High Tunnels Can Promote Growth, Yield, and Fruit Quality of Organic Bitter Melons (Momordica charantia) in Regions with Cool and Short Growing Seasons

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Additional index words. anti-insect netting, pest, disease incidence

Abstract. There is a potentially large market for locally produced organic bitter melons (Momordica charantia L.) in Canada, but it is a great challenge to grow this warm-season crop in open fields (OFs) due to the cool and short growing season. To test the feasibility of using high tunnels (HTs) for organic production of bitter melons in southern Ontario, plant growth, fruit yield and quality, and pest and disease incidence were compared among three production systems: OF, HT, and high tunnel with anti-insect netting (HTN) at Guelph in 2015. The highest marketable fruit yield was achieved in HTN (~36 t·ha⁻¹), followed by HT (~29 t·ha⁻¹), with the lowest yield obtained in OF (~13 t·ha⁻¹). Compared with OF, there were several other benefits for bitter melon production in HT and HTN: increased plant growth, advanced harvest timing, reduced pest numbers and disease incidence, and improved fruit quality traits such as increased individual fruit weight and size, and reduced postharvest water loss. In addition to higher yield, HTN had fewer insect pests and disease incidence compared with HT. The results suggest that HTs can be used for organic production of bitter melon in southern Ontario and regions with similar climates. Also, the addition of anti-insect netting to HTs is beneficial to production if combined with an effective pollination strategy.

Bitter melon (Momordica charantia), also known as bitter gourd, karela, or balsam pear (Palada and Chang, 2003), is a popular vegetable for many culture groups in Canadian urban centers, such as the Greater Toronto Area. Consumption of bitter melon has also been shown to be beneficial for the management of some symptoms of type II diabetes (Abascal and Yarnell, 2005). It is estimated that there is a CAD$12.4 million/year market for bitter melons in just a few of the largest Canadian metropolitan centers, and a potential countrywide market of CAD$37–66 million/year (Zheng, 2010).

Currently, the majority of bitter melon sold in Canada are imported from other countries such as Honduras (Zheng, 2010). However, for the imported bitter melons, the lost freshness due to a short postharvest life of the fruits (Palada and Chang, 2003) negatively affects their price, and Canadian consumers also worry about food safety of imported bitter melons. Moreover, there is hardly any organic bitter melon in Canadian market. Although there is a demand for local, organically produced bitter melon, the supply of such products is currently limited by Canada’s cold climate (Zheng, 2010). Bitter melons, which are native to southern China and eastern India, grow well in tropical and subtropical climates (Behera et al., 2010). In Canada, OF production of warm-season crops such as bitter melons is difficult unless some means are employed to improve the growing environment (Watterer, 2003).

HTs, as low-cost protective structures, can create a warmer microclimate for plants and have been used worldwide to promote earlier crop production, higher yields per unit area, and better-quality products compared with OF production (Lamont, 2009; Ogden and Van Iersel, 2009). However, since HTs are unheated and passively ventilated structures, the actual benefits of HT production for different crop species are determined by local environmental conditions (Carey et al., 2009). There is limited information on HT production under Canadian climatic conditions, especially in Ontario. In Saskatchewan, it has been reported that crops of muskmelon, pepper, and tomato in HTs matured 1 to 2 weeks earlier and produced substantially greater fruit yields before frost than those in low tunnels (Watterer, 2003). However, no information is available on whether HTs can be used for bitter melon production in regions with similarly short growing seasons, such as Ontario.

For organic production, the use of anti-insect netting on the vents and doors of HTs is often recommended, since it can provide a nonchemical way to effectively exclude many insect pests (Teitel, 2001). For bitter melon production in tropical and subtropical regions, the most common insect pests are fruit flies, beetles, thrips, aphids, and mites (Palada and Chang, 2003). These pests have been found in other cucurbit crops in southern Ontario. To exclude these pests, the maximum mesh size of anti-insect netting needs to be small; up to around 200 μm (Bethke and Paine, 1991). However, fine mesh size also impedes air flow through the netting and may thus increase temperature inside HTs (Fatnassi et al., 2006). During summer in southern Ontario, solar radiation intensity often exceeds most crops’ requirements (Llewellyn et al., 2013). Excessive solar radiation can increase air temperatures beyond the optimum for growing crops in protected agricultural structures that use passive ventilation, including HTs (Zhang, 2001). It is therefore important to test the impact of anti-insect netting on HT temperature and organic bitter melon production, including growth and harvest metrics as well as incidence of insects and diseases.

The objectives of this study were to explore the feasibility of organic production of bitter melons in HTs in southern Ontario, and to determine the effects of anti-insect netting on HT production of organic bitter melon.

Materials and Methods

Experimental site and design. The trial was conducted at the Guelph Center for Urban Organic Farming, Guelph, Ontario, Canada (lat. 43°33′ N, long. 80°15′ W) during the 2015 growing season. This farm has been certified organic by Ecocert Canada since 2009. The soil is a clay loam with limestone bedrock, 3.5% to 6% organic matter, and pH 7.4. Cover crops of buckwheat (Fagopyrum esculentum) and sorghum (Sorghum bicolor), lightly seeded with.
red clover (*Trifolium pratense*), were used to maintain soil stability and structure and reduce weed incidence, in the years before this trial. There was no recent history of *Momordica* production at this site.

Six freestanding, NE–SW oriented, quonset-style HTs (10.8 m long × 7.2 m wide × 3.8 m high; DeCloet Greenhouse Mfg. Ltd., Delhi, Ontario, Canada) were constructed on-site in the fall of 2014. The side vents and door openings of three of the tunnels were installed with Econet T anti-insect screens (Gintec Shade Technologies Inc., Windham Center, Ontario, Canada), which has 0.15 mm × 0.35 mm hole size, 0.5 mm thread diameter, and 85% initial light transmission. These tunnels represented the HT treatment. The other three tunnels, without anti-insect netting, were used as the HTN treatment. Three equivalent-sized field plots (10.8 m × 7.2 m) were established as controls (OF treatment). The nine rectangular plots were arranged as a 3 × 3 randomized block design with 3-m buffer zones between adjacent plots (Fig. 1).

The tunnels were covered with a single layer of 0.15-mm polyethylene film with 90% initial light (photosynthetically active radiation) transmission (Suncover Clear CA; Ginegar Plastic Products Ltd., Kibbutz Ginegar, Israel). Doors built into the end walls were wide enough to allow the passage of a rototiller. The side walls were manually rolled up or down to adjust interior air temperature based on weather conditions and crop requirements.

The soil in all nine plots was cultivated by a rototiller before transplanting, and then 0.8 m × 0.25 m × 10.3 m raised beds, spaced 0.4 m apart, were prepared. One drip irrigation line (Garden Drip Tape, GO151000; Dubois Agrinovation Inc., St-Remi, Quebec, Canada) was installed down the middle of each raised bed.

**Plant materials and management.** Bitter melon (*Momordica charantia*, ‘Canton Green F1’; AgroHaitai Ltd., Lynden, Ontario, Canada) seedlings were propagated using a peat-perlite mix (Pro-Mix MP MYCORRHIZAE ORGANIK; Premier Tech Horticuluture Ltd., Riviere-du-Loup, Quebec, Canada) was installed down the middle of each raised bed. After transplanting, 14–18 plants were randomly selected, weekly, from each plot to evaluate the initial fresh weights (FW) fruit. For the latter measurement, after record- ing the flesh thickness in the middle part of the stele, the other half were used to evaluate postharvest water loss. For the former measurement, each fruit was cut into two halves from the middle line along the long axis, and the flesh thickness in the middle part of the fruit was measured using a digital Vernier caliper after taking out all the seeds in the fruit. For the latter measurement, after record- ing the initial fresh weights (FW), the sampled fruits were kept in paper bags at 23 °C for 4 d to determine the final fresh weights (FW), and then dried at 65 °C to determine the DW. The postharvest water loss [Eq. (1)], dry matter

![Image](image-url)
content [Eq. (2)], and water content [Eq. (3)] of
the fruits were calculated as follows:

\[ \text{Postharvest water loss (\%) = } \left( \frac{FW_i - FW_f}{FW_i} \right) \times 100 \quad (1) \]

\[ \text{Dry matter content (\%) = } \left( \frac{DW}{FW} \right) \times 100 \quad (2) \]

Water content (g\,g\(^{-1}\)) = \frac{FW_i - DW}{DW} \quad (3)

**Insect and disease evaluations.** Yellow and blue sticky traps (7.5 cm \times 12 cm; Canadian Hydrogardens Ltd., Ancaster, Ontario, Canada) were hung amid the plant canopy, at a height of 150 cm in each plot, to trap flying insects. All insects on each trap were counted weekly and used to determine cumulative totals at the end of crop production. Disease incidence was checked weekly, and the numbers of infected and dead plants due to disease were recorded in each plot.

**Weather parameter recording.** Weather parameters were measured continuously at 1-min intervals at the geometric center of one plot of each treatment (Fig. 1; OF2, HT2, and HTN2). Air temperature was measured 100 cm aboveground using RMY Young 81000 sonic anemometers (RM Young, Traverse City, MI), and recorded using Campbell Scientific CR1000 data loggers (Campbell Scientific, Logan, UT). Soil temperature was measured at 11.4-cm depth using PT916 sonic anemometers (RM Young, Traverse City, MI), and recorded using Campbell Scientific data loggers (Campbell Scientific Inc., Mooresville, NC). Soil temperature and radiation data were recorded using XR5-SE data loggers (Pace Scientific Inc.). The calibration of all sensors was verified experimentally before deployment. These environmental data were used for the calculation of daily average air and soil temperatures, and daily light integrals (DLIs). Monthly precipitation data were sourced from Environment Canada. Figure 2 shows average monthly weather situations for the site calculated from these data.

**Statistical analysis.** Data were subjected to analysis of variance using the Data Processing System Software (DPS, version 7.05; Refine Information Tech. Co., Hangzhou, China) and were presented as means \pm se. Separation of means was performed using Duncan’s new multiple range test at the \(P \leq 0.05\) level. Logistic [Eq. (4)] or Gompertz [Eq. (5)] formulae were used to fit the curves of variation of cumulative marketable yield with weeks of harvesting.

\[ Y = \frac{a}{1 + e^{b-x}} \quad (4) \]

\[ Y = ae^{-be^{-ax}} \quad (5) \]

where \(Y = \text{cumulative marketable yield (kg/plant, or number/plant)}; X = \text{weeks since the beginning of harvesting (week)}; a, b, k \text{ are parameters to be fitted; and } e = \text{exponential} = 2.71828. \) To describe the features of the curves, three parameters were calculated as follows: inflexion time point = \(\ln(b)/k\); maximum weekly yield increment = \(a \times e^{k/4}\) (logistic), or \(a \times k/2.7\) (Gompertz); and upper limit of marketable yield = \(a\) (Ma et al., 2013). Correlation analysis was used to determine the relationship between marketable fruit yield or fruit quality traits vs. growth of the bitter melon plants.

**Results**

**Environmental parameters.** Weather conditions during the whole 2015 growing season were generally similar to the long-term average except that rainfall was distributed unevenly between June and July (Fig. 2). Daily mean air and soil temperatures were the highest in HTN, followed by HT, and the lowest in OF. For example, during May the daily mean air temperatures were 21.3, 20.2, and 16.7 °C and the daily mean soil temperatures were 19.5, 19.4, and 16.3 °C in the HTN, HT, and OF treatments, respectively (Fig. 2A and B). During May, daily mean soil temperatures were consistently above 15 °C in HTN and HT, but were below 15 °C for 21 d in OF (data not shown). However, due to the shading effects of plastic coverings, the DLI was lower by around 20% in HTN and HT vs. OF (Fig. 2C).

**Plant growth and development.** Due to the higher temperatures (especially soil temperatures) (Fig. 2), the bitter melon plants were transplanted 21 d earlier into HT and HTN vs. OF (Table 1). Plant leader vines in HT and HTN showed higher growth rates than those in OF, regardless of time, but there were no significant differences in the rate of vine growth between HT and HTN (Fig. 3).

The first female flowers opened in late June in HT and HTN plots and in mid August in OF plots. The first female flowers appeared 15–20 d faster, relative to the transplant date, in HT and HTN vs. in OF, with no significant difference between HT and HTN (Fig. 4A). Furthermore, the time between flowering and harvesting of the first fruits was 2 to 4 (10% to 20%) d shorter in HT and HTN vs. OF (Fig. 4B).

At the end of the production season, the plants in HT and HTN had longer and thicker leader vines, with more nodes, and greater aboveground DW (not including fruits) than those in OF, but there were no significant differences between HT and HTN (Table 2).

**Fruit yield and quality.** Fruit harvest started 6 weeks earlier in HT and HTN than in OF (Fig. 5), though it ended on the same date in all treatments (Table 1) due to a killing frost on a night of mid October, when the air temperature dropped below –3 °C. By the end of the production season, both the total weight and number of marketable fruits harvested from each plant were greatest in HTN, followed closely by HT, and were lowest in OF (Fig. 5). The weekly variation of cumulative yield was characterized using either logistic or Gompertz formulae (Table 3). The maximum weekly yield increments in HT and HTN (collectively, HTN plots) were 4–5 times (by fruit weight) and 2–3 times (by fruit number) of those in OF. The weekly yield increment began to slow about 2 weeks in OF and 7.5 weeks in HT and HTN after the start of harvest. By the end of the production season,
Phytophthora blight were observed during the cropping period, with the latter two diseases exerting the most damage and even killing the infected plants. The percentage of disease-infected plants was lowest in HTN, followed by HT, then OF. The percentage of dead plants was lower in HT and HTN than in OF (Fig. 7B). Furthermore, disease outbreaks occurred earlier in the growing season in OF than in HT and HTN, but the predominant disease was gummy stem blight in OF and phytophthora blight in HT and HTN.

Discussion

HTs make organic bitter melon production possible in regions with short growing seasons. Fruit yields of 20–30 t·ha⁻¹ are common for OF production of bitter melon in tropical and subtropical regions (Morgan and Midmore, 2002). In the present study, under the conditions of the relatively cool and short growing season available in Ontario, a marketable yield of only 3 t·ha⁻¹ was achieved in OF, while yields of 29 to 36 t·ha⁻¹ were achieved in HTs. The higher yields seen in HT vs. OF cultivation resulted mainly from higher average individual fruit weight, and greater numbers of marketable fruits harvested from each plant. The potential to achieve higher yields by producing larger fruit has been shown in a previous bitter melon study (Islam et al., 2014). Stronger vegetative growth, as evidenced by higher final above-ground vegetative biomass, larger vine diameter and length, and greater number of nodes (Table 5) also contributed to the higher yields in HTs (Wang, 2003). Others have also shown that the yield of bitter melon was directly related to plant growth characteristics such as vine length (Islam et al., 2014).

In addition to the higher yield, fruit harvest began 6 weeks earlier in the HTs than in the OF. The earlier fruit harvest in HTs was due to the (4-week) earlier planting dates, and higher plant growth rates in HTs compared with OF plots. The earlier planting date in the HT was made possible due to the higher spring-time soil temperature in HTs compared with OFs (Fig. 2). Soil temperature is a reliable index for determining when to plant within a HT, and cucurbit crops can be transplanted when the soil temperature at the 5-cm depth maintains 15 °C and above (Jett, 2006). However, for spring production in OFs in Ontario, the transplanting date of warm-season crops is normally around 1 week after the average date of the latest frost. The faster plant growth in HTs may have been attributed to the higher temperature during the same period relative to transplanting date (Table 6). For bitter melons, a minimum air temperature of 18 °C is preferred during early growth (Palada and Chang, 2003). Air temperatures below 10 °C during early growth (Palada and Chang, 2003) and 20–30 °C is the optimal air temperature for fruit setting and fruit growth of bitter melon (Wang, 2003). A study in Australia has demonstrated similar effects of temperature on bitter melon plant growth (Morgan and Midmore, 2002).

The cumulative marketable yield in OF reached the upper limit of yield calculated from the formulae, but this did not occur in HT and HTN (Table 3; Fig. 5). This was supported by the observation that many immature fruits were found on the plants killed by frost in HT and HTN, but not in OF.

The percentage of scarred fruits was lower in HT and HTN than in OF, with no significant difference between HT and HTN, but the percentage of deformed fruits was not significantly different among OF, HT, and HTN (Fig. 6).

Fruit grown in HT and HTN had greater average individual weight, larger fruit size (length and diameter), thicker fruit flesh, and showed less postharvest water loss than fruit grown in OF. There were no significant differences between HTN and HT for any of the fruit quality parameters measured (Table 4). There were no significant differences among OF, HT, and HTN for fruit dry matter content and water content.

Insects and disease. There were fewer insects trapped on both blue and yellow sticky traps in HTN than in HT and OF. There were also fewer insects recorded on the blue traps, in HT vs. OF (Fig. 7A). Most of the trapped insects were found to be pests such as cucumber beetles, white flies, thrips, mites, and aphids.

For disease incidence, downy mildew, powdery mildew, gummy stem blight, and

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**Table 2. Morphological characteristics and biomass accumulation (not including fruits) at the end of the production period for bitter melon plants under different cultivation systems.**

| Treatment | Leader vine length (m) | Leader vine node (no.) | Leader vine diam (mm) | Aboveground dry wt (g) |
|-----------|------------------------|------------------------|-----------------------|-----------------------|
| OF        | 4.3 ± 0.3 a b          | 75.9 ± 1.5 b           | 7.5 ± 0.3 b           | 89.2 ± 6.3 b          |
| HT        | 8.9 ± 0.4 a            | 112.7 ± 2.1 a          | 9.5 ± 0.6 a           | 182.0 ± 29.2 a        |
| HTN       | 9.0 ± 0.1 a            | 120.2 ± 1.6 a          | 9.9 ± 0.2 a           | 192.7 ± 19.7 a        |

OF = open field; HT = high tunnel; HTN = high tunnel with anti-insect netting.

Data are means ± SE. Bars bearing the same letter are not significantly different at P ≤ 0.05 according to Duncan’s new multiple range test. Insects and disease. There were fewer insects trapped on both blue and yellow sticky traps in HTN than in HT and OF. There were also fewer insects recorded on the blue traps, in HT vs. OF (Fig. 7A). Most of the trapped insects were found to be pests such as cucumber beetles, white flies, thrips, mites, and aphids. For disease incidence, downy mildew, powdery mildew, gummy stem blight, and phytophthora blight
Table 3. The fitness and estimated parameters of the formulae for the variation of cumulative marketable fruit yield of bitter melon with time in different cultivation systems. *X* = weeks after beginning fruit harvest.

| Treatment | Fitted formula | $R^2$ | Inflection time (wk) | Maximum weekly yield increment | Upper limit of marketable yield |
|-----------|----------------|-------|----------------------|-------------------------------|--------------------------------|
| OF        | $Y = \frac{0.15}{1+e^{-\frac{X-1.8}{0.04}}}$ | 0.994*** | 1.8                  | 0.04                          | 0.15 (0.15)                  |
| HT        | $Y = 1.72e^{-7.07e^{-0.28X}}$ | 0.996*** | 7.0                  | 0.18                          | 1.72 (1.69)                  |
| HTN       | $Y = 2.28e^{-6.53e^{-0.28X}}$ | 0.998*** | 7.2                  | 0.22                          | 2.28 (2.14)                  |

| Treatment | Fitted formula | $R^2$ | Marketable fruit number (no./plant) |
|-----------|----------------|-------|------------------------------------|
| OF        | $Y = \frac{1.97}{1+e^{-\frac{X-1.97}{0.47}}}$ | 0.998*** | 1.97 (1.97)                        |
| HT        | $Y = 14.77e^{-5.33e^{-0.28X}}$ | 0.991*** | 8.3 (10.09)                        |
| HTN       | $Y = 19.12e^{-5.12e^{-0.28X}}$ | 0.996*** | 8.6 (13.5)                         |

OF = open field; HT = high tunnel; HTN = high tunnel with anti-insect netting.

*Data are means ± se. Bars bearing the same letter are not significantly different at $P \leq 0.05$ according to Duncan’s new multiple range test.

**Regression analysis was performed, and the results demonstrated a positive relationship between fruit size and positive yield increment.**

Table 4. Some quality attributes of individual fruit harvested from bitter melon plants in different cultivation systems.

| Parameters | OF | HT  | HTN |
|------------|----|-----|-----|
| Fruit weight (g) | 72.2 ± 2.1 c | 128.9 ± 3.1 a | 136.8 ± 1.5 a |
| Fruit length (mm) | 15.2 ± 0.0 b | 18.1 ± 0.2 a | 19.0 ± 0.2 a |
| Fruit diameter (mm) | 32.2 ± 0.5 b | 39.0 ± 0.1 a | 40.3 ± 0.4 a |
| Flesh thickness (mm) | 8.4 ± 0.1 b | 10.1 ± 0.2 a | 9.5 ± 0.2 a |
| Dry matter content (%) | 6.6 ± 0.1 a | 6.9 ± 0.3 a | 6.9 ± 0.2 a |
| Water content (g·kg⁻¹ dry weight) | 14.3 ± 0.2 a | 13.8 ± 0.5 a | 13.7 ± 0.4 a |
| Postharvest water loss (%) | 13.2 ± 0.6 a | 9.3 ± 0.3 b | 10.4 ± 0.4 b |

OF = open field; HT = high tunnel; HTN = high tunnel with anti-insect netting.

*Data are means ± se. Values in the same row followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan’s new multiple range test.

While HT structures offer warmer environments and physical protection, it should be noted that HTs, by themselves, are not effective in providing adequate frost protection (Ogden and Van Iersel, 2009). This was also demonstrated in the present study, where the recent transplants in the HTs survived the frost ($-3^\circ$C) in late May only when covered with plastic mulching film temporarily on the frost nights, but much more robust plants were completely killed by a similar frost.
Insect netting on the HTs increased marketable effective pollination strategy. Of organic bitter melons when combined with an increased, since the upper limit of marketable protection, fruit yields may have been further during early stages of tall crops. Had thermal rowcovers can only be used for short crops or effective for frost protection in HTs (Both and thermal curtains have been shown to be ing vines. Some measures such as rowcovers due to the difficulty in covering large, climb-ing vines. One additional frost protection was not possible, and its fruit yield is highly influenced by the number of successfully pollinated female flowers (Morgan and Midmore, 2002; Palada and Chang, 2003). In this study, the anti-insect netting may negatively affect insect pollination, and thereby reduce fruit yield from crops therein. This is particularly important in crops such as bitter melon, since it is monoecious (i.e., with male and female flowers growing separately on the same plant) and its fruit yield is highly influenced by the number of successfully pollinated female flowers (Morgan and Midmore, 2002; Palada and Chang, 2003). It is worth noting that the use of anti-insect netting for HTs may negatively affect insect pollination, and thereby reduce fruit yield from crops therein. This is particularly important in crops such as bitter melon, since it is monoecious (i.e., with male and female flowers growing separately on the same plant) and its fruit yield is highly influenced by the number of successfully pollinated female flowers (Morgan and Midmore, 2002; Palada and Chang, 2003). The seasonal ambient environmental conditions during this trial (from May to Octo-ber) were generally representative of the typical climate in southern Ontario. From the trial results, it can be concluded that while field production of bitter melon is not feas-ible, it is possible to use HTs for organic production of bitter melon in southern Ontario and in regions with similar climates. The addition of anti-insect netting to HTs can further benefit bitter melon production, provided adequate consideration is given to an effective pollination strategy.

**Table 5. Correlations of plant growth attributes with marketable fruit yield (number and weight), and fruit quality traits of bitter melon.**

| Plant growth attributes | Yield and quality attributes |
|-------------------------|-----------------------------|
|                        | ADW (g) | LVD (mm) | LVL (m) | LVN (no.) |
| MFN (no/plant)         | 0.90**  | 0.92**   | 0.98**  | 0.99**    |
| MFW (kg/plant)         | 0.91**  | 0.92**   | 0.97**  | 0.99**    |
| FW (g)                 | 0.87**  | 0.92**   | 0.98**  | 0.99**    |
| FL (cm)                | 0.87**  | 0.92**   | 0.97**  | 0.99**    |
| FD (mm)                | 0.82*   | 0.90**   | 0.96**  | 0.98**    |
| FT (mm)                | 0.82*   | 0.91***  | 0.95**  | 0.90**    |

*Data are expressed as correlation coefficient (r) values.
**Correlations significant at P ≤ 0.05 or 0.01, respectively.

**Table 6. Cumulative growing degree days and days with daily mean temperature in the range of the referenced temperature, from transplanting until the end of production for different cultivation systems.**

| Treatment | Before 8 WAT | After 8 WAT |
|-----------|--------------|-------------|
|           | CGDD Days above 18°C | CGDD Days between 20 and 30°C |
| OF        | 520          | 610         | 20 (25) |
| HT        | 532          | 904         | 41 (39) |
| HTN       | 604          | 1036        | 54 (51) |

OF = open field; HT = high tunnel; HTN = high tunnel with anti-insect netting; CGDD = cumulative growing degree days, calculated using 10°C as the base temperature; WAT = weeks after transplanting.

**Fig. 7.** (A) Numbers of trapped insects and (B) disease incidence in bitter melon plants under different cultivation systems. The insect numbers per trap in each plot are cumulative values over a 7-week collection period. Disease outbreak occurred in late June in OF, and in early October in HT and HTN. Data are means ± SE. Bars bearing the same letter are not significantly different at P = 0.05 according to Duncan’s new multiple range test. OF = open field; HT = high tunnel; HTN = high tunnel with anti-insect netting.

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