EFFECTS OF NEAR INFRA-RED REFLECTION GREENHOUSE COOLING ON BLOSSOM-END ROT AND FRUIT CRACKING IN TOMATO (*Solanum lycopersicum* L.)

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ABSTRACT

Blocking the near infra-red (NIR) portion of the global radiation from entering a greenhouse is one of the emerging environmentally friendly and economical ways of reducing greenhouse temperature without increasing the humidity. In this study, the effect of cooling greenhouses by NIR-reflection on the microclimate, fruit quality and growth of tomato crop was investigated. Two greenhouses measuring 10 m long by 20 m wide by 6 m high were constructed at the Asian Institute of Technology, Klong Luang, Thailand. Both greenhouses were naturally ventilated and were clad using insect proof screens (78-mesh) on the sidewalls and ventilation openings, while the roof was covered with an ultra violet (UV) absorbing plastic film. Reduheat®, a NIR-reflecting pigment was applied on the roof of one of the greenhouses treated (Trt). Tomato plants were grown in the greenhouses in 10 L white plastic pots at a density of 1.5 plants/m^2 and grown following commercial recommendations using the high wire system. Results show that the quantities (both weight and count) of tomato fruits affected by blossom-end rot (BER) as well as undersized fruits (weighing less than 50 g) during both dry and rainy seasons were lower for the plants grown inside the greenhouse with the NIR-reflecting pigment on the roof. On the other hand, in this greenhouse the number of cracked fruits was slightly higher. Additionally, NIR-reflecting pigment reduced electricity consumption by the ventilation fans (used during emergency). Application of NIR-reflecting pigments on greenhouse covers for cooling, reduction of water requirement and fruit quality improvement is recommended for crops grown inside greenhouses when solar radiation is in abundance.

Key words: Natural Ventilation, Insect-proof Nets, Tropics, Protected Cultivation

INTRODUCTION

Blossom-end rot (BER) of tomato is a physiological disorder usually associated with calcium deficiency or stress-related reactions (Saure, 2001). It has been shown to be markedly affected by excess light and high temperatures, independent of the calcium supply to the plant (Ho et al., 1993). Amongst others, high light intensity (Karni et al., 2000) and high temperatures (Ho et al., 1993), apparent characteristics of tropical climates, have been reported to increase the incidence of BER. The susceptibility for BER is particularly pronounced during phases of rapid cell expansion, i.e. during the initial growth stages of the berry (Marcelis and Ho, 1999). Since calcium is almost exclusively transported via the xylem, transpiration is the main driving force for its transport within the plant. In periods of intensive radiation and/or high temperatures transpiration is high and thus the transpiratory current is mainly directed to the mature leaves as they are the highest transpiring plant parts. In the process, Ca supply to the low transpiring fruits is decreased, possibly leading to localized Ca deficiency. Such competition for calcium between leaves and fruits has also been suggested as a possible cause of BER (Ho, 1989). The role of soil moisture in BER occurrence is controversial with most researchers reporting aggravation of BER with increase in soil water stress (Obreza et al., 1996), while others report increased incidences with increased irrigation (Mohammed et al., 1989). According to Taylor and Locascio (2004) yield losses caused by BER can amount up to 50% of the total yield.

Global radiation entering a greenhouse comprises of three main parts: ultra violet (UV) radiation at wavelength 300-400 nm, photosynthetic active radiation (PAR) at wavelength 400-700 nm and the near infra-red radiation (NIR) at wavelength 800-2500 nm (Hemming et al., 2006). Both UV and NIR are less absorbed by the plant. Blocking the transmission of UV reduces the infestation of a crop by some insect pests, as it influences their visual behaviour (Mutwiwa et al., 2005; Kumar and Poehling, 2006). Plants absorb and use PAR for growth and photosynthesis and hence its availability inside the greenhouse should not be limited.

In protected cultivation, various methods are used in order to optimize the microclimate, especially air temperature and light in relation to plant growth and development. High solar radiation increases air temperature inside greenhouses to levels above the optimum values for crop growth. Application of white washes and shading screens has been used to block excess radiation transmission into the greenhouse thereby reducing the air temperature, but these methods also reduce the transmission of PAR (Baille et al., 2001; Glaser et al., 2000; Zanon, 2000). Most of the NIR transmitted into the greenhouse is absorbed by the soil, installations and construction parts of the greenhouse and increases the air temperature. Greenhouse covers that filter the NIR radiation from entering the greenhouse have been suggested as suitable methods of cooling the greenhouse (Hemming et al., 2006; von Elsner, 2005; 2003; Mutwiwa et al., 2007). Poor fruit set and poor yields coupled with high incidences of fruit abnormalities such as cracking and BER are some of the effects of high temperature on tomatoes (El-Ahmadi and Stevens, 1979). Increasing the area of ventilation openings usually screened with insect-proof meshes and blocking off the transmission of NIR into the greenhouse are some of the methods currently employed to control greenhouse temperature in the tropics. In the present study, the effects of greenhouse cover materials that block the transmission of NIR on production and fruit quality, specifically BER and fruit cracking of tomato crops were investigated in greenhouses clad with insect proof nets.

MATERIAL AND METHODS

The present research was conducted in greenhouses of the "Protected Cultivation Project" at the Asian Institute of Technology (AIT), Klong Luang (45 km north of Bangkok), Thailand at 14°04'N latitude, 100°37'E longitude and altitude 2.3 m. The dimensions of the greenhouses were 10 m long by 20 m wide with a height of 6.4 m at ridge and 3.8 m at gutter. The greenhouses were naturally ventilated with total ventilation opening 228 m^2 and they were equipped with two exhaust fans of 1 m diameter and 1100 m^3 per minute capacity, which were operated when the temperature exceeded 30°C. The greenhouses were covered with a UV-absorbing plastic film (Wepelen thermic diffused, Werra Plastic, Philippsthal, Germany) on the roof, while the side walls and ventilation opening on the roof were covered with a 78-mesh UV-transmitting insect proof screen (Econet-T, Ab Ludvig Svensson, Kinna, Sweden). To prevent insect entry through the door, the greenhouses were equipped with a two-door system with a foot-bath in between. A newly developed NIR-reflecting pigment, Reduheat® (Mardenkro B.V., Baarle-Nassau, The Netherlands) was manually sprayed on the roof of one of the greenhouses at mixing ratio of 1:2.5 pigment to water using a high pressure system on 18th July 2005 and 29th June 2006. The two greenhouses were referred to as treated (Trt) and Control (Con) for the greenhouse with and without the NIR-reflecting pigment, respectively.

Temperature and relative humidity inside the greenhouses were measured with aspirated psychrometers (BGT, Leibniz University Hannover, Germany) fitted with a solar radiation shield, while incoming global radiation inside the greenhouses was measured using a pyranometers (Kipp and Zonen, Delft, The Netherlands). Tomato plants, *Solanum lycopersicum*

L. cv. FMTT260 (AVDRC, Shanhua, Taiwan) were transplanted in 10 L white pots filled with substrate consisting of 28% organic matter at a pH of 5.3. Substrate texture was 30% sand, 39% silt and 31% clay, for the dry and rainy seasons, respectively. In the greenhouse, plants were arranged in 6 rows of 50 plants each, giving a planting density of 1.5 plants per square meter. Fertilizer and irrigation water were applied through a drip irrigation system based on the light integral from global radiation.

Climatic data were recorded automatically every 5 minutes using a purpose built data-logging system (Leibniz University Hannover, Germany). Plant height and total number of trusses were recorded weekly while leaf area was measured fortnightly through destructive sampling using a leaf area index meter (LICOR, Lincoln, NC, USA). Tomato fruits were harvested weekly starting from 10 weeks after transplanting (WAT). The fruits were separated into marketable and non-marketable ones. The non-marketable class consisted of small usually parthenocarpic fruits of less than 50 g weight, fruits affected by BER and cracks. For the marketable fruits, only the total weight per harvest was recorded, while both the weight and total count were recorded for the non-marketable ones. The data were subjected to Student's t-test using SAS statistical software Version, 9.1 at a 5% level of significance. Count data were square-root transformed before analysis.

RESULTS AND DISCUSSION

In both the dry and rainy seasons, the NIR-reflecting pigment reduced the total yield production (average total tomato yield per plant and harvest) by between 16% and 17%, respectively, although the difference was not significant ($t=0.81$, $df=20$, $P=0.42$ and $t=1.32$, $df=12$, $P=0.21$, for the dry and rainy seasons, respectively) (Fig. 1A). Hemming et al. (2005) reported 8.6% increase in production of tomatoes grown in greenhouses covered with NIR filtering material. Garcia et al. (2006) reported a 26% increase in commercial fruit production, while waste yield was reduced by up to 67% in peppers grown inside greenhouses covered with a NIR-filtering plastic film. Various reasons could account for this discrepancy in production, such as the use of different tomato cultivars or crop and completely different external climatic conditions, e.g. higher humidity and intensity of radiation in Thailand. Moreover, in the present study, the NIR-reflecting pigment was manually sprayed on the greenhouse roof making it impossible to achieve a uniform spread while in the case of Hemming et al. (2005), the NIR-reflecting pigment was incorporated in the film production, which led to differences in the spectral behaviour especially PAR transmission and NIR-reflection of both greenhouse covers.

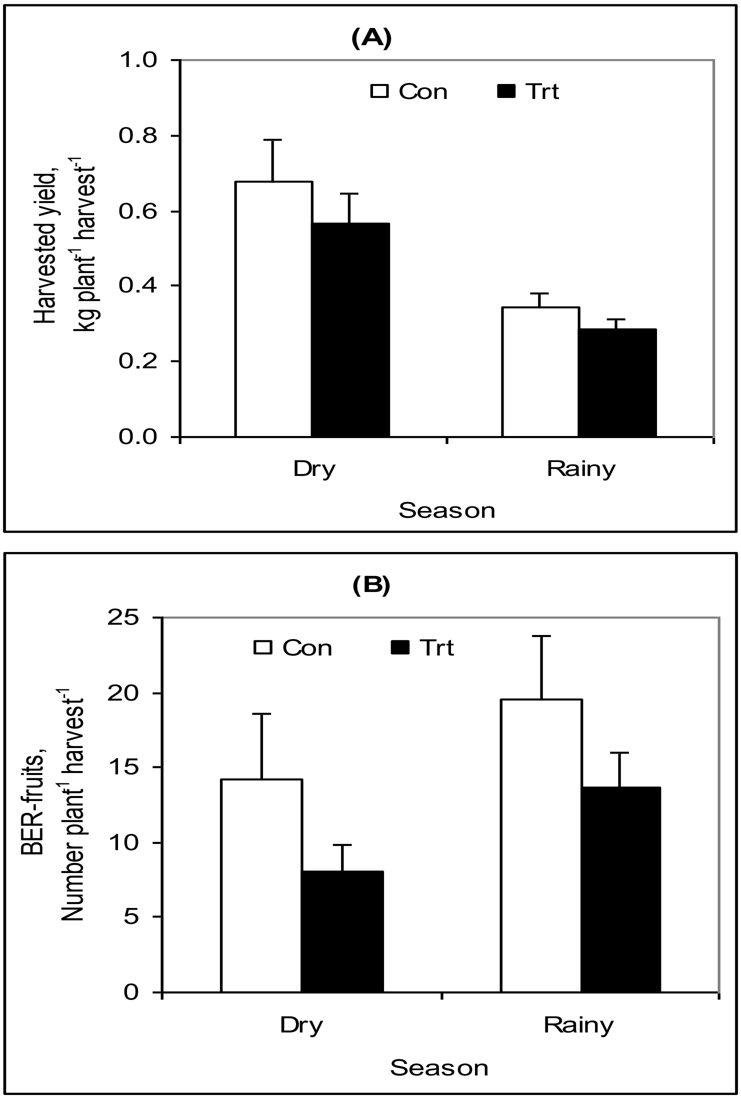

Figure 1. Total yield of tomato plants (average per plant per harvest) (A) and the average number of blossom-end rot affected fruits (B) grown in greenhouses with (Trt) or without (Con) a NIR-reflecting pigment roof cover.

During the rainy season, late application of the NIR-reflecting pigment at 7 WAT might have reduced its beneficial effects as plants might have already adjusted themselves physiologically or morphologically to the unfavourable conditions. Many shading materials in the market reduce the overall radiation transmission into the greenhouse and consequently the heat load (von Elsner and Xie, 2003; Hemming et al., 2006). The NIR reflecting pigment used in the present study reduced the overall light by a maximum of 31% (Mutwiwa et al., 2006) and PAR transmission by 26% during the rainy season. Besides, the NIR-reflecting pigment was applied on the outer surface of the plastic film; thus, it could have formed a suitable base for dust particles to adhere thereby reducing transmissibility further. Reduction of PAR transmission might be responsible for the slight reduction of total yield observed in Trt. The number of BER affected fruits (Fig. 1B) and consequently the total weight of non-marketable fruits (Fig. 2A) was reduced in Trt.

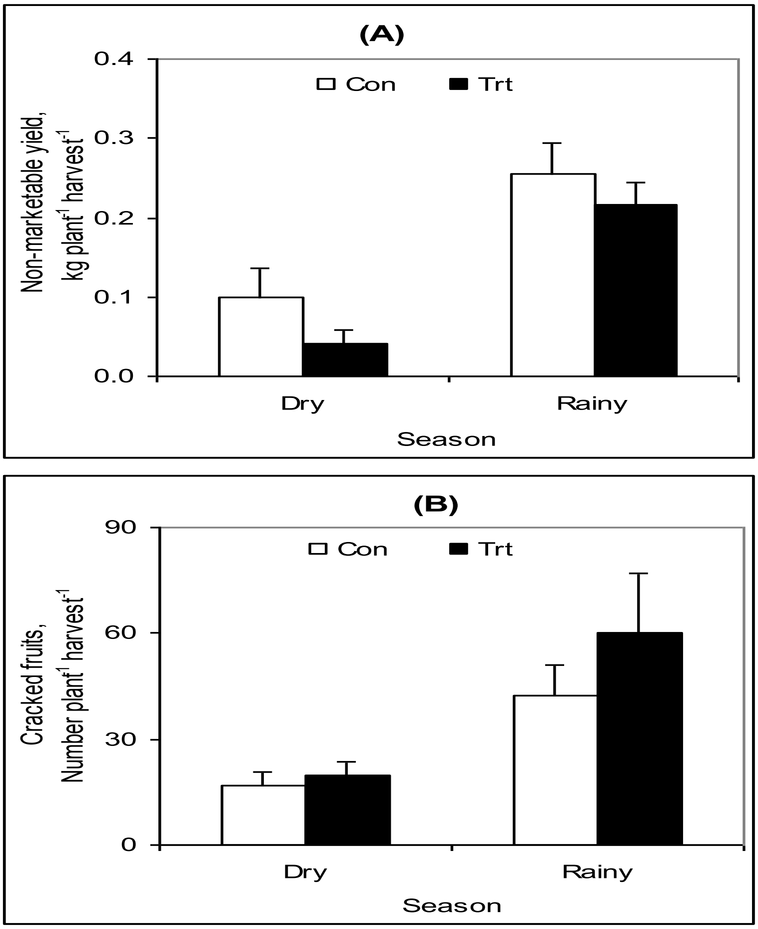

Figure 2. Non-marketable (A) (average weight per plant and harvest) and cracked (B) fruits (average number per plant and harvest) grown inside greenhouse with (Trt) or without (Con) NIR-reflecting pigment on the roof of the greenhouse.

In the dry and rainy seasons, the quantity of BER affected fruits was reduced by 43% and 30%, respectively, and consequently the proportion of non-marketable yield was reduced by 59% and 16%, respectively, in the corresponding periods. However, the differences among the treatments were not statistically significant (student's t-test, $\alpha<0.05$, dry season n=11, rainy season n=7). The reduction in BER was attributed to the reduction in transpiration of the plants in response to the microclimate improvement. The fact that typical symptoms of Ca deficiency such as contorted growth, tip die back and curled leaves were less frequently observed in Trt corroborates this interpretation. Lower greenhouse air temperature as a result of less incoming NIR radiation lowered crop transpiration (Hemming et al., 2005; Mutwiwa et al., 2006) and crop water requirement. Since fertigation was the same in both greenhouses, the variations in moisture of the substrate in Trt was lower compared to Con, thus reducing leaf transpiration and consequently the deficiency of Ca on the mature fruit by enhancing Ca transport to fruits (Ho et al., 1993). High irradiance enhances leaf transpiration thus Ca^{2+} absorbed by the roots is deposited on the leaves instead of the fruits thereby increasing BER (Saure, 2001). Relatively high irradiance and high temperatures are responsible for the increase in the number of BER affected fruits in the rainy season. High temperature stimulates cell enlargement and hence greater rate of fruit enlargement; thus, without an increase in supply of calcium on the distal end of the fruit, BER occurs (Ho et al., 1993).

On the other hand, the number of cracked fruits increased in Trt by 16.1% and 43.1% during dry and rainy seasons, respectively (Fig. 2B). One of the reasons was the reduced transpiration possibly entailing increased water influx into the fruits. Peet and Willits (1995) reported a clear relationship between excess water availability to plants and tomato fruit cracking, although this increased the fresh weight of total yield.

An improved microclimate led to the production of less undersize, usually parthenocarpic fruits (Fig. 3A) with the total marketable yield reduced by only 9% and 23% in the dry and rainy seasons, respectively (Fig. 3B). The reduction in marketable weight (though statistically insignificant according to t-test, $\alpha<0.05$, dry season n=11, rainy season n=7) corresponds more with the reduction in PAR transmission into the greenhouse but the reduction in income could be compensated by the savings from resource use mainly water and power. Plant water requirement was reduced by 7% and 9% in the dry and rainy seasons, respectively, while power consumption by the ventilation fans was reduced by 15% in the rainy season. The improved microclimate inside Trt provided better working conditions for the workers leading to an increase in benefits such as higher efficiency (output).

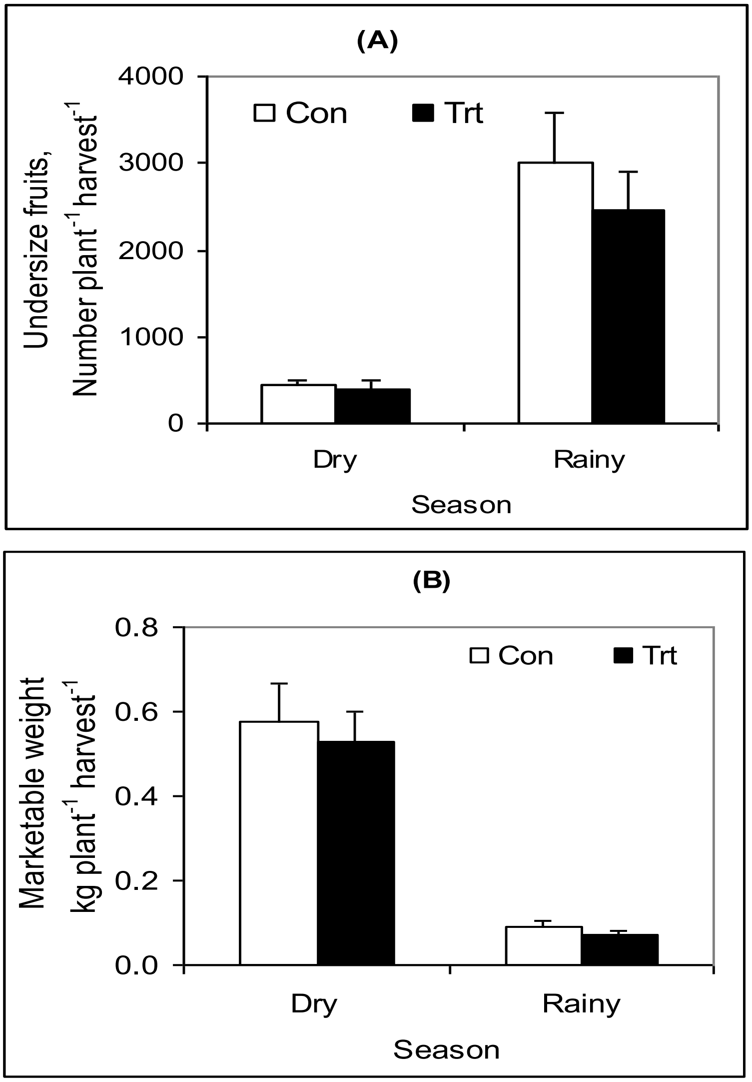

Figure 3. Average number of undersized (weighing less than 50 g) (A) and marketable fruits (B) (average per plant per harvest) grown in greenhouses with (Trt) or without (Con) NIR-reflecting pigment on the roof of the greenhouse.

Moreover, plant growth notably height, number of trusses and leaf area were not significantly different in the two greenhouses. Since the rainy season is the hottest and most humid, the NIR treatment was shown to be a sustainable method of cooling greenhouses as only one application per year is required. Thus, it is sustainable and cheap; for instance, nets physically and optically prevent insect pest entry (hence the diseases they vector), natural ventilation leads to a reduction power consumption etc.

CONCLUSIONS AND RECOMMENDATIONS

The NIR-reflecting pigment improved the greenhouse microclimate and reduced the proportion of non-marketable yield by 58% and 16% in the dry and rainy seasons, respectively. The numbers of BER affected and parthenocarpic fruits were reduced by 29.9% and 17.9% in the dry and rainy seasons, respectively. The NIR-reflecting pigment reduced plant transpiration and hence plant water requirement by 7% and 8.8% in the dry and rainy seasons, respectively. Moreover, the greenhouse Trt was cooler and hence power consumption by the exhaust fans was reduced by 15.5% in the rainy season. Although the NIR-reflecting pigment slightly reduced PAR transmission, it exerted no significant effect on total yield. The use of greenhouse covers that block the transmission of NIR-radiation into the greenhouse should be considered as an option in cooling greenhouses and controlling BER when solar radiation is not limited.

There is need for more research to develop cheaper greenhouse systems for sustainable vegetable production in developing countries, including Kenya. Such greenhouses should be constructed using locally available materials and technology to ensure it is easy to adopt. More specifically, research should be conducted to investigate the durability of the pigment and best application methods, possibility cheaper alternatives to the pigment.

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