Arbuscular Mycorrhizal Fungi Inoculation Improves Flower Yield and Postharvest Quality Component of Gerbera Grown under Different Salinity Levels

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Abstract: High salinity levels of irrigated water and the accumulation of salt over time in the soil is a major concern worldwide, including in Jordan. The objective of this two-year study was to assess the influence of arbuscular mycorrhizal fungi (AMF) inoculation on the physiology, yield, and flower quality of gerbera (Gerbera jamesonii cvs. Beaudine and Palm Beach) under different salinity levels (0.0, 20.0 and 40.0 mM-NaCl). The study was arranged in a randomized complete block design with five replicates. During the experimental period (2018–2019), chlorophyll content index (SPAD), leaf gas exchange (photosynthesis, Pn; stomatal conductance, gs; transpiration, E), flower yield, flower quality (pedicel length and diameter, number of days to flowering, flower diameter, and vase life), root sporulation, and colonization were measured. Irrigation with saline water (20 and 40 mM-NaCl) significantly increased salt accumulation in soil. The mean soil electrical conductivity (EC) after two growing seasons for the 20 mM-NaCl treatment was 2.9 dS m$^{-1}$ and 4.4 dS m$^{-1}$ for the 40 mM. High salinity level (40 mM-NaCl) reduced root AMF sporulation by 53–62% and colonization by 12–25% across cultivars. Interestingly, root colonization was higher than 50% across salinity level and in both cultivars. Saline water at 40 mM-NaCl significantly reduced SPAD, Pn, gs, E, flower yield, and quality component, especially vase life. Interestingly, leaf chlorophyll content index from AMF-inoculated plants was significantly higher than uninoculated ones across cultivars at the second growing season. In addition, inoculation with AMF significantly increased yield in both ‘Beaudine’ (34–40%) and ‘Palm Beach’ (42–44%) cultivars and across the study period, 2018 to 2019. In addition, AMF increased vase life in ‘Beaudine’ by 19% to 28% and in ‘Palm Beach’ by 21% to 22%. Overall, our results revealed that gerbera growers can increase their flower yield and postharvest flower quality component (vase life) under saline conditions (soil EC < 4.4 dS m$^{-1}$) by inoculating the seedlings with AMF.

Keywords: vase life; chlorophyll; salt stress; mycorrhiza; microorganisms

1. Introduction

High demand for fresh water coupled with shortage of water resources reduces water allotment for agricultural lands. Jordan is considered among the poorest countries in the world in terms of water resources [1]. Groundwater is the major source of water in Jordan. The potential need for irrigation water leads to over-abstraction of groundwater and consequently, reduces the water quality and increases the water salinity [1]. Irrigation with low-quality (saline) water leads to salt accumulation in the soil and causes a reduction in plant growth and productivity [2]. Several approaches have been suggested to overcome this problem, such as leaching saline soil with fresh water and cultivar screening [2,3]. However, water resources—specifically fresh water—is limited [3]. Another possible alternative is to improve soil health using beneficial microorganisms such as Arbuscular...
mycorrhizal fungi (AMF). These fungi are the major component of the agricultural natural resource, and they are members of the kingdom Fungi [4]. AMF contribute to the uptake of soil macro- and micro-nutrients in plants, thus increasing their productivity and conferring resistance to stresses [3].

The primary goal of AMF inoculation is to increase plant growth and productivity [5]. The main benefits of AMF are to enhance the acquisition of mineral nutrients by plants and to increase the ability of those plants to withstand environmental stresses [6]. In fact, AMF enhances the root surface area to explore greater volumes of soil and to overcome water and nutrient depletion zones around active root surfaces [4]. Al-Karaki and Clark [7] found that AMF had a significant positive effect on plants, including improved plant growth and mineral nutrition (e.g., P, Cu, Fe, and Zn concentrations) and water use efficiency. Scrase et al. [8] found that mycorrhizas enhanced the uptake of non-available P by Tithonia diversifolia in poor soils through rapid root proliferation in soil rhizosphere. In fact, roots colonized by AMF are more highly branched compared to non-colonized plants and the adventitious root diameters are larger [9]. Dugassa et al. [10] showed that the colonization of tomato (Solanum lycopersicum) root by Glomus mosseae led to larger and more branched root system. Interestingly, AMF has shown to improve the tolerance and/or resistance of plants to soilborne pathogens [11]. Different mechanisms have been reported to explain bio-control by AMF including biochemical changes in plant tissues, microbial changes in rhizosphere, nutrient status, anatomical changes to cells, changes to root system morphology, and stress alleviation [12].

The production of cut flowers is a growing industry worldwide [13]. In 2021, Royal FloraHolland, the largest global marketplace for the floriculture industry, reported a revenue of EUR 5.63 billion [14]. Gerbera was among the top five cut flowers sold by Royal FloraHolland with over one billion gerbera flowers were traded and total value of about USD 167 million [14]. The main goals of gerbera producers are to increase flower production, and improve the flower quality component including color, diameter, pedicel length, and vase life (time period during which a cut flower retains its aesthetic appearance). High quality gerbera requires precise nutrient and water management practices including the use of fresh water. In fact, the gerbera plant is moderately sensitive to salinity [15]. In soilless culture systems, the salinity threshold values for gerbera range from 1.4 to 2.1 dS m$^{-1}$ for the electrical conductivity (EC) of the nutrient solution [15]. However, limited water resources as well as the low-quality water (e.g., salinity) are major concerns for cut flower growers, specifically in Mediterranean regions. A possible approach to mitigate salinity is the biological approach, which includes inoculating transplants by AMF. In the last two decades, research studies revealed that AMF fungi associated with plant roots deliberates numerous benefits to host plants, including improved plant growth, mineral nutrition status, resistance to disease, and tolerance to abiotic stresses such as soil salinity [16–18]. In addition, AMF increased flower yield and quality component (e.g., vase life) in several ornamental and cut flower plants such as Petunia and Chrysanthemum [19,20]. Few studies have assessed the effect of AMF inoculation in cut flowers, specifically under salinity conditions [21,22]. In addition, and to our knowledge, the influence of AMF on gerbera leaf gas exchange (photosynthesis, $P_n$; stomatal conductance, $g_s$; transpiration rate, $E$), and flower quality under salinity conditions are unknown. We hypothesized that AMF inoculation will alleviate the negative effects of salinity and improve the flower quality of gerbera, especially its vase life. The objective of this study was to assess the influence of AMF inoculation on the physiology (chlorophyll content, gas exchange) flower yield, and the quality of gerbera cultivars under salinity stress.

2. Materials and Methods

2.1. Plant Material and AMF Inoculation

A two-year greenhouse study was conducted at the Department of Horticulture and Crop Science, University of Jordan, Amman, Jordan from April 2018 to July 2019. Temperatures and light intensity during the study period are illustrated in Figure 1. Two gerbera
cultivars (Gerbera jamesonii cvs. Beaudine and Palm Beach) were used. Both ‘Beaudine’ (red) and ‘Palm Beach’ (yellow) are commercially used in Jordan due to their high flower production and adaption to Mediterranean conditions [13]. Indigenous AMF, native to the northern side of Jordan (Alramtha), was used. The AMF belongs to Glomeraceae (Glomus mosseae) [23]. AMF inoculum was propagated to increase spores number using pot culture technique with sorghum plant as a host [24]. The growth medium for AMF was sand: clay soil (1:3) with a pH of 7.5. The soil was sterilized using an oven at 121 °C for 6 h. Then, AMF spores were added to soil at a rate of 100 spore/1000 g of dried soil. Seedlings (6 weeks after seeding) were transplanted into 0.3 L pots filled with a mixture of AMF spores and 3:1 peat-moss-perlite. During that period, fertigation was conducted weekly using commercial fertilizers. The composition of fertigation nutrient solution was N, 180 mg L⁻¹; P, 60 mg L⁻¹; K, 172 mg L⁻¹; Mg, 35 mg L⁻¹; Ca, 95 mg L⁻¹; Fe-EDTA, 30 mg L⁻¹; Zn and Mn, 20 mg L⁻¹; B and Cu, 5 mg L⁻¹. One month after AMF inoculation, root samples from those inoculated transplants were collected and assessed to ensure that the roots of AMF-inoculated treatment were colonized with AMF. AMF-colonized transplants were then transferred from the 0.3 L pots into larger size pots (5 L) filled with soil-peat-moss-perlite mixture (2:1:1 v/v/v) for salinity assessment process. The pot preparation was conducted at the beginning of the experimental period (April 2018) and the same inoculated plants were used for both growing seasons.

![Figure 1. Maximum, minimum, and mean air temperature and light intensity during the study period.](image)

**2.2. Treatments**

In this study, two AMF colonizations and three water salinity levels were tested. During the assessment period (May 2018–July 2019), AMF-inoculated and uninoculated gerbera transplants were irrigated with three levels of saline water: 0.0, 20.0, and 40.0 mM-NaCl. These salinity levels were equivalent to EC of 0.7 dS m⁻¹ (tap water, control), 2.0 and 4.0 dS m⁻¹. Tap water and NaCl were used to prepare the different saline water treatments. Irrigation with saline water (300 mL per irrigation) was conducted manually twice a week. Fertilizers (20N-20P₂O₅-20K₂O and KCl) at rate N, 150 mg L⁻¹; P, 65 mg L⁻¹; and K, 200 mg L⁻¹ were added to saline water monthly from April to July 2018 and 2019. The pots were placed in a bench (6 × 3 m) at the greenhouse, arranged in a randomized complete block design (RCBD) and replicated five times. The greenhouse environment...
(temperature, humidity, and light intensity) was not fully controlled. During the study period, the same gerbera plants that were planted in 2018 were evaluated in the successive year, 2019, and the saline water was continuously applied from May 2018 to July 2019.

2.3. Measurements

The chlorophyll content index and leaf gas exchange (Pn, E, and gs) were measured at the vegetative and flowering stages in the two growing seasons; 2018 and 2019. Measurements were conducted between 11:00 a.m. and 1:00 p.m. on two sun-exposed and fully mature leaves. The chlorophyll content index was measured using a chlorophyll meter (SPAD-502 Plus, Minolta, Japan). The leaf gas exchange was determined using a portable photosynthesis system (LI-6400XT; LI-COR Biosciences, Lincoln, NE, USA). Reference carbon dioxide for the portable photosynthesis system was set to 400 µmol, flow rate to 500 µmol s⁻¹, light intensity to track ambient photosynthetically active radiation (sun track), and leaf area to 6 cm² [25]. During the experimental period, soil samples were collected to determine EC. For each pot, a soil core (1 cm diameter, 10 cm depth) sample was collected and oven-dried at 65 °C for two days. Electrical conductivity was then determined in a 1:1 (water: dry soil) extract using an EC meter (YK-22CT, Lutron Electronic Enterprise CO, Taipei, Taiwan).

Flower yield and quality (pedicel length and diameter, number of days to flowering, flower diameter, and vase life) in both growing seasons were determined during the flowering period. The flowering period for the 2018 growing season was from July to August, and for 2019 from May to July. The flower was harvested when the outer two rows of petal discs were open. The number of days to flowering was from the day of transplanting to the blooming of the first bud. Vase life was the number of days from harvest to the first three petals falling off or when bent neck problem occurred in the flower pedicel [13].

At the end of the experiment, root samples were collected from each pot for AMF colonization assessment. Root AMF colonization (%) was determined following the procedure of Phillips and Hayman [26]. Root samples were cleared with 10% KOH and stained using 0.05% trypan blue in lactophenol. The percentage of roots colonized by AMF was evaluated microscopically using the following equation:

\[
\text{Root colonization (\%)} = \left( \frac{\text{number of colonized segments}}{\text{total number of segments examined}} \right) \times 100
\]

AMF sporulation and extraction was determined in the soil following the wet sieving and decanting techniques [28]. A 10 g of dried soil was collected, suspended in 250 mL of water, the suspension was decanted through sieves ranging from 1 mm to 40 µm, the shallow suspension was observed under binocular microscope, and the AMF spores were counted.

2.4. Statistical Analysis

The study was arranged in a RCBD with five replications and two factors (AMF, salinity). The analysis of variance (ANOVA) and the least significant difference test (p < 0.05) were analyzed by SAS (Version 9.4 for Windows; SAS Institute, Cary, NC, USA).

3. Results and Discussion

3.1. Salinity Increment, Root Colonization, and Sporulation

Soil salinity is a major concern for cut flower growers in Jordan. Irrigation with saline water leads to salt accumulation in the soil and causes a reduction in growth and productivity. In this study, salt accumulation in the soil was evaluated in April and December 2018 and July 2019 (Figure 2). At the beginning of the study period (April 2018), soil EC was similar across treatments, 0.3 dS m⁻¹. Irrigation with saline water significantly increased salt accumulation in soil, specifically at 20 and 40 mM-NaCl treatments. The mean EC for the 20 mM treatment was 1.8 dS m⁻¹ in December 2018 and 2.9 dS m⁻¹ in July 2019. Similarly, EC for 40 mM-NaCl was 2.4 and 4.4 dS m⁻¹ in December 2018 and July 2019,
respectively. However, soil EC for control (0.0 mM-NaCl) plants was below 1 dS m$^{-1}$ across the study period.

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Irrigation with saline water and the accumulation of salts in the soil significantly affected root AMF colonization and sporulation, especially at 40 mM-NaCl level (Figure 3). For example, root sampling in July 2019 revealed that AMF colonization from ‘Palm Beach’ irrigated with tap water (0.0 mM-NaCl) was 78% while the percentage for the 20 and 40 mM-NaCl salinity levels ranged from 55% to 58%. In both cultivars, the total AMF spores was between 26 and 29 spores g$^{-1}$ soil for gerbera irrigated with tap water (0.0 mM-NaCl), 15 and 16 spores g$^{-1}$ for 20 mM-NaCl, and 11 and 12 spores g$^{-1}$ for 40 mM-NaCl level (Figure 3).

Terrestrial plants roots, including several commercial crops, are colonized by beneficial fungi of the Glomeromycotina (a division within the kingdom Fungi) forming a symbiotic relationship called arbuscular mycorrhiza [4]. AMF release specific chemicals (glycoprotein, glomalin) into soil rhizosphere, leading to better soil structure, fertility, and soil physio-chemical properties [29]. AMF develop an extensive network and enlarge the contacted areas of the roots to the soil, improve root architecture, and consequently enhance the nutrient status of citrus plants [29]. Hajiboland [17] concluded that the roles of AMF in amelioration of salinity include (1) improvement of nutrient uptake by crops, especially P, (2) elevation of K: Na ratio, (3) stimulating the accumulation of osmosolutes, and (4) sustaining extraordinary antioxidant enzymatic activities. However, soil salinity can significantly reduce root AMF colonization as well the total spore in root rhizosphere (Figure 3).

For example, growing trifoliate orange (Poncirus trifoliata) seedlings in saline (100 mM NaCl) growing medium significantly inhibited mycorrhizal colonization, plant biomass, and leaf relative water content [30]. Irrigation with saline water contained 4500 ppm of NaCl, MgCl$_2$, and CaCl$_2$ (3:1:1 by weight) and reduced AMF colonization [31]. Interestingly, a small amount of AMF spores is adequate to induce colonization in a salt stress environment. McGee et al. [32] suggested a number of 5 spores g$^{-1}$ soil to initiate acceptable levels of colonization, considering that normally only 5% of the spores germinate. In coffee seedlings, 0.5 spores g$^{-1}$ soil was enough for good root colonization [33].
spores density at 40 mM-NaCl reduced by 53% for ‘Beaudine’ and 62% for ‘Palm Beach’ (compared to control), the colonization percentage was higher than 50%. Overall, irrigation with saline water (20–40 mM-NaCl) increased salt accumulation in the soil (2–4 dS m⁻¹) and reduced AMF sporulation in the root rhizosphere. However, the low spore density in the soil (10–11 spores g⁻¹) was able to colonize 50% to 60% of the roots.

![Figure 3](image-url)

**Figure 3.** Root AMF colonization and the number of spores for gerbera cultivars (‘Beaudine’ red; ‘Palm Beach’ yellow) inoculated with AMF under different salinity levels at the end of the experiment. No root colonization or soil spores were found in uninoculated gerbera plants. The different letters above the bars indicate significant differences between treatments according to Tukey’s HSD test (p ≤ 0.05).

### 3.2. Leaf Physiology

The chlorophyll content index (SPAD), gas exchange (Pn, gs, and E), and leaf temperature of AMF inoculated and uninoculated gerbera under different salt stress levels are presented in Table 1 (2018) and Table 2 (2019). In 2018, high salinity level (40 mM-NaCl) significantly reduced SPAD by 14–30%, Pn by 16–18%, gs by 50%, and E by 1–42% across cultivars (Table 1). A similar reduction in SPAD and gas exchange (Pn, gs and E) was noticed in gerbera plants irrigated with 40 mM-NaCl saline water in 2019 (Table 2). Lower concentration of NaCl (20 mM-NaCl) had no negative effect on physiological variables in 2018 except for chlorophyll content index in ‘Palm Beach’ cultivar (Table 1). However, frequent irrigation with saline water (20 mM-NaCl) for two growing seasons increased soil EC to 2.9 dS m⁻¹ (Figure 2) and reduced SPAD, Pn, gs, and E in ‘Palm Beach’ (Table 2). ‘Beaudine’ leaf SPAD and gas exchange (Pn, gs and E) at 20 mM-NaCl were similar to control across the study period, except for gs in 2018 (soil EC, 1.8 dS m⁻¹) and Pn in 2019 (soil EC, 2.9 dS m⁻¹). Leaf chlorophyll is an essential pigment for Pn because it provides the prerequisite energy for metabolism reactions through capturing energy from sunlight [34]. Photosynthesis is a vital process for plant growth and flower quality [13,35,36]. Accordingly, the reduction in chlorophyll pigmentation and gas exchange (Pn, gs and E) can lead to negative impact on gerbera growth and productivity. Growing Marigold (*Tagetes patula* L.) in saline environment (100 mM-NaCl) reduced plant biomass, gs, and chlorophylls content [37]. Santos [38] found that the reduction in chlorophyll content in salt-stressed
gerbera plants can be attributed to the inhibition of synthesis of 5-aminolaevulinic acid (precursor of chlorophyll), and the generation of reactive oxygen species which degrade the chlorophyll molecules and inhibit chlorophyll synthesis. In barley (*Hordeum vulgare* L.), salt stress separated the light-harvesting complex from core proteins of PSII and decreased the structural stability of PSII by disturbing the electron transfer system [39]. Overall, irrigation with saline water (20 or 40 mM-NaCl) significantly reduced *Pn* in both cultivars, specifically when soil accumulated in the soil and EC for soil extract exceeded 1.8 dS m$^{-1}$ (Figure 2, Table 2).

**Table 1.** Chlorophyll content index (SPAD), gas exchange (photosynthesis (*Pn*), stomatal conductance (*gs*), and transpiration (*E*)) and leaf temperature of gerbera cultivars (‘Beaudine’ red; ‘Palm Beach’ yellow) inoculated (AMF) or uninoculated (No AMF), grown under different salt stress levels in 2018.

| Treatment         | SPAD | *Pn* (µmol m$^{-2}$ s$^{-1}$) | *gs* (mol m$^{-2}$ s$^{-1}$) | *E* (mmol m$^{-2}$ s$^{-1}$) | Leaf Temperature (°C) |
|-------------------|------|-------------------------------|-------------------------------|-----------------------------|----------------------|
|                   | Beaudine | Palm Beach | Beaudine | Palm Beach | Beaudine | Palm Beach | Beaudine | Palm Beach | Beaudine | Palm Beach | Beaudine | Palm Beach |
| Salinity          |        |                      |                  |                                       |                      |              |                |                |                      |              |                  |                |              |
| 0.0 mM            | 44.7 a  | 52.3 b               | 12.4 a           | 12.0 a                               | 0.14 a               | 0.16 a       | 4.74          | 4.94 a       | 31.9          | 31.9          |
| 20 mM             | 43.5 ab | 42.8 b               | 12.0 a           | 12.1 a                               | 0.10 b               | 0.13 a       | 4.29          | 4.71 a       | 32.4          | 32.0          |
| 40 mM             | 38.3 b  | 36.8 c               | 10.4 b           | 9.80 b                               | 0.07 b               | 0.08 b       | 3.71          | 3.86 b       | 32.9          | 32.3          |
| Mycorrhiza (AMF)  |        |                      |                  |                                       |                      |              |                |                |                      |              |                  |                |              |
| With AMF          | 42.8   | 45.3                 | 12.2             | 11.4                                 | 0.12                 | 0.12         | 4.28          | 4.31         | 32.3          | 32.1          |
| No AMF            | 41.1   | 42.7                 | 11.3             | 11.3                                 | 0.10                 | 0.13         | 4.19          | 3.97         | 32.5          | 31.9          |
| Significance      |        |                      |                  |                                       |                      |              |                |                |                      |              |                  |                |              |
| Salinity          | *      | ***                 | **               | **                                   | **                   | *            | NS            | **           | NS            | NS            |
| AMF               | NS     | NS                  | NS               | NS                                   | NS                   | NS           | NS            | NS           | NS            | NS            |
| Salinity × AMF    | NS     | NS                  | NS               | NS                                   | NS                   | NS           | NS            | NS           | NS            | NS            |

Different letters in the same column indicate significant difference at *p* ≤ 0.05. * *p* ≤ 0.05, *** *p* ≤ 0.0001, NS, not significant.

**Table 2.** Chlorophyll content index (SPAD), gas exchange (photosynthesis (*Pn*), stomatal conductance (*gs*), and transpiration (*E*)) and leaf temperature of gerbera cultivars (‘Beaudine’ red; ‘Palm Beach’ yellow) inoculated (AMF) or uninoculated (No AMF), grown under different salt stress levels in 2019.

| Treatment         | SPAD | *Pn* (µmol m$^{-2}$ s$^{-1}$) | *gs* (mol m$^{-2}$ s$^{-1}$) | *E* (mmol m$^{-2}$ s$^{-1}$) | Leaf Temperature (°C) |
|-------------------|------|-------------------------------|-------------------------------|-----------------------------|----------------------|
|                   | Beaudine | Palm Beach | Beaudine | Palm Beach | Beaudine | Palm Beach | Beaudine | Palm Beach | Beaudine | Palm Beach | Beaudine | Palm Beach |
| Salinity          |        |                      |                  |                                       |                      |              |                |                |                      |              |                  |                |              |
| 0.0 mM            | 48.4 a  | 49.8 a               | 9.17 a           | 9.30 a                               | 0.08                 | 0.22 a       | 1.46          | 2.16 a       | 18.3          | 19.1          |
| 20 mM             | 43.2 a  | 38.5 b               | 6.68 b           | 6.52 b                               | 0.07                 | 0.11 b       | 1.30          | 1.45 a       | 19.0          | 18.5          |
| 40 mM             | 33.6 b  | 32.7 c               | 5.32 b           | 3.36 c                               | 0.07                 | 0.06 c       | 0.97          | 1.04 c       | 19.4          | 17.8          |
| Mycorrhiza (AMF)  |        |                      |                  |                                       |                      |              |                |                |                      |              |                  |                |              |
| With AMF          | 43.3 a  | 42.3 a               | 7.43             | 7.07                                 | 0.09                 | 0.15         | 1.27          | 1.76 a       | 19.0          | 18.4          |
| No AMF            | 39.1 b  | 38.3 b               | 7.38             | 6.42                                 | 0.07                 | 0.13         | 1.25          | 1.47 b       | 18.8          | 18.6          |
| Significance      |        |                      |                  |                                       |                      |              |                |                |                      |              |                  |                |              |
| Salinity          | ***    | ***                 | ***              | **                                   | NS                   | ***          | NS            | ***          | NS            | NS            |
| AMF               | *      | *                  | NS               | NS                                   | NS                   | *            | NS            | NS           | NS            | NS            |
| Salinity × AMF    | NS     | NS                  | NS               | NS                                   | NS                   | NS           | NS            | NS           | NS            | NS            |

Different letters in the same column indicate significant difference at *p* ≤ 0.05. * *p* ≤ 0.05, *** *p* ≤ 0.0001, NS, not significant.

Root inoculation with AMF can improve plants adaptation to a stressed environment such as soil salinity [3]. AMF alleviate abiotic stress (e.g., salinity) by improving plant morphology and physiology (*Pn* and water relations) and regulating root tonoplast intrinsic proteins including aquaporins genes (PtTIPs expression) [40]. In this study, no significant differences were found for SPAD, gas exchange, and leaf temperature in inoculated or uninoculated gerbera cultivars in 2018 (Table 1). However, in 2019, the chlorophyll content index (SPAD) of AMF-inoculated plants were significantly higher than uninoculated across cultivars (Table 2). The differences between 2018 and 2019 could be due to the fact that the same pots are used, therefore at the beginning of the experiment with a reduced salinity content (Figure 2) the plants were not significantly stressed and the AMF response was
low. However, the greater response of AMF was noticed when the salinity content in the soil increased.

3.3. Flower Yield and Quality

The main objective of cut flower producers is to increase the flower yield and quality component [13,35]. Flower, color, size, stem or pedicel length and diameter, number of days to flowering, and vase life are the main components that can potentially influence the appearance and marketing cut flowers, including gerbera [13,41]. Stem or pedicel length is a major determinant for designing flower bouquets and therefore several flower species (e.g., rose, gerbera) are graded by stem length [42]. In this study, higher salt stress treatment (40 mM-NaCl) in 2018 significantly reduced flower yield and quality component (pedicel diameter and vase life) in both cultivars (Table 3). For example, ‘Beaudine’ gerbera irrigated with tap water (0.0 mM-NaCl) had 8 flowers per plant per year while the ones irrigated with 40 mM-NaCl saline water had about 5 flowers (Table 3). Similar results for yield and flower quality components were noticed in the 2019 growing season (Table 4). Under salinity conditions, flower appearance and weight losses acceleration led to a reduction in vase life [37]. Akat et al. [43] found that irrigation with saline water (3 dS m$^{-1}$) reduced gerbera flower yield by 32% when compared to the control (1 dS m$^{-1}$). In this study, the reduction in SPAD and $P_n$ at 40 mM-NaCl treatment was consistently coupled with a significant decrease in flower yield and vase life in both cultivars and across years, 2018–2019. However, at 20 mM-NaCl treatment, the relationship between physiological and yield components was not consistent across growing seasons. Overall, salt accumulation in the soil even at low levels (EC for soil, 1.8 dS m$^{-1}$) resulted in a significant reduction in gerbera flower yield and vase life in both cultivars.

Table 3. Flower yield and quality component of gerbera cultivars (‘Beaudine’ red; ‘Palm Beach’ yellow) inoculated (AMF) or uninoculated (No AMF), grown under different salt stress levels in 2018.

| Treatment | Flower Yield (No Plant$^{-1}$) | Flower Diameter (cm) | Pedicel Diameter (cm) | Pedicel Length (cm) | Vase Life (day) |
|-----------|--------------------------------|----------------------|-----------------------|---------------------|-----------------|
|           | Beaudine | Palm Beach | Beaudine | Palm Beach | Beaudine | Palm Beach | Beaudine | Palm Beach | Beaudine | Palm Beach | Beaudine | Palm Beach |
| Salinity  |         |          |          |           |          |            |          |           |          |            |          |            |
| 0.0 mM    | 8.42 a   | 9.92 a   | 9.55     | 8.87 a    | 5.93 a    | 5.84 a     | 42.4       | 41.7      | 13.3 a   | 11.8 a     |
| 20 mM     | 6.50 b   | 6.42 b   | 9.60     | 8.75 ab   | 5.56 b    | 5.60 a     | 42.9       | 44.1      | 12.4 a   | 10.6 b     |
| 40 mM     | 4.75 c   | 3.67 c   | 9.53     | 8.38 b    | 5.13 c    | 5.28 b     | 42.4       | 40.4      | 11.2 b   | 9.36 c     |
| Mycorrhiza (AMF) |           |            |          |           |          |            |          |           |          |            |          |            |
| With AMF  | 7.50 a   | 7.83 a   | 9.67     | 8.84 a    | 5.86 a    | 6.02 a     | 42.3       | 42.8      | 13.3 a   | 11.6 a     |
| No AMF    | 5.61 b   | 5.50 b   | 9.45     | 8.50 b    | 5.06 b    | 5.13 b     | 42.8       | 41.3      | 11.2 b   | 9.56 b     |
| Significance | *** | *** | NS | * | *** | *** | NS | NS | *** | *** | NS | NS |
| Salinity  |         |          |          |           |          |            |          |           |          |            |          |            |
| AMF       | *** | *** | NS | * | *** | *** | NS | NS | *** | *** | NS | NS |
| Salinity × AMF | NS | NS | NS | NS | * | NS | NS | NS | NS | NS | NS | NS |

Different letters in the same column indicate significant difference at $p \leq 0.05$. * $p \leq 0.05$, *** $p \leq 0.0001$, NS, not significant.

In both years (2018 and 2019), the flower yield, flower diameter, pedicel diameter, and vase life for AMF inoculated plants were significantly higher than un inoculated plants across cultivars (Tables 3 and 4). For example, the total number of flowers per plant for ‘Beaudine’ across the study period was about 14 flowers while the uninoculated gerbera had about 10 (Tables 3 and 4). Mycorrhizas improve the tolerance of plant to biotic (diseases and insect pests) and abiotic (drought and salinity) stresses [29]. AMF release biochemical compounds such as glycoprotein, a glomalin that can improve the physical and chemical properties of soil, especially soil fertility [29]. In fact, AMF enhance shoot and root growth, chlorophyll content, nutrient (P and K) uptake, epidermis and cortical region thickness, xylem and phloem diameter, and, consequently, crop productivity [3,44]. In gerbera, inoculated transplants with AMF had significant positive effect on leaf area, flower number, and vase life [21]. When AMF colonize roots, it develops an extensive hyphae network
that extends to neighboring plants and enhances their adaptation to drought and salt stress [29]. The beneficial effect of mycorrhization under salinity condition is associated with nutritional status by improving P, K$^{+}$, Fe, Mg$^{2+}$, and Cu uptake [45]. However, the total number of days to flowering were similar across the salinity levels and in both AMF-inoculated and uninoculated plants (data not presented). The first flower harvest for all treatments ranged from 120 to 135 days.

Table 4. Flower yield and quality component of gerbera cultivars ('Beaudine' red; ‘Palm Beach’ yellow) inoculated (AMF) or uninoculated (No AMF), grown under different salt stress levels in 2019.

| Treatment         | Flower Yield (No Plant$^{-1}$) | Flower Diameter (cm) | Pedicel Diameter (cm) | Pedicel Length (cm) | Vase Life (day) |
|-------------------|-------------------------------|----------------------|-----------------------|---------------------|-----------------|
|                   | Beaudine | Palm Beach | Beaudine | Palm Beach | Beaudine | Palm Beach | Beaudine | Palm Beach | Beaudine | Palm Beach |
| Salinity          |          |            |          |            |          |            |          |            |          |            |          |
| 0.0 mM            | 7.67 a   | 7.92 a     | 9.45     | 8.55 a     | 5.83 a   | 5.93 a     | 36.2      | 38.8      | 12.8 a   | 11.5 a     |
| 20 mM             | 5.42 b   | 5.25 b     | 9.63     | 8.58 a     | 5.57 b   | 5.51 b     | 36.0      | 41.0      | 12.4 a   | 10.3 b     |
| 40 mM             | 3.08 c   | 2.50 c     | 9.21     | 8.18 b     | 5.08 c   | 5.05 c     | 38.7      | 39.0      | 11.3 b   | 8.73 c     |
| Mycorrhiza (AMF)  |          |            |          |            |          |            |          |            |          |            |          |
| With AMF          | 6.28 a   | 6.17 a     | 9.63 a   | 8.62 a     | 5.84 a   | 5.89 a     | 37.5      | 40.1      | 13.7 a   | 11.2 a     |
| No AMF            | 4.50 b   | 4.26 b     | 9.23 b   | 8.25 b     | 5.12 b   | 5.00 b     | 36.0      | 39.1      | 10.7 b   | 9.18 b     |
| Significance      |          |            |          |            |          |            |          |            |          |            |          |
| Salinity          | ***      | ***        | NS       | *          | ***      | ***        | NS        | NS        | **       | ***        |
| AMF               | ***      | ***        | *        | *          | ***      | ***        | NS        | NS        | ***      | ***        |
| Salinity × AMF    | NS       | NS         | NS       | NS         | NS       | NS         | NS        | NS        | NS       | NS         |

Different letters in the same column indicate significant difference at P ≤ 0.05. * p ≤ 0.05, ** p ≤ 0.01, *** p ≤ 0.0001, NS, not significant.

Long flower pedicle in gerbera is essential for florets to designed flower bouquets. However, high pedicel length can potentially reduce lignification and increase the probability of bent neck, a physiological disorder that significantly reduces gerbera flower quality [13]. Perik et al. [46] found that bending in gerbera flowers was associated with adverse water relations, lack of pedicle sclerenchyma development, as well as lignin levels. In that study, a cylinder of sclerenchyma in the pedicle was found to end about 20 cm below the floral head at flowering stage. Interestingly, AMF inoculation can increase the vascular bundle tissues, the lignification of xylem in the stem, and stimulate flower production [20]. In both years, 2018–2019, AMF inoculation significantly increased the pedicel diameter and vase life (postponed bent neck formation) (Tables 3 and 4). This could be attribution to the role of AMF in improving water relations and the extent of sclerenchyma formation and lignin level at the pedicel. Considering the potential positive improvement in flower yield and quality in gerbera inoculated with AMF, the use of this approach will be of great interest for cut flower growers.

4. Conclusions

The influence of AMF inoculation on physiology (chlorophyll, $P_n$, $g_s$, and $E$), flower yield and quality of gerbera plants grown in saline conditions was assessed for two growing seasons. Irrigation with saline water at a level of 40 mM-NaCl for two growing seasons (14 months) increased the soil salinity to 4.4 dS m$^{-1}$ and reduced the AMF sporulation as well as root colonization. Although the spores count was low in the 40 mM-NaCl level (10 to 11 spores g$^{-1}$ soil), the colonization (%) was 50% to 60% across gerbera cultivars. Soil salinity of 2.4 dS m$^{-1}$ (40 mM-NaCl, 2018) to 4.4 dS m$^{-1}$ (40 mM-NaCl, 2019) resulted in a significant reduction in chlorophyll content index across cultivars. In addition, irrigation with saline water (20 or 40 mM-NaCl) significantly reduced $P_n$ in both cultivars, specifically when soil accumulated in the soil and EC for soil extract exceeded 1.8 dS m$^{-1}$. In this study, we found that the highest yield and postharvest quality (vase life) were achieved in the control treatment (0.0 mM-NaCl, EC soil < 1 dS m$^{-1}$), while the lowest yield (reduction, 35 to 60%) was found in the highest salt stress treatment (40 mM-NaCl) in both cultivars and across growing seasons. However, gerbera inoculated with AMF had a higher yield than...
non-inoculated ones in both ‘Beaudine’ (34–40%) and ‘Palm Beach’ (42–44%) and across the study period. In both growing seasons, 2018–2019, AMF inoculation increased vase life (essential cut flower variable) in ‘Beaudine’ by 19% to 28% and in ‘Palm Beach’ by 21% to 22%. Overall, soil salinity even the low level (EC for soil, 1.8 dS m$^{-1}$), significantly reduced gerbera flower yield and quality. At these saline conditions (EC for soil 1.8–4.4 dS m$^{-1}$), AMF inoculation at seedling stage can significantly increase gerbera flower yield and longevity after harvesting (vase life).

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