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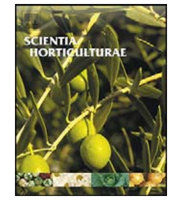

Effects of day length on flowering and yield production of *Salicornia* and *Sarcocornia* species

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A B S T R A C T

Salicornia is a new vegetable crop that can be irrigated with highly saline water, even at salt concentrations equivalent to full-strength seawater. During leafy vegetable cultivation, the onset of the reproductive phase is an undesired phenomenon that reduces yield and quality and prevents year-round cultivation. Knowledge about the regulation of floral induction in the members of the tribe Salicornieae, however, is lacking. To establish year-round cultivation, we studied the flower induction of five *Salicornia* and two *Sarcocornia* varieties. Plants were grown under two day lengths, 13.5 h and 18 h, and harvested by a repetitive harvest regime. A 13.5-h day length prevented flower induction in the Israeli *Salicornia* varieties, but a longer day length was required to prevent flower induction in two species originating from more northern latitudes. The onset of the reproductive phase under suboptimal short day length conditions severely reduced vegetative growth and yields in *Salicornia*. In *Sarcocornia*, the repetitive harvest regime prevented flowering, making it a promising candidate for year-round cultivation. Irrigating the plants with full-strength seawater (electrical conductivity 48 dS m^{-1}) vs. water with moderate salinity (electrical conductivity 10 dS m^{-1}) did not change the general flowering pattern of the studied Salicornieae members.

1. Introduction

Salicornia has long been consumed by humans as a fresh or pickled vegetable (Chevalier, 1922; Davy et al., 2001). It has recently generated considerable interest as a new vegetable crop that can be irrigated with highly saline water and seawater (Ventura et al., 2010, 2011). The almost identical *Sarcocornia* is distinguished from the annual *Salicornia* by its distinct perennial growth habit (Davy et al., 2006) and by differences in flower arrangement (Kadereit et al., 2007). Both genera produce succulent shoots suitable for leafy vegetable production, but they differ in terms of yield and nutritional value (Ventura et al., 2010, 2011).

In light of the increasing interest in *Salicornia* for its versatile commercial products, such as seed oil, protein meal, and fresh salad greens, the flowering pattern of *Salicornia bigelovii* was investigated (York et al., 2000). This species was found to be sensitive to photoperiod, and as such, shortening the number of hours of day light (day length) resulted in flowering (Fu and Zhao, 2003; Lu et al., 2001; Zerai et al., 2010). Flower induction reduces vegetative growth in leafy vegetables (Chweya, 1997), and therefore, it presents an important productivity parameter. At the onset of the reproductive phase, *Salicornia* terminal fruiting spikes are produced at the shoot tips and vegetative development is retarded, which ultimately may negatively impact yield performance. Moreover, flowering is undesired during *Salicornia* vegetable production as only young, fibreless vegetative shoots have market value.

The use of photoperiodic light is a well known agro-technique to regulate flowering in horticultural crop production (Demers et al., 1998). Preventing *Salicornia* from entering its natural, early flowering mode may enable year-round market supplies to the benefit of consumers and farmers alike. Toward the development of a practice that will enable the farmer to control and regulate the vegetative to reproductive relationship, we investigated the effect of day length as a means of controlling the flowering of Salicornieae tribe members.

Salinity stress, which may also affect a plant's flowering pattern, was shown to delay flowering in *Arthrocnemum fruticosum*, a halophyte plant belonging to the tribe Salicornieae (Saad Eddin and

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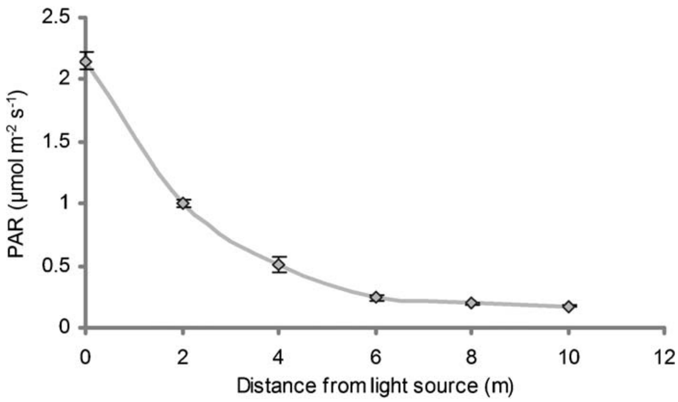

Fig. 1. Photosynthetically active photon flux density created by 3 incandescent bulbs as a function of the distance from the light source. Measurements were performed horizontal at plant height during the time of artificial light addition. Each value represents the mean of 3 measurements (±SE).

Doddema, 1986). Because information about the effects of salinity on the flowering behaviors of Salicornieae members is virtually non-existent, this study also examined whether salinity had an effect on plant flowering patterns.

The current research indicates that the control of day length regime, but not salinity, together with the selection of suitable species or varieties with different day length requirements, should result in sustainable, year-round *Salicornia* vegetable production.

2. Materials and methods

2.1. Plant material

We evaluated a selection of *Salicornia* and *Sarcocornia* samples from different regions of Europe and Asia. *Salicornia* types RN (31°N) and DS (31°N) were collected in the Dead Sea area, and *Sarcocornia* EL (32°N) and *Salicornia* N (32°N) originated from the northern Mediterranean coastline of Israel. *Sarcocornia* type VM (31°N) was found in an inland salt pan in the Ramat HaNegev district. *Salicornia* type FR originated from the coast of Brittany (France, ~48°N) and KZ from a highly saline area near the shore of the Aral Sea (Kazakhstan, ~46°N).

2.2. Experimental layout

All experiments were carried out in the south of Israel, either in the city of Beer Sheva (31°14′N 34°47′E) or at the Ramat HaNegev research station (30°52′N 34°47′E).

To simulate differences in the amount of time plants were exposed to daylight (i.e., to shorten day length) we tested light gradients. We used a fixed light source (three 100-W incandescent bulbs in a row), perpendicular to which the plants were positioned at increasingly larger distances, either incrementally (2-m intervals) or continuously (i.e., plants arranged in rows of cultivation sleeves). Natural daylight was extended by turning the lights on earlier in the morning and by turning them off later in the evening to create a total day length of either 13.5 h or 18 h. The resulting light flux during the artificial light supplement was measured on a horizontal surface in plant height and presented in photosynthetically active radiation (PAR), which reached maximum values of 2.15 μmol m^2 s^{-1} directly below the light source. The light flux decreased rapidly to 0.24 μmol m^2 s^{-1} at a distance of 6 m from the light source with a subsequent minor reduction to 0.17 μmol m^2 s^{-1} at a distance of 10 m (Fig. 1). Mid-day photosynthetic photon flux density in the greenhouse was 300–500 μmol m^{-2} s^{-1}.

Seeds were germinated in cultivation sleeves filled with perlite (Agrekal Habonim Industries Ltd., Moshav Habonim, Israel; www.agrekal.co.il) or on sand dune soil and irrigated daily with tap water [Electroconductivity (EC) 0.7 dS m^{-1}] supplemented with 90 mM NaCl (EC 10 dS m^{-1}) and commercial fertilizer N-P-K (5-3-8; Haifa Chemicals Ltd., Haifa, Israel) to supply the plants with approximately 80 ppm nitrogen.

To investigate the effects of sowing date on reproductive stage onset, we sowed RN genotype seeds four times during the shorter days of fall and winter at one-month intervals from October (natural day length: 11 h 20 min, shortening days), to January (natural day length: 10 h 6 min, lengthening days). Plants were grown under natural light conditions in a greenhouse approaching ambient temperatures (Ramat HaNegev area, Israel).

We studied the effect of a 13.5-h day length with plants germinated in the beginning of October, at decreasing day length condition, and arranged at continuous distances (0–20 m) from the light source. An identical greenhouse without extended daylight was used as a control.

To study the effect of natural flower initiation on yield production, plants were sown at the beginning of March at increasing day length condition and grown without artificially extended daylight in sand-dune soil. Shoots were harvested, as described below, during a one-year growing season or until the natural occurrence of flowers stopped plant growth.

To examine the effect of seawater salinity (EC 48 dS m^{-1}) on flower induction, plants were cultivated in a hydroponic system as previously described (Ventura et al., 2011). Briefly, seeds were germinated at the end of August in 14-cm plastic pots filled with perlite. Pots were placed in 18-L boxes (dimensions 37 cm × 31 cm × 16 cm) that were then filled with equal amounts of 50% seawater supplemented with 200 ppm commercial N-P-K fertilizer (20-20-20 + microelements, Haifa Chemicals Ltd.). The seawater solution (RSW) was prepared by dissolving 33 g Red Sea Salt® in 1 L water (Red Sea Fish Pharm Ltd., Eilat, Israel; www.redseafish.com) according to the manufacturer's instructions. Irrigation water salinity was gradually increased – over the course of one month – until it reached full-strength seawater concentration. This experiment investigated the 18-h light regime with plants positioned at 2-m intervals from 0 m (directly below the light source) to 10 m from the light source.

2.3. Evaluation of reproductive and vegetative parameters

The flowering index was determined by the visual observation of a plant population of at least 20 plants before every harvest. The index was defined by the following values: 0-vegetative nodes; 1-emergence of short, fertile segments; 2-beginning of pistil appearance from the fertile segments; 3-beginning of stamen appearance from the fertile segments; 4-completely flowering cones and beginning of seed development (Supplementary Fig. A).

Plant height and the number of reproductive and vegetative nodes were determined two months after sowing in the end of November (natural day length: 10 h 17 min) before the first harvest.

2.4. Harvest regime and biomass accumulation

In all experiments, plants were harvested under a repetitive harvest regime. Harvesting started approximately two months after sowing when a shoot size of approximately 10–15 cm was reached, by cutting the plants about 5 cm above ground level, resulting in a "cutting-table". After about one month, when the majority of the shoots had re-grown 10 cm or more above cutting-table height, they were again harvested by cutting them back to the height of