physiological indexes of Xindong 22 at seedling stage.

<table>
<thead>
<tr>
<th>Items</th>
<th>Chlorophyll (mg·L⁻¹)</th>
<th>MDA (µmol·g⁻¹)</th>
<th>Soluble Sugar (µg·g⁻¹)</th>
<th>Proline (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Chlorophyll a</td>
<td>Chlorophyll b</td>
<td>Total Chlorophyll</td>
<td></td>
</tr>
<tr>
<td>0%</td>
<td>348.82 ± 8.22 b</td>
<td>32.50 ± 13.73 b</td>
<td>381.32 ± 21.31 b</td>
<td>0.014 ± 0.001 ab</td>
</tr>
<tr>
<td>0.4%</td>
<td>729.71 ± 9.16 a</td>
<td>223.19 ± 5.44 a</td>
<td>952.90 ± 14.31 a</td>
<td>0.015 ± 0.002 a</td>
</tr>
<tr>
<td>0.8%</td>
<td>269.72 ± 8.62 c</td>
<td>ND</td>
<td>269.72 ± 8.62 c</td>
<td>0.016 ± 0.003 a</td>
</tr>
<tr>
<td>1.2%</td>
<td>94.45 ± 8.00 d</td>
<td>ND</td>
<td>94.45 ± 8.00 d</td>
<td>0.010 ± 0.003 b</td>
</tr>
<tr>
<td>1.6%</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>0.005 ± 0.002 c</td>
</tr>
</tbody>
</table>

Different lowercase letters in the same column indicate significant differences between the different treatments of the same index (p < 0.05). ND, not detected; MDA, malondialdehyde.

3.3. Nutrition Characteristics

As can be seen from Table 5, nutrient contents were significantly affected (p < 0.05) by compound salt concentration. The DM content was the highest at 43.82% in the 6% concentration group. The ash in the 0.4%, 0.8%, 1.2% and 1.6% concentration groups was significantly higher (p < 0.05) than that in the 0% concentration group. ADF and NDF of Xindong 22 seedlings in 0.4% concentration group were significantly higher than those of the other four groups (p < 0.05) and their NDF and ADF were the highest, at 35% and 8.48%, respectively. The EE content of Xindong 22 seedlings decreased with the increase
in compound salt concentration, and the 0% concentration group was significantly higher than that of the 0.4%, 0.8%, 1.2% and 1.6% concentration groups \( p < 0.05 \). The CP content at 0.4% and 0.8% concentration was significantly higher than that in the 0%, 1.2% and 1.6% concentration groups \( p < 0.05 \).

**Table 5. Effects of different compound salt concentrations on nutrients of Xindong 22.**

<table>
<thead>
<tr>
<th>Items</th>
<th>DM (%)</th>
<th>Ash (%)</th>
<th>NDF (%)</th>
<th>ADF (%)</th>
<th>EE (%)</th>
<th>CP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>17.90 ± 0.44 c</td>
<td>1.93 ± 0.12 d</td>
<td>23.18 ± 0.57 b</td>
<td>5.37 ± 0.66 c</td>
<td>14.09 ± 0.68 a</td>
<td>12.73 ± 0.04 c</td>
</tr>
<tr>
<td>0.4%</td>
<td>25.73 ± 0.89 d</td>
<td>5.14 ± 0.05 ab</td>
<td>35.00 ± 0.79 a</td>
<td>8.48 ± 0.25 a</td>
<td>11.30 ± 0.48 b</td>
<td>15.23 ± 0.05 a</td>
</tr>
<tr>
<td>0.8%</td>
<td>38.73 ± 0.79 c</td>
<td>5.38 ± 0.08 a</td>
<td>21.51 ± 0.89 c</td>
<td>6.55 ± 0.47 b</td>
<td>10.98 ± 0.44 b</td>
<td>13.26 ± 0.01 b</td>
</tr>
<tr>
<td>1.2%</td>
<td>40.47 ± 0.84 b</td>
<td>4.90 ± 0.04 bc</td>
<td>17.81 ± 0.55 d</td>
<td>2.96 ± 0.04 d</td>
<td>9.12 ± 0.64 c</td>
<td>12.64 ± 0.08 d</td>
</tr>
<tr>
<td>1.6%</td>
<td>43.82 ± 0.99 a</td>
<td>4.80 ± 0.30 c</td>
<td>16.72 ± 0.67 d</td>
<td>1.55 ± 0.06 e</td>
<td>9.39 ± 0.70 c</td>
<td>12.03 ± 0.04 e</td>
</tr>
</tbody>
</table>

Different lowercase letters in the same column indicate significant differences between the different treatments of the same index \( p < 0.05 \). DM, dry matter; Ash, crude ash; NDF, neutral detergent fiber; ADF, acid detergent fiber; EE, ether extract; CP, crude protein.

### 3.4. In Vitro Gas Production and Kinetic Parameters of Hydroponic Herbage

As can be seen from Figure 1, the gas production of each group showed an upward trend and remained consistent from 0 h to 4 h. The gas production of the 1.6% concentration group was significantly higher than that of the other groups from 6 h to 72 h \( p < 0.05 \); especially at 24 h, the rising trend in gas production was higher than that of the 0%, 0.4%, 0.8% and 1.2% concentration groups. The 0% concentration group reached full gas production after 48 h, while the compound salt treatment groups reached maximum gas production after 60 h. Then, the gas production rate slowed down.

![Figure 1. In vitro gas production (mL·g^{-1} DM) of hydroponic Xindong 22 with different compound salt concentrations for 72 h.](image)

The gas production parameters are shown in Table 6. Rapid gas production \( a \) in the 0.4% concentration group was significantly higher than that in the control group and other compound salt concentration treatment groups \( p < 0.05 \), while slow gas production \( b \) was significantly lower than that of the other treatment groups \( p < 0.05 \), which reached 62.97 mL. The gas production rate constant \( c \) was similar, and the 1.2% and 0% concentration groups were significantly higher than that of other treatment groups \( p < 0.05 \). The potential gas content \( a + b \) increased with the increase in compound salt...
concentration, which was significantly higher than that of the control group ($p < 0.05$). The pH value of fermentation broth ranged from 6.82 to 7.18, but the pH value of the 0.4%, 0.8% and 1.2% treatments was significantly higher than that of the 0% and 1.6% treatment groups ($p < 0.05$). There is no significant difference in NH$_3$-N concentration between the experimental groups ($p > 0.05$). The IVDMD in the 0.8%, 1.2% and 1.6% treatment groups was significantly higher than that in the 0% and 0.4% treatment groups ($p < 0.05$).

Table 6. In vitro fermentation gas production parameters of hydroponic Xindong 22 with different compound salt concentrations.

<table>
<thead>
<tr>
<th>Items</th>
<th>a $^1$</th>
<th>b $^2$</th>
<th>c $^3$</th>
<th>a + b</th>
<th>pH</th>
<th>NH$_3$-N (mg·DL$^{-1}$)</th>
<th>IVDMD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>$-2.47 \pm 1.25$ c</td>
<td>$69.62 \pm 0.13$ c</td>
<td>$0.20 \pm 0.02$ a</td>
<td>$67.15 \pm 1.25$ c</td>
<td>$6.85 \pm 0.09$ c</td>
<td>$11.12 \pm 0.10$</td>
<td>$41.29 \pm 1.05$ b</td>
</tr>
<tr>
<td>0.4%</td>
<td>$9.19 \pm 2.07$ a</td>
<td>$62.97 \pm 1.53$ d</td>
<td>$0.11 \pm 0.02$ b</td>
<td>$72.16 \pm 2.68$ b</td>
<td>$7.13 \pm 0.04$ ab</td>
<td>$11.20 \pm 0.05$</td>
<td>$42.85 \pm 1.23$ b</td>
</tr>
<tr>
<td>0.8%</td>
<td>$5.17 \pm 0.83$ b</td>
<td>$68.09 \pm 1.38$ c</td>
<td>$0.13 \pm 0.01$ b</td>
<td>$73.26 \pm 1.90$ b</td>
<td>$7.18 \pm 0.07$ a</td>
<td>$10.99 \pm 0.06$</td>
<td>$47.68 \pm 1.43$ a</td>
</tr>
<tr>
<td>1.2%</td>
<td>$-2.64 \pm 2.58$ c</td>
<td>$75.68 \pm 3.82$ b</td>
<td>$0.21 \pm 0.06$ a</td>
<td>$73.05 \pm 1.52$ b</td>
<td>$7.03 \pm 0.05$ b</td>
<td>$11.00 \pm 0.20$</td>
<td>$48.41 \pm 0.82$ a</td>
</tr>
<tr>
<td>1.6%</td>
<td>$2.05 \pm 2.00$ b</td>
<td>$89.23 \pm 2.13$ a</td>
<td>$0.13 \pm 0.01$ b</td>
<td>$91.27 \pm 3.94$ a</td>
<td>$6.82 \pm 0.05$ c</td>
<td>$11.00 \pm 0.12$</td>
<td>$49.39 \pm 0.84$ a</td>
</tr>
</tbody>
</table>

Different lowercase letters in the same column indicate significant differences between the different treatments of the same index ($p < 0.05$). $^1$ a = Instant gas production from rapidly soluble fraction (mL·g$^{-1}$ DM), $^2$ b = slow gas production from insoluble fraction (mL·g$^{-1}$ DM), $^3$ c = the rate of gas production from slowly insoluble fraction (mL·h$^{-1}$).

4. Discussion

4.1. Germination

The most sensitive stage of plants to salt stress is seed germination. The effect of salt stress on plant seed germination rate, bud length and root system [26]. The salt tolerance of plants is reflected by the germination rate, and the higher the germination rate, the stronger the salt tolerance [14]. This experiment showed that when the compound salt concentration was greater than 0.8%, the germination of Xindong 22 was inhibited. The bud length was also inhibited with the increase in compound salt concentration. This is consistent with the results of Nefissi Ouertani et al. [27,28]. Salt stress caused plant metabolism disorder, disrupted development, decreased the net photosynthetic rate and increased activities of antioxidant enzymes [29,30].

In terms of root growth, on day 5 and 6, the roots of wheat seedlings in the 0.4% concentration group were well developed, and the root length reached the maximum. This might be caused by the variety of ions in the soil near the banks of the Tarim River [17]. On day 6 and 7, 0.4%, 0.8% and 1.2% of the compound salt concentrations did not affect the root system, and 1.6% compound salt concentration inhibited root growth, indicating that the saline concentrations disrupted root development, which was similar to Sun et al. [31], whose results showed that root lengths had a trend of first increasing and then decreasing with the application of saline stress to sorghum (Sorghum bicolor L.). In this experiment, winter wheat grew well when the compound salts concentration was less than 0.8%.

4.2. Physiological Indexes at Seedling Stage

Chlorophyll is one of the important indicators of plant salt tolerance, and chlorophyll a and b are the main products of photosynthesis [32]. The results of this study showed that chlorophyll content had a trend of increasing and then decreasing with increasing concentrations of compound salt (highest at 0.4% and lowest at 1.2%), which was consistent with the findings of Tavangar et al. [33] in a study of salinity tolerance in Iranian borage. The chlorophyll content of winter wheat was increased at a salt concentration of 0.4% compared to the 0% group. Ma et al. [34] also found that salt stress induced moisture loss (the primary injury) and then depressed chlorophyll biosynthesis.

The change in MDA content is also of great significance in plant stress physiology, MDA content can indirectly evaluate the damage degree of plant membrane systems under
a high salt environment. The membrane system is the main site of plant salt damage under saline-alkali stress [35]. The MDA content increased when the cell membrane was damaged [35]. With the increase in concentration, cell membranes were severely damaged by alkali stress, and the contents of MDA increased significantly, which stimulated the plants’ antioxidant defense system [36]. In this study, the content of MDA reached the highest value of 0.016 µmol·g⁻¹ at a concentration of 0.8%. This was consistent with the results by Babakhani et al. [37], who reported that the MDA content of alfalfa cultivars’ seeding had increased with increasing salinity levels. However, the content of MDA in the 1.2% and 1.6% concentration groups was lower than that in the 0.8% concentration group, which may be due to the timely removal of MDA generated during this stress, ensuring the selective permeability of the cell membrane.

Osmoregulation substances, such as proline and soluble sugar, are positively correlated with salt concentration [38]. When plants are in stress by adversity, proline will increase, clear up the accumulated superoxide anion, regulate osmotic pressure and maintain structure and function of the cell membrane [39]. Soluble sugar is essential for maintaining the osmotic pressure in plants, and its content will increase under adversity conditions [38]. The results of this study showed that the contents of soluble sugar and proline increased with the increase in compound salt stress concentrations. Birhanie et al. [40] had similar results in their research on the contents of soluble sugar and free proline on kenaf (Hibiscus cannabinus L.). The proline content was significantly lower than that of the control group at 0.4% concentration, indicating no damage to seedlings in the 0.4% concentration group.

4.3. Nutritional Characteristics

The nutritional value initially reflects the feeding value of herbage. CP, NDF and ADF are important indicators for the evaluation of the nutritional value of herbage, which is not only directly related to the quality and digestibility of herbage, but also related to the utilization efficiency of forage grass by animals [41]. In the present study, when the salt concentration was greater than 0.8%, the contents of CP, NDF and ADF began to decline, which was consistent with the results of Lu et al. [42]. In this paper, the CP content at 0.4% and 0.8% concentrations were significantly higher than the control, with the highest (15.23%) CP content at 0.4% concentration.

4.4. Gas Production and Gas Production Parameters In Vitro Rumen Fermentation

The gas produced in the rumen is mainly derived from the decomposition of carbohydrates and the carbon-containing fraction of protein in the feed by microorganisms [43]. In vitro gas production can reflect the degradation activity of microorganisms in the rumen and feed degradation rate [23,44]. In this study, the gas production at 1.6% concentration was higher than the other concentration groups. The growth rate of gas production in the 0% concentration group slowed down after 48 h, while the growth rate in the other concentration groups started to slow down after 60 h. The negative value of rapid gas production indicates the delay of feed fermentation, and the larger the negative value, the shorter the delay time. With the increased salt and alkali concentration ratio of hydroponic wheat seedlings, there was a significant difference in rapid gas production, indicating that 0.4% and 0.8% concentrations could effectively improve the substrate fermentation delay. The slow gas production and 72 h gas production at 1.6% concentration were significantly higher than the other treatment group, indicating the best digestibility of hydroponic wheat seedlings at 1.6% concentration, which may be due to the inhibition of seed germination at high concentrations. The nutrients in the seeds were consumed less and contained great substrates, such as starch, which led to higher digestibility. In a comprehensive comparison, the digestibility of wheat seedlings under 0.8% concentration treatment was found to be better.

Ruminal fluid pH is an important indicator of the steady-state condition of the rumen environment and fermentation characteristics, which is necessary for the normal survival and function of rumen microorganisms. The normal pH of ruminal fluid is 5.5 to 7.5 [45].
In this experiment, the pH of fermentation fluid in each group was between 6.82 and 7.18, which was slightly higher than the optimum range of ruminal fluid pH of 6.6 to 7.0. The increased pH of the culture herbage may be due to the concentration of compound salt.

The content of NH$_3$-N is one of the main indices to evaluate the status of rumen fermentation. Furthermore, NH$_3$-N is an important product of protein metabolism during rumen fermentation and is the main raw material for microbial protein synthesis. In this experiment, NH$_3$-N concentrations were 10.99–11.20 mg·dL$^{-1}$, with no significant difference. The study showed that the optimum concentration of NH$_3$-N for microbial growth in the rumen was from 5.00 mg·dL$^{-1}$ to 30.00 mg·dL$^{-1}$ [46]. The results indicate that the compound salt concentration did not affect the ability of rumen microorganisms to decompose protein in the diet and the absorption rate.

The index of IVDMD could be used to directly evaluate the feeding value of feed, reflecting the digestibility of feed by animals [3]. Higher IVDMD indicates more microbial activity and better substrate fermentation [47]. In this experiment, the IVDMD of wheat seedlings grown hydroponically at 0.8%, 1.2% and 1.6% concentrations was significantly higher than that of the 0% and 0.4% compound salt concentration. High concentrations of compound salt can inhibit enzyme activity and seed germination, resulting in more retention of starch within the seeds, which could lead to higher IVDMD due to the easily fermentation and digestion of starch.

5. Conclusions

This study confirmed that the germination and growth of hydroponic Xindong 22 can be inhibited by increasing compound salt concentration. The results demonstrated that there was no significant effect on sprouting and rooting, except for the inhibition of the height of seedlings with the 0.4% compound salt concentration. Regarding feeding value, hydroponic wheat in the 0.4% and 0.8% concentration groups was easier to digest and absorb by ruminant than that in 0%, 1.2% and 1.6% concentration groups. Overall, considering the results, 0.8% as the maximum concentration and 0% to 0.4% as recommended optimal concentration range of compound salt can be considered for cultivating hydroponic forage wheat.

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