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SUITABILITY OF GREENHOUSE BUILDING TYPES AND ROOF COVER MATERIALS FOR GROWTH OF EXPORT TOMATOES IN THE BESOR REGION OF ISRAEL. II. EFFECT ON FRESH AND DRY MATTER PRODUCTION*

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DAYAN E., ENOCH H. Z., FUCHS M. and ZIPORI I. *Suitability of greenhouse building types and roof cover materials for growth of export tomatoes in the Besor region of Israel. II. Effect on fresh and dry matter production.* BIOTRONICS **15**, 71–79, 1986. The suitability of various building types and roof cover materials for growth of export tomatoes was tested at the Besor Experiment Station in the western Negev of Israel. The buildings studied were of the Dutch Venlo and Israeli Sharsheret types. The roof-cover materials tested were glass, polyethylene (P.E.), fiberglass (F.G.) and polycarbonate (P.C.). The climatic conditions created in the P.E.-covered building caused fruit deformation and a decrease in quality, probably because of the low night temperatures compared with the other buildings. The conditions in the P.C.-covered building caused a decrease in fruit yield and quality, especially when production was at its highest rate in the other buildings. The low yields were probably due to the lower radiation levels under this cover. The Sharsheret greenhouse with a glass-covered roof seemed to be the most suitable for tomatoes, although the other constructions tested may be used as well. The type of building and the roof cover materials should be selected according to economic considerations.

Key words: *Licopersicon esculentum* Mill.; tomato; greenhouses; covering materials; microclimate; radiation; air temperature; growth; development; photosynthesis.

INTRODUCTION

In the Besor region (western Negev of Israel), hundreds of unheated greenhouses have been erected during the last decade, for winter vegetable production, mainly of export tomatoes. The large investments involved will be economically

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profitable only if high yields of very good quality are obtained (*7*).

Production of high yields of good quality tomatoes is influenced by climatic factors such as temperature, relative humidity and solar radiation levels (*1*). These factors influence vegetative growth, fruit setting and development, and fruit quality (*11*). The climatic conditions in the above mentioned greenhouses are determined by the climatic conditions outside, by the type of building and by the cover material used.

The difficulties encountered in obtaining high yields of good quality have led to the testing of different buildings and roof cover materials. This paper presents findings on tomato plant performance in relation to the climatic conditions created under different constructions and roof cover materials.

MATERIAL AND METHODS

The experiment was carried out at the Besor Experiment Station (western Negev, Israel) during the growing season of 1979 to 1980. Tomato plants (*Lycopersicon esculentum* Mill. cv. 'Angela') were grown in a Dutch "Venlo"-type greenhouse (all glass) and in greenhouses of the Israeli "Sharsheret" type, all with polyethylene side-walls, but each with a different roof-cover material: glass, polyethylene (P.E., double layer, ultra-violet resistant), corrugated fiberglass plates, and polycarbonate (P.C., tabular, 6 mm thick Cualex). The area of each greenhouse was about 600 m^2.

Seeds were sown in a nursery on Sep. 15, '79 and transplanted into the greenhouses on Oct. 21 '79. Planting was in pairs of rows directed north-south, three plants per square meter. Water and fertilizer were applied via a trickle irrigation system. The timing of irrigation was determined by tensiometers: whenever soil water tension reached 14–15 cbar, water was supplied to reduce it to 7–8 cbar. All other agrotechnical treatments were according to the regional field advisory service recommendations.

The common ventilation regime recommended for commercial greenhouses in the region is to open the vents during the day and to close them toward nightfall. No heating is applied. The same regime was applied to the experimental greenhouses, apart from extreme cases such as days with very low temperatures, when the vents were kept closed also during part of the day.

Fresh and dry matter accumulation in different plant organs was measured once a month, in each greenhouse. Three plants from each greenhouse were cut and separated into stem, leaves, trusses and fruits. Fresh weight was determined immediately, and dry weight—after drying at 65°C for 72 h. Other parameters measured were leaf area, flowering dates of trusses no. 3, 6 and 9, ripening time (from anthesis to colour change) and photosynthesis rates, using the method described by Lake (*8*) and Dayan *et al.* (*5*).

Fresh fruit yields were determined by weekly harvests of the fruit reaching the proper colour from 42 plants in each greenhouse. Fruits were classified as marketable or non-marketable, and sorted according to size: small (less than 30 mm diameter), medium (30–45 mm), large (45–60 mm) and extra large (more than 60 mm).

RESULTS

The data on the relative morphological and physiological development of the plants in the different greenhouses are presented in Tables 1, 2 and 3. The basis for the calculations of relative values was data collected from the glass-covered Sharsheret greenhouse used as a reference (control).

Fresh and dry matter production in vegetative plant parts (leaves and stems) is presented in Table 1 together with growth rates, stem elongation rate, leaf area development and specific leaf weight. In most greenhouses the vegetative growth was lower than in the control. Most measured parameters indicate that growth was lowest under the P.E. and the P.C. roof-covers.

The differences in growth and elongation rates of the plants in the different greenhouses were especially large in January–February (Fig. 1). In the plants grown under a P.E. roof, dry matter content was higher, so that the differences between this greenhouse and the control are relatively smaller when compared on

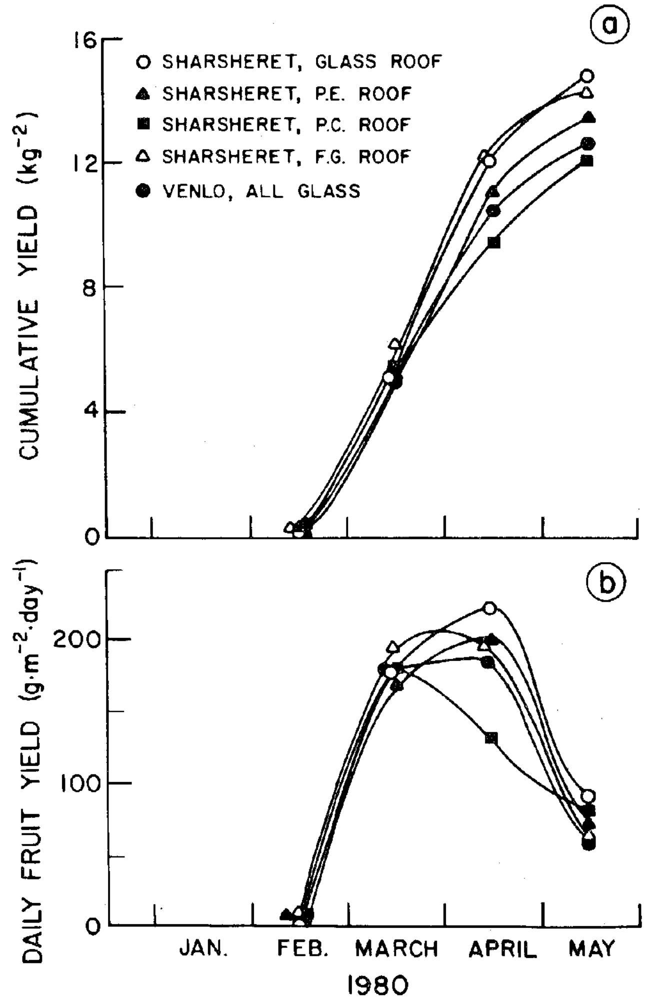

Fig. 1. Cumulative fresh fruit yields in the different greenhouses (a) and fresh fruit production rates in the different greenhouses (b).

the basis of total dry matter production than when compared on the basis of fresh matter. In the P.E.-covered greenhouse the specific leaf area was low compared with the other greenhouses (Table 1).

In January–February there was a decrease in vegetative growth in all greenhouses. During this period the amount of fruit on the plants was at its maximum, as only a small part of the fruits had ripened and been picked by then.

Photosynthesis rates in all greenhouses are presented in Table 2. Lowest rates were measured in the P.E.- and the P.C.-covered greenhouses.

The duration of the fruit development period on trusses 3, 6 and 9 is presented in Table 3. The relative values are calculated as well. The average number of days to flowering of the second flower on each truss was greater in all the test greenhouses than in the control. The difference was large especially during the winter (trusses 3–6). On the other hand, fruit development periods in all the greenhouses were essentially the same and were not influenced by the building type, except for a decrease in the P.E.-covered greenhouse at the beginning of the season and a slight increase in the second half of the season. As the season progressed, the time lapse between the appearance of two successive trusses was longer, but the ripening period was shorter.

Table 1. Relative weights, accumulation rates, stem elongation and leaf area of tomatoes in the different greenhouses, compared with the values measured in the glass-covered greenhouse (control). The numbers indicate the slope of the linear regression line; in parenthesis, R^2

Results from:	Venlo	F.G.	P.C.	P.E.	Glass
Vegetative fresh yield	0.91 (0.88)	0.92 (0.92)	0.88 (0.99)	0.80 (0.94)	1.0
Vegetative dry yield	1.0 (0.98)	0.98 (0.96)	0.89 (0.98)	0.88 (0.99)	1.0
Daily accumulation rate, fresh yield*	0.89 (0.74)	0.75 (0.12)	0.86 (0.85)	0.61 (0.28)	1.0
Daily accumulation rate, dry yield*	0.98 (0.82)	0.82 (0.37)	0.83 (0.51)	0.78 (0.55)	1.0
Stem elongation rate**	0.85	1.08	0.79	0.79	1.0
Leaf area***	1.0 (0.98)	0.78 (0.87)	0.84 (0.91)	0.69 (0.73)	1.0
Specific leaf weight***	0.96 (0.88)	0.93 (0.92)	1.0 (0.78)	0.90 (0.88)	1.0

* December–March measurements, ** January–February measurements.
*** Whole-season measurements.

Table 2. Coefficients of the linear regression equations describing the photosynthesis rates in the different greenhouses, measured at midday in March 1980, when global radiation levels were 400–700 W m^{-2}

	Greenhouse type				
	Venlo	F.G. roof	P.C. roof	P.E. roof	Glass roof
Photosynthesis rate g CO_2 m^{-2} h^{-1}	1.66	1.75	1.16	1.44	1.52
R^2	0.82	0.75	0.81	0.75	0.78
Compared with a glass-covered greenhouse	1.09	1.15	0.76	0.95	1.00

Table 3. Duration of flower development and fruit-ripening periods in the different greenhouses, absolute and relative values, compared with the control (a Sharsheret-type greenhouse with glass roof, Gl.)

	Duration of period (days)					Relative values				
	Venlo	F.G.	P.C.	P.E.	Gl.	Venlo	F.G.	P.C.	P.E.	Gl.
a. Truss appearance										
From sowing to truss #3	64	64	64	64	64	1.00	1.00	1.00	1.00	1.00
From truss #3 to truss #6	28	29	29	32	26	1.08	1.12	1.12	1.23	1.00
From truss #6 to truss #9	38	36	39	43	36	1.06	1.00	1.08	1.19	1.00
b. Fruit ripening										
From flowering to ripening of truss #3	83.5	87.5	88.1	101.0	86.0	0.90	1.02	1.02	1.17	1.00
From flowering to ripening of truss #6	75.8	73.3	74.7	70.4	76.1	1.00	0.96	0.88	0.93	1.00
From flowering to ripening of truss #9	57.6	59.2	56.6	57.7	58.1	0.99	1.02	0.97	0.99	1.00

Table 4. Some parameters of fruit quality as measured in the different greenhouses. In parentheses, the relative values, compared with the control (a Sharsheret type greenhouse with glass roof)

Type of greenhouse	Uniform color (%)	Hollow fruit (%)	Regular fruit (%)	Marketable fruit (%)	60 mm diameter (%)
Glass roof	45 (1)	28 (1)	70 (1)	61 (1)	82 (1)
P.E. roof	38 (0.84)	33 (0.93)	47 (0.67)	69 (1.19)	82 (1)
P.C. roof	39 (0.86)	35 (0.90)	58 (0.82)	63 (1.03)	80 (0.97)
F.G. roof	40 (0.88)	26 (1.02)	72 (1.02)	61 (1.0)	69 (0.84)
Venlo	48 (1.06)	25 (0.89)	75 (1.07)	65 (1.08)	72 (0.87)

Cumulative fresh yields in the different greenhouses are presented in Fig. 1a, and daily yields in Fig. 1b. According to these data, the fruit production season can be divided into three periods: January–February, in which the fruit production rate is slow but increases; March–April, with a maximum production rate; and May, when the fruit production rate decreases.

The differences between buildings can be observed best during the March–April period, i.e., when the production rate was at its maximum. The P.C.-covered greenhouse had the lowest yields and the control greenhouse the highest. Maximum production rate in the P.E.-covered greenhouse was reached late in comparison with the others.

Some parameters of fruit quality are presented in Table 4. Fruit quality was higher in the control greenhouse than in the others throughout most of the season. Fruit from the P.E.-covered greenhouse was relatively larger, especially toward the end of the season. In all cases the percentage of "small" fruit and dry matter content increased toward the end of the season. Fruit dry matter content in the P.E.-covered greenhouse was highest during most of the season but fruit from this greenhouse was usually more deformed in shape and had irregular coloration compared with the other greenhouses. The fruit from the P.C.-covered greenhouse had a typical angular shape, also with irregular coloration.

Fruit quality increased in all cases with time, from 40–55% marketable fruit in March to 70–90% in May. There were indications that leaf fungal diseases and fruit damage were strongest in the P.E.-covered greenhouse.

DISCUSSION

Using different materials as roof-covers, or using different types of buildings, caused morphological and physiological differences among the plants. Most of these differences can be explained by the differences in microclimatic conditions among the greenhouses. These microclimatic conditions can influence photosynthesis, growth rates and plant development as well as the distribution of photosynthates between plant organs, fruit setting, fruit development rate and quality.

In the P.E.-covered greenhouse, low night temperatures are expected, due to the penetrability of this material to long-wave radiation. Low night temperatures may reduce the growth respiration of the plants and hence explain the observed decrease in growth rates as expressed in slower fresh matter accumulation—especially in the vegetative organs, stem elongation and leaf area growth (Table 1).

Low night temperatures may also explain the observed slow rate of development of the vegetative parts under the P.E.-covered greenhouse (Table 1). The appearance-rate of trusses depends on the rate of growth of vegetative parts and therefore decreases as well (Table 3). Low temperatures may have also caused the lower ripening rate of fruit (Table 3b). Low temperatures, especially around the flowers, may damage the ovaries (*10*) and therefore account for the appearance of deformed fruit during the cold period (Table 4). The minimum temperatures measured in the P.E.-covered greenhouse were only slightly lower than those measured in the other buildings (*2*), and cannot account for the morphological and physiological phenomena observed in this greenhouse. However, as mentioned before, the greenhouses were not heated during the night and thus the temperature inside depended strongly on the thermal isolation properties of the building. Eventually, the temperature inside the greenhouses reached values close to those measured outdoors. The outgoing infrared radiation from the greenhouse penetrated the polyethylene used as a roof-cover more easily than the other roof covers, and thus the plants in the P.E.-covered greenhouse were exposed to low temperatures for longer periods in the night (*2*).

Another aspect of the effect of temperature on plant and fruit development and growth is seen in the Venlo-type greenhouse. At both ends of the season, day temperature in this greenhouse was higher than in the other buildings (*2*). An increase in temperature brings about also an increase in maintenance respiration (*6*). A low LAI at the beginning of the season, combined with the occurrence of high temperatures, may have caused a shortage of carbohydrate supply to the plants and therefore restricted their growth (Table 1). The large amounts of dry matter present toward the end of the season may have caused high maintenance respiration rates (*6*). The high temperatures prevailing then increased these rates and thus caused again an insufficient carbohydrate supply, expressed especially in fruit size (Fig. 1).

Low growth and fruit production rates were observed also in the P.C.-covered greenhouse, mainly in mid-season (Fig. 1). Night temperatures in this greenhouse were higher than in the other buildings, on the other hand, radiation levels were lower than in the others (*2*). The effect of low radiation can also be seen in the relatively low photosynthesis rates measured in this greenhouse (Table 2). The relative retardation in growth, flowering and ripening rates, characterizing plants grown in the P.C.-covered greenhouse can be explained mainly by a lack of photosynthates caused by the low radiation levels and the high night temperatures. The retardation probably caused the considerable decrease in fruit yields produced in this greenhouse. The amount of photosynthates is a limiting factor in fruit production, especially in winter, when days are short and radiation is low (*4*, *9*, *10*). For the same reason, the amount of fruit set in February and harvested in April is small.

Radiation levels in Israel in the first part of the season (September–October) and at the end (March–May) are high and thus do not seem to be the limiting factor for photosynthesis in greenhouses (*5*). A low LAI at the beginning of the season, or low canopy efficiency for photosynthesis and high maintenance respiration toward the end, prevailed in all greenhouses. The effect of radiation was less pronounced in these parts of the season and the differences between the P.C.-covered greenhouse and the other buildings were limited.

Radiation levels inside the P.E.-covered greenhouse were similar to those in the glass-covered one (*2*). However, photosynthesis rates measured in the P.E.-covered greenhouse were slightly lower than those measured in the control (Table 2). This difference was probably caused by the differences in LAI between the two greenhouses rather than by radiation level (Table 1).

It is assumed that the temperature-dependent growth processes were held back in the P.E.-covered greenhouse more than were the radiation-dependent dry matter production rates. This can explain the relatively high dry matter content of the plants in the P.E.-covered greenhouse. When growth rates in the two different houses are compared on a dry matter basis, differences are relatively small whereas they are large when the comparison is done on a fresh matter basis (Table 1).

Greenhouses covered with polyethylene or polycarbonate seem to be less suitable for high quality tomato production than is a glass-covered building: the P.E.-covered greenhouse due to the low indoor night temperatures, and the P.C.-covered one because of the low radiation levels.

It can be assumed that other roof covers, which create similar conditions in the greenhouse, will cause a similar response. The transparency of fiberglass, for example, decreases with the years, although during the present experiment plant performance in the F.G.-covered greenhouse was similar to that in the glass-covered one.

The choice of growing tomatoes under a given roof-cover material seems to be an economic issue. It is possible to grow tomatoes under each of the materials tested in this work, and maybe also others. If too low temperatures occur, losses will be caused mainly through low quality and late ripening. If radiation levels are low, losses will be mainly due to lower yields produced. The expected losses can be evaluated economically. It might be profitable to produce a little less, but to save on expenses significantly. It might also be possible to solve the problems faced in other ways, e.g. events of low temperatures can be treated by heating or by using plant varieties adapted to cold; low radiation levels can be treated by CO_2 enrichment during those parts of the season in which assimilates become the limiting factor, or by locating the greenhouses on southwestern slopes, etc.

In this work it was shown that although climatic differences among greenhouses or under the covering materials may cause most of the physiological and morphological differences that were noticed, it is still easier to determine the overall suitability of greenhouses or covering materials according to the physiological and morphological differences among the plants, than to the usual physical parameters such as temperature and radiation. The reasons for this are that either there is no major known measured physical parameter which is of importance, or there are only extreme events, which hardly affect the averages of the physical parameters, but which are the most significant in long-term morphological and physiological processes within the plant. It is also possible that there is not only one detectable physical condition but a complex of one or more conditions during the sensitive periods of the plant's life and which are responsible for the long-term effect.

The suitability of certain buildings or cover-materials, as well as of other agrotechniques, cannot be determined without knowing the seasonally changeable physiological properties of the plant and the goals of the farmers.

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