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Impact of low-temperature transplant treatment on yield and quality of cauliflower curds in late spring production

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ABSTRACT

Abiotic stresses elicit complex responses of plants at the physiological, biochemical, cellular, and molecular levels, leading to acclimation to adverse conditions. Exposing young plants to abiotic stress (e.g., by lowering the temperature below optimum) provides an improvement of tolerance to further stress. It may also unlock yield potential of temperate-climate crops. Therefore, a study was initiated to investigate the effects of low, non-freezing temperature treatments (6, 10, 14, and 18 °C [control]) applied to cauliflower transplants for 1 or 2 wk before planting on subsequent crop yield and quality parameters of the curds. Yield analysis confirmed that plants pretreated with lower temperatures exhibited higher marketable yields. A low temperature of 6 °C, maintained for both 1 and 2 wk, resulted in a significant increase in yield, of 6.8 and 7.8%, respectively, compared to the controls. Low-temperature treatments affected mass of the curds and slightly increased numbers of curds with better commercial quality. Cauliflower plants exhibited significantly higher curd diameter in comparison to controls when plants were subjected to 6 °C for 1 wk. The occurrence of fuzziness, riciness, and browning of mature curds of cauliflower was not influenced by stress application. The results suggested that controlled, low-temperature treatment of cauliflower transplants could play an important role in enhancing tolerance to field conditions and could offer an opportunity to improve yield of cauliflower grown in the field.

1. Introduction

The high yield potential of modern cultivars of vegetable crops is often neutralized by various environmental stresses, mainly drought and suboptimal temperatures (Ruelland et al., 2009). In temperate latitudes, early vegetable production is usually a result of using transplants produced in greenhouses or heated tunnels. After transplanting in the field, plants often encounter more severe environmental conditions, such as extreme temperatures and radiation, reduced water, and low nutrient availability (Kalisz and Siwek, 2006; Grabowska et al., 2007), which may generate serious disturbances in crop performance and yield. There are some methods of increasing the stress tolerance of plants. One example is hardening, which relies on controlled stress application, such as through lowering the temperature, before transplanting plants to the field (Jian et al., 2005; Li et al., 2011). It has been shown that low temperature treatment, applied at this phase of plant production, may improve growth and yield of some vegetable crops (Kalisz and Siwek, 2006; Kalisz et al., 2014).

Low-temperature stress is a direct result of temperature action on cellular macromolecules, which leads to slowing of metabolism, solidification of cell membranes, and loss of membrane functions (Thakur and Nayyar, 2013). Many plants develop an array of mechanisms that enable them to minimize the negative effects of cold (Ruelland et al., 2009). After exposure to low temperatures (but above 0 °C), stress tolerance of plants usually increases through acclimation (Sasaki et al., 2001). Response of the plants to temperature stress depends on the duration and intensity of the stress (Sękara et al., 2012). Plants have been divided into three groups in this regard: either sensitive or tolerant to low, non-freezing temperatures as well as tolerant to temperatures below 0 °C (Li et al., 2011; Thakur and Nayyar, 2013). Sensitive plants, such as pepper, eggplant, tomato, cucumber, and watermelon, native to warm regions are injured at temperatures below 10–13 °C (Lukatkin et al., 2012). The tolerant plants (like *Brassicaceae*) naturally survive low, non-freezing temperatures. Controlled, low-temperature application to these species induces their global tolerance against a wide range of environmental stressors.

The acclimation process is a complex plant response involving biochemical, physiological, and morphological changes in the living organisms (Ruelland et al., 2009). Plants are able to acclimatize through mechanisms such as protein synthesis, membrane

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composition changes, and activation of anti-oxidative defense systems composed of non-enzymatic and enzymatic components to scavenge reactive oxygen species (ROS) (Janská et al., 2010; Li et al., 2011). Increase of tolerance to one stress factor induces tolerance to another stressor via "cross-tolerance" (Pastori and Foyer, 2002; Sękara et al., 2012; Thakur and Nayyar, 2013). As a consequence, plants can better withstand field conditions where they often simultaneously face several abiotic stresses. Crops with enhanced tolerance to field environments may potentially exhibit higher yields (Grabowska et al., 2013). Several reports describe the short-term effects of low-temperature treatments on vegetable transplants (Nam et al., 2001; Sasaki et al., 2001; Gao et al., 2008). However, relatively few studies presented relationships between this abiotic stress applied to the crop at the transplant stage and subsequent growth, development, and yield (Korkmaz and Dufault, 2001; Kalisz and Siwek, 2006; Javanmardi et al., 2013).

Grevsen and Olesen (1994) divided development of the cauliflower plant into three phases: the juvenile phase, curd induction (initiation), and curd growth. In the juvenile phase, the plant produces leaves at a given temperature, and the duration of this phase is measured in terms of initiated leaves, of which various numbers have been reported (19–50) before initiating a curd (Wurr et al., 1993; Wurr and Fellows, 1998). In this phase, the plants cannot be induced to initiate a curd (Grevsen and Olesen, 1994). The juvenility is followed by a phase of curd induction, for which relatively low temperature is required (Dixon, 2007). Wurr and Fellows (2000) reported that for early summer, summer/autumn, and winter cauliflower types, temperatures from 9 to 14 °C are optimal for curd induction. It is worth noting that very low temperatures are not required for curd initiation. The curd growth phase is also influenced by temperature. The rate of curd growth increases at higher temperatures up to a maximum value, specific for a particular cultivar. Solar radiation also plays an important role in this phase (Dixon, 2007).

According to Grevsen and Olesen (1994), the juvenile phase begins with transplanting. However, the response of cauliflower plants to low temperature, applied at the transplant stage, is still not well characterized. Thus, the purposes of this study were (1) to determine the long-term impact of low-temperature treatment of cauliflower transplants on the subsequent yield and curd quality, (2) identify the most advantageous temperature in terms of plant productivity, and (3) develop a model describing the effect of temperature and photosynthetically active radiation (PAR) on marketable yield of cauliflower.

2. Material and methods

2.1. Experimental design

The goal of the research, which was conducted during 2011–2012, was to estimate the effect of low, non-freezing temperature (LT) treatments of transplants (6, 10, 14, and 18 °C [control]) maintained for 1 or 2 wk before planting on yield and select biometrical and quality parameters of 'Bruce' F_1 cauliflower curds. Seeds were sown in a greenhouse of the University of Agriculture in Kraków, Poland, in 96-cell black trays (volume of a single cell was 53 cm^3) filled with standard peat substrate (Klasman TS2, Klasmann-Deilmann GmbH, Geeste, Germany). Temperature in the greenhouse was maintained at 24 °C ± 2 °C until emergence, at which time the temperature was lowered to 18/15 °C ± 2 °C (day/night). Transplant production took approximately 40 d. A portion of the plants were exposed to low temperature for a period of 1 or 2 wk in vegetative growth chambers (factor I, LT duration) under a 14-h photoperiod (via metal halide lamps: Sunmaster LM 400W U46 CDX, Venture Lighting Europe Ltd., Rickmansworth, UK). Intensity of irradiance (canopy level) was approximately 300 μmol m^{-2} s^{-1} and relative air humidity approximately 75%. The temperatures in the particular chambers were 6, 10, and 14 °C (factor II, temperature). Temperatures of 18 ± 2 °C during the day and 15 ± 2 °C at night were maintained for control plants, which remained in the greenhouse until planting. All transplants were fertilized twice with Kristalon Zielony liquid fertilizer (18% N, 18% P_2O_5, 18% K_2O, 3% MgO, and 2% S) (Yara International ASA, Szczecin, Poland) at a dose of 10 g dm^{-3} water and once with 98.5% ammonium molybdate—$(NH_4)_6Mo_7O_{24}{\cdot}4H_2O$ (POCH S.A., Gliwice, Poland), applied just before planting, at a dose of 1 g dm^{-3} water.

2.2. Field trials

Directly after the LT treatments, 40-d-old plants were transplanted to the experimental field of the University of Agriculture in Kraków, on April 18–19. The climate of the experimental station, located in southern Poland (N 51°13′, E 22°38′), is humid continental (Dfb), according to Köppen's classification. The soil type was a Fluvic Cambisol (Humic), with respect to the classification of the Food and Agriculture Organization of the United Nations (FAO, 2006). The experimental design was a split-block with low-temperature duration being the main plot and temperature the sub-plots. Each treatment was replicated three times. Plant spacing was 50 × 45 cm. The single plot size was 9 m^2 and was composed of 40 plants (30 plants intended for harvest plus protective rows). We performed standard cultivation practices, including fertilization, sprinkler irrigation, and plant protection, as recommended for cauliflower (Rumpel, 2002; Adamicki and Nawrocka, 2005). The amount of fertilizer was calculated on the basis of a soil analysis to achieve the content of nutrients in 1 dm^3 of soil of 140 mg N, 60 mg P, 200 mg K, 70 mg Mg, and 1,500 mg Ca. Borax was applied at a dose of 15 kg ha^{-1}. A 19-g m^{-2} Agryl PP nonwoven fleece was used for direct covering for 3 wk after transplanting. Harvest occurred from 16 June to 12 July in 2011 and from 25 June to 2 July in 2012.

2.3. Weather data

During the experiment, the air temperature was recorded with the use of HOBO Pro RH/Temp automatic logger sensors (Onset Comp. Corp., USA) placed on the plots. The HOBO Weather Station, located at the experimental station, was used to record the precipitation and PAR. The daily course of microclimate data are shown in Fig. 1. In both years, the mean air temperature, averaged for the growing season, was similar, amounting to 16.2 °C (2011) and 16.7 °C (2012). In 2011, the maximum and minimum air temperatures were 23.1 and 9.5 °C, respectively, and in 2012 they were 24.1 and 9.4 °C, respectively. The lowest air temperatures were noted in the first half of May in both years. Ground frost, up to −1.7 °C, occurred only in 2012. In the first year (2011) of the experiment, total precipitation was 213.2 mm, which was 75.6 mm more compared to the subsequent year (2012). Plants were irrigated by a sprinkler system when soil water potential was equal to or less than −40 kPa. Table 1 shows the mean, maximum, and minimum air temperatures and PAR values averaged for major developmental phases of cauliflower, including up to curd initiation and from curd initiation to harvest culmination. Field temperatures up to curd initiation were averaged with temperatures of the LT treatment of the transplants. These data were used for modeling marketable yield of cauliflower, according to methods described hereafter.

2.4. Yield attributes

Yields of curds at commercial fresh market maturity were recorded three times per week starting 16 June 2011 and 25 June 2012. All curds were trimmed to market standards and weighed.