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Research paper

Light modification by color nets improve quality of lettuce from summer production

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ABSTRACT

The effects of utilization of different color shade nets in lettuce production during the summer season were evaluated in Serbian climate conditions for pearl, blue, red and black shade nets in comparison to open field production. Applied shade nets (with shade index of 50%) significantly reduced solar irradiation (from 890 in open field to 400–560 Wm^{-2} under the shade nets) and photosynthetically active radiation (from 2020 in open field to less than 1000 $\mu mol\ s^{-1}\ m^{-2}$ under the shade nets). Color shade nets affected both, properties of lettuce during the growing period and its morphological properties. Namely, the leaf area index was increased, lettuce heads were characterized with significantly higher marketable head weight and head diameter, the period from planting to bolting was significantly shorter, the outer leafs were characterized with more intensive green tone (–a*) and the lettuce leafs were softer and more tender for lettuce grown under the shade nets in comparison to open field production. In respect to lettuce composition, total chlorophyll content, contents of both chlorophyll a and chlorophyll *b*, as well as carotenoid content were significantly higher in shaded leaves of lettuce than in the control plants. Significantly higher (30.78 mg GAE g^{-1} d.m.) total phenol content was determined in plants grown under the pearl shade nets accompanied with significantly higher flavonoids content (14.28 mg RE g^{-1} d.m.) and significantly higher antioxidant properties (lower EC50 DPPH values) in comparison to all other nets. However, the antioxidant properties of control plants were at the same level as for the pearl net, in spite of lower phenols and flavonoids content.

1. Introduction

Lettuce (*Lactuca sativa* L.) is among the most important cultivated vegetables in Serbia. Its leaves are usually consumed raw, without any restriction to daily intake (Kosma et al., 2013). Lettuce contains a number of phytonutrients – plant metabolites known to promote human health (Martin et al., 2011). The amount of antioxidants in lettuce leaves is susceptible to high variation in response to cultivars (Llorach et al., 2008), growing conditions (i.e. outdoor or indoor cultivation) as well as to environmental stress.

Lettuce is one of the main crops grown in greenhouses (Li and Kubota, 2009), but also in open field. It seems to be a model crop well studied for light quality and temperature response (Kim et al., 2004). Production of lettuce can be organized on different plot sizes since it has a short vegetation period (Čabilovski et al., 2011). The dominant type of lettuce grown and consumed in Serbia is butter lettuce. Lettuce is used almost throughout the year since there is a number of varieties which are successfully cultivated during different growing seasons (Zdravković et al., 2014). Lettuce crops are exposed to considerable variations in environmental conditions. Early spring, late fall, and even winter production of lettuce can be successfully achieved in high tunnels in temperate climates (Gent, 2002), but the potential for extension of the production season to the hot summer months is less recognized.

Depending on location, lettuce production may be limited during late spring and summer months because of unfavorable temperatures (air temperature exceeding 30/16 °C day/night) that increase the risk of bolting (forming of non desirable flower stalks), tip burn, rib discoloration (Jenni and Yan, 2009), leaf bitterness (Zhao and Corey, 2009) and form loose heads (Fukuda et al., 2011). Beside temperature, lettuce production also depends on light properties (Dufault et al.,

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2009), light quality and light intensity (Ilić and Fallik, 2017). However, Dufault et al. (2006) reported that as planting dates progressed toward warmer temperatures and longer days, lettuce yield and quality were negatively affected. Flower initiation generally occurs between 21 and 27 °C; however, higher temperatures coupled with warm nights may initiate premature bolting and increase the potential for physiological tip burn (Simonne et al., 2002). Both disorders will decrease lettuce quality and marketability. In these conditions bitter flavors can rapidly develop and the leaves become less tender (Bunning et al., 2010).

Light intensity of 400 μmol s^{-1} m^{-2} can be an optimal value of supplementary light for winter greenhouse production of certain types of lettuce in higher latitudes, while light intensity of 600 μmol s^{-1} m^{-2} can be an optimal value of shading light for late spring and early autumn production of certain types of lettuce in lower latitudes (Fu et al., 2012). In order to overcome or at least decrease the impacts of high light intensity, reaching around 2000 μmol s^{-1} m^{-2} in southern Europe during the hot summer months, cool-season vegetables like lettuce must be grown under shaded conditions. Photo-selective shade netting technology is an emerging agro-technological concept which aims at combining physical crop protection with different filtrations of solar radiation (Ilić et al., 2015). Radiometric properties of the nets depend on their porosity and color. Besides affecting the amount of radiation, photo-selective netting can also transform the radiation from direct to the scattered light, allowing penetration into the inner plant canopy (Stamps, 2009). Hereby it prevents burning, offers a moderate cooling effect and improves pest control (Shahak, 2008).

Consequently, shade net color also has influences on physiological processes in the plants as well as the yield and quality of produce. Lettuce cultivation in South Africa conditions under photo-selective pearl and yellow nets with 40% shading improved the fresh leaf mass and percentage of marketable yield at harvest (Ntsoane et al., 2016). The pearl net is designed to scatter the light to higher extent than other types of colored shade nets (Rajapakse and Shahak, 2007). However, the commercially available black shade cloth does not have the ability to scatter light at all (Selahle et al., 2014) and the widely used common black nets are completely opaque and the spectral quality of radiation is not modified in any way by the net (Arthurs et al., 2013). The major purpose of adopting the colored shade netting approach is to extend the harvest season (maturation rate) and decrease the potential for physiological disorders.

The main lettuce quality parameters are: leaf freshness, color, overall appearance, head shape and size and nutritional value (Kader and Rolle, 2004). The appearance of physiological disorders can be observed visually on leaf surfaces. The performance of lettuce during summer trials varied significantly among cultivars.The appearance of physiological disorders can be observed visually on leaf surfaces (Chutichudet and Chutichudet, 2011). Lettuce production may be limited during summer months, because of unfavourably high temperatures, that increase the risk of small and inferior heads, causing the crop to bolt, leaf bitterness, and disorders such as rib discoloration (Jenni, 2005), tipburn (Mashego, 2001) and bolting. Saure (1998) reviewed the mechanism of tip burn, which results from the plant's inability to supply sufficient calcium (Ca) to rapidly developing leaves. Beneficial effects of shade nets (increased yield, reduced incidence of tip burn and improved quality) are associated with a reduction in solar irradiation, resulting in impairment of heat stress in the plants. Bolting is mostly increased by early plant exposure to increasing irradiance, temperatures and day lengths, causing crops to be very prone to flowering prematurely and resultng in quality loss (Wallace et al., 2012). Unshaded high tunnels generally led to more rapid bolting and increased bitterness of lettuce compared with the open field. Lettuce grown in high tunnels covered by shade cloth had a lower bolting rate, but decreased yield relative to the open field (Zhao and Carey, 2009).

Accumulation of phytochemicals during production of plants depends on many factors, such as light quality, quantity, type of varieties or cultivars, growing season, and metabolic factors (Sivakumar and Jifon, 2017). Light quality changes could potentially alter crop physiological and biochemical processes, metabolite profiles and quality. Different shade levels, with the resultant changes in plant morphology and physiological characteristics, affected the secondary metabolites such as phenolic compounds in plants (Ntsoane et al., 2016). However, different plants had diverse reactions to shade levels, which alter the production of total phenolics (TP) and total flavonoids (TF). A negative effect was verified as a consequence of a reduction of 40–50% of light transmission (Oh et al., 2011) while an exposure to high light intensity increased phenolic accumulation and antioxidant capacity (Zhou et al., 2009; Oh et al., 2009). Exposure to high temperature and radiation has been shown to increase the production of phenolic compounds in green lettuce (Caldwell, 2003) and pigmented lettuce (Marin et al., 2015).

The variability in quality is extensive and is probably a result of complex genetic, physiological and environmental conditions. Improved yield and quality of lettuce can be obtained by selecting the correct cultivar for summer production (Maboko and Du Plooy, 2008). Thus, in addition to application of shade netting technology, cultivars suitable for summer production should be used.

The objectives of the present investigation were to assess the effects of color photo-selective nets compared to open field production for the lettuce summer variety Tizian, with respect to (1) leaf area indices, the fresh weight and overall market quality (2) incidence of physiological disorders (tip burn, rib discoloration and bolting) (3) photosynthetic pigments content, and (4) accumulation of bioactive compounds (β-carotene, phenols and flavonoids) and their scavenging activity.

2. Materials and methods

2.1. Plant material, growth conditions and experimental design

Production of a summer variety of lettuce (*Lactuca sativa* L. cv. Tizian) was carried out in 2016 (same experiment was repeat three times (June, July and August) during the summer season), in an experimental garden located in the village of Moravac near Aleksinac (21∘ 42′ E, 43∘ 30′ N, altitude 159 m) in the central area of south Serbia. The color shade nets were mounted on a structure placed about 2.0 m above the plants (net house). A randomised block design was adopted with four treatments (red, blue, white and black shade nets, with a shade index of 50%) with three replications of 40 plants (5 m^2). Plants grown in the open field served as control.

The colored shade-nets were obtained from Polysack Plastics Industries (Nir-Yitzhak, Israel) under the trade mark ChromatiNet. The nets used both spectrally modify as well as scatter the transmitted light. The photo-selective net products are obtained by the incorporation of various chromatic additives, light dispersive and reflective elements into the netting materials during manufacturing.

Lettuce seeds were sown during the second week of May, June and July in seed trays containing substrate consisting of 30% soil, 50% manure, 20% peat and a small part of marble. When plants developed four true leaves and a mean aboveground mass of 0.9 g (4 weeks after sowing) they were transferred into the experimental field to soil with spacing 40 cm between rows and 30 cm in row with a plant density of 8.3 plants m^{-2}. The seedlings were transplanted on June, July and August 10th. Growing technology involved the primary soil preparation before planting and fertilization with formulation 12: 11: 24 + ME (Yara Mila Complex) applied through regular supplemental feeding drip system and foliar application.

The effect of nets on the interception of light was measured annually as a percentage of total photosynthetically active radiation (PAR) above canopy, using a Ceptometer mod. Sun scan (SS1-UM-1.05; Delta-T Devices Ltd, Cambridge, UK) with a 64-sensor photodiode linearly sorted in a 100 cm length sword. Readings are in units of PAR quantum flux (μmol m^{-2} s^{-1}). The Solarimeter −SL 100 (KIMO, France) is an easy-to-use portable autonomous solarimeter that measures solar irradiation ranging from 1 W$m^{-2}$to 1300 Wm^{-2}.