Temperatures and Net Heat Gain in Normal and Whitewashed Cantaloupe Fruits[1]

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Abstract. A method is presented to calculate net heat gain per unit time (G) for normal (N) and for whitewashed (W) cantaloupe fruits (*Cucumis melo,* L., var. *reticulatus* Naud.) exposed to direct solar radiation. Calculations of G were based on pulp temp. G of the W fruits averaged 80% of that for the N fruits during warming. Values of G can aid in evaluating the effectiveness of radiation-reflective materials that protect cantaloupe fruits from sunburn, a major cause of culls and market quality losses. Maximum pulp temp about 1 mm below the surface reached 49°C for the N and 42° for the W fruit. Maximum ambient air temp was 43°C.

The feasibility of calculating net heat gain per unit of time (G), based on measured temp, has been demonstrated in a growing mature head of lettuce (3). The same technique might be useful for cantaloupe fruits, because quantitative comparisons can be more meaningful in terms of G (cal g^{-1} hr^{-1}) than in terms of temp alone for comparison of different environments, or modifications in the environment resulting from whitewashing (4).

Material and Methods

Treatment of melons and measurements. Cantaloupes for this study (*Cucumis melo,* L., var. *reticulatus* Naud., 'Top Mark') were grown in a field located about 35 miles SW of Fresno, Calif. Test fruits were fully exposed to solar radiation while still attached to their respective vines. One fruit of a pair remained untreated (N), whereas the top half of the other one (W) was whitewashed either by brushing on a thin paste (1969) of aluminum silicate or by spraying on (1971) a suspension of the material (1-1/2 lb./gal water). The spray also contained adjuvant S-22[4] at 20 ml/gal water.

Pulp temp were measured at 1/2-hr intervals between 08:15[5] and 16:15 on July 24, 1969 and between 08:45 and 14:45 PST on July 17, 1971, 8 to 12 days before harvest. Wind was less than 5 mph during both periods. Readings were taken at 7

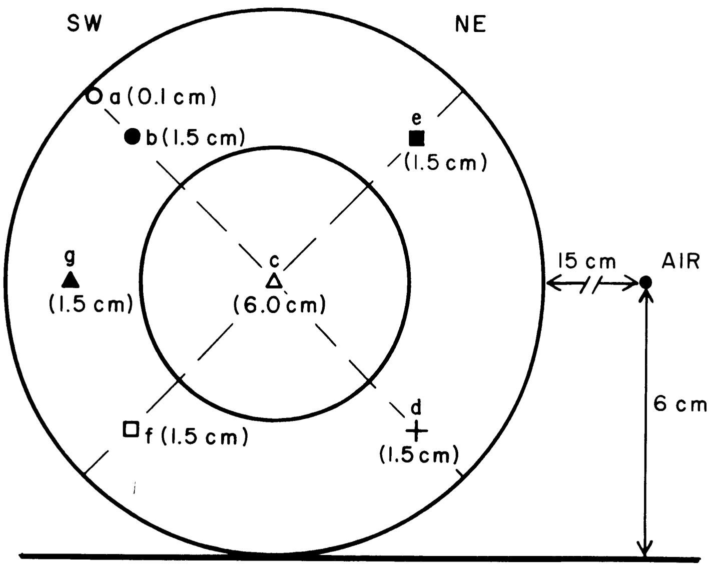

Fig. 1. Schematic cross-section of cantaloupe fruit viewed from SE direction, indicating locations of thermocouple junctions. Distances given are those from the periphery of the fruit to the thermocouple junctions. SW and NE refer to points on the compass. External distances are not drawn to scale. Horizontal line is ground level.

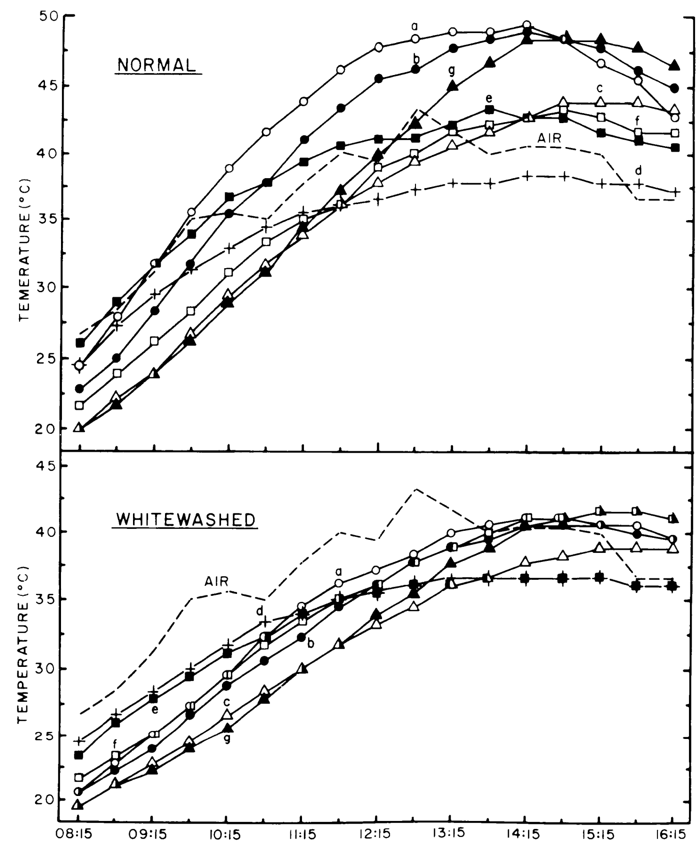

Fig. 2. Temperatures recorded at various locations in a normal and a whitewashed cantaloupe fruit exposed to solar radiation. Letters next to curves refer to location indicated in Fig. 1. Air temp was measured 6 cm above soil surface.

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[3]I appreciate the cooperation of K. Tyler and D. May, Univ. Calif. Agr. Ext. Serv., who provided the melons and of the Wilbur-Ellis Co., Fresno, who furnished the whitewash material and adjuvant.

[4]Mention of a specific commercial product does not imply endoresement by the U. S. Department of Agriculture.

[5]24-hr time was used for time of day.

Table 1. Calculated mean temp of normal and whitewashed cantaloupe fruits at hourly intervals, July 24, 1969.

	Time (PST)								
	08:15	09:15	10:15	11:15	12:15	13:15	14:15	15:15	16:15
Fruit surface	Mean temp (°C)								
Normal	23.1	28.0	33.5	36.5	40.1	42.3	43.5	42.9	41.1
Whitewashed	22.2	25.9	29.6	32.7	35.2	37.2	38.3	38.7	38.1

locations in each melon (Fig. 1) in 1969 but in 1971 only at 2 points (Fig. 3). The locations 1.5 cm from the surface were about in the middle of the flesh. Iron-constantan thermocouples used in fruits or in air had diam of 0.7 mm and 0.4 mm, respectively. The thermocouple at location "a" (Fig. 1) was inserted parallel to the surface, with the junction about 5 mm from the puncture and about 1 mm below the surface. Specific heat was taken as 0.94 cal g^{-1} $^{\circ}C^{-1}$ (5).

Air temp was measured 6 cm above the soil, about level with the middle of the fruits and about 15 cm to the side. The thermocouple was not shaded, which may have produced an error of about 2°C in the readings (1).

Detailed results are given only for the fruits tested in 1969 because those used in 1971 yielded nearly identical results.

Calculations. Calculations of net heat gain per unit of time (G), as adapted from Sellers' (7) equation 3.11, were identical to those for lettuce (3), except that for cantaloupe fruits, G is expressed per unit of wt rather than vol. This exception applies to G for each entire fruit or for 2 hypothetical cubes that are representative of an entire structure (3).

The equation for the entire fruit is:

$$G = c\,(\Delta\bar{T}\,\Delta t^{-1}) \quad \text{cal } g^{-1}\ hr^{-1} \qquad \text{(I)}$$

where c = specific heat of cantaloupe fruits in cal g^{-1} $^{\circ}C^{-1}$, $\Delta\bar{T}$ = change in mean temp of the fruit in °C during time interval Δt in hr.

For the cubes, the quation is:

$$G = c\,(\Delta T\,\Delta t^{-1}) \quad \text{cal } g^{-1}\ hr^{-1} \qquad \text{(II)}$$

where ΔT is the change in temp at the center of the appropriate cube during Δt. The probable error inherent in these determinations was discussed previously (3).

Results

Pulp temperatures. Pulp temp were higher and had a wider range in the N fruit than in the W fruit (Fig. 2). When similar

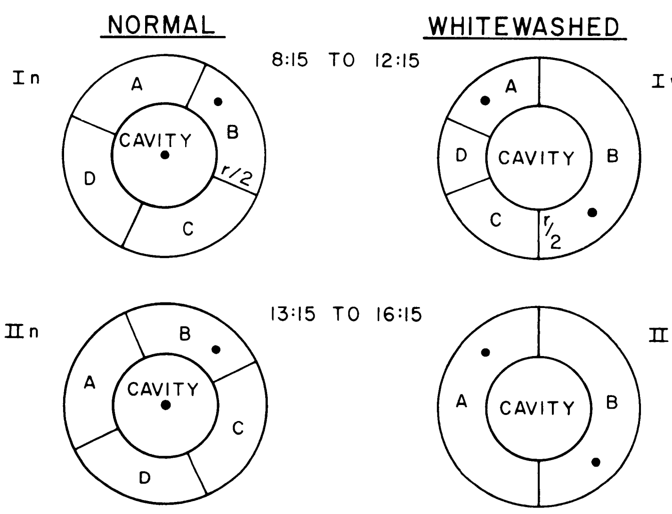

Fig. 3. Patterns for the hypothetical vol used to calculate the mean temp and from them mean G of a normal or a whitewashed cantaloupe fruit from 08:15 to 12:15 and from 13:15 to 16:15. Dots indicate the centers of hypothetical cubes used to calculate G from temp measured at only 2 locations (r = radius).

positions (b, Fig. 1) are compared, the moderating effect of the whitewash (about 10°C) was nearly identical to that for a natural cover of leaves (6).

Whitewashing, like a cover of leaves (6), held fruit temp below that of the air most of the time; in contrast, the N fruit warmed to well above the air (Fig. 2).

Mean temperature of fruits. Differences among pulp temp at any one time necessitated calculating a mean temp ($\bar{T}$) for each fruit to determine G. $\bar{T}$ was calculated from means of hypothetical vol (Fig. 3) of fairly uniform temp and each of

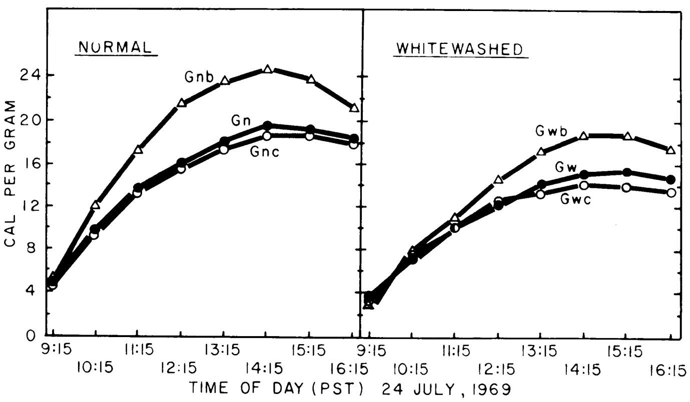

Fig. 4. Cumulative net heat gain (cal g^{-1}) in a normal and a whitewashed cantaloupe fruit. Gn or Gw– for entire fruit based on 6 thermocouple locations; Gnc or Gwc–for entire fruit based on 2 locations only (see Fig. 3); Gnb or Gwb–for location b in Fig. 1.

which contained at least 1 thermocouple. Location "a" was omitted because it represents only a small portion of each fruit. The lengthy formulas for calculating the mean temp for each vol have been omitted (furnished on request). Before means of the hypothetical volumes were combined to determine $\bar{T}$ (Table 1). each was weighted by the fraction by which the corresponding vol contributed to the total vol of the fruit.

Net heat gain of fruits. Net heat gain for the normal (Gn) or for the whitewashed (Gw) fruit was calculated from the appropriate $\bar{T}$ by formula I. As expected, Gn substantially exceeded Gw while the fruits warmed up (Table 2). Later, the N fruit cooled more rapidly (-Gn values) than the W fruit.

Net heat gain for cubes. Calculating $\bar{T}$ as a basis for determining G is cumbersome. Consequently, 2 thermocouple locations in each fruit were chosen by trial and error so that their mean would diverge minimally from the mean based on 6 locations. Locations c and e met the above criterion for the N fruit and b and d for the W fruit (Fig. 1). Each thermocouple junction was considered to represent a cube weighing 1 g. G for each cube was then calculated by equation II. Values presented (Table 2) are means for the 2 cubes each in the normal (Gnc) and whitewashed (Gwc) fruits, Gwc as percent of Gnc, and percent divergence between G values based on 6 locations and those based on only 2.

Mean divergence between Gn and Gnc or between Gw and Gwc was 6.3% and 10.3%, respectively, while the fruits warmed up (until 14:00, Table 2). The divergences were greater during cooling.

Mean G of the W fruit during warming was about 80% that of

Table 2. Net heat gain of a normal (Gn) and a whitewashed (Gw) cantaloupe fruit based on the calculated mean temp of entire fruits or based on temp of 2 hypothetical cubes in each fruit (Gnc and Gwc)[z]; divergence of the differently based values; Gw as percent of Gn, and Gwc as percent of Gnc, all at 1-hr intervals, July 24, 1969.

Fruit surface	Energy term and units	Net heat gain of melons at indicated time interval (PST)[y]							
		8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16
Normal									
	Gn--cal g^{-1} hr^{-1} x 10^2	460	520	350	260	210	150	-20	-110
	Gnc--cal $g^{-1}$$hr^{-1}$ x 10^2	450	490	340	260	180	130	0	-70
	Divergence--Gn-Gnc as % of Gn	2	6	3	0	14	13	--[x]	36
Whitewashed									
	Gw--cal g^{-1} hr^{-1} x 10^2	350	350	290	230	190	100	40	-60
	Gwc--cal $g^{-1}$$hr^{-1}$ x 10^2	340	390	260	260	180	80	0	-80
	Divergence--Gw-Gwc as % of Gw	3	-11	10	-13	5	20	--[x]	-33
Gw as % of Gn		76	67	83	88	90	67	-200	54
Gwc as % of Gnc		75	80	76	100	100	61	100	114

[z]Gnc is based on temp measured at locations c and e in the normal fruit, and Gwc is based on temp measured at locations b and d in the whitewashed fruit (Fig. 1).

[y]Actual times were 15 min after hr.

[x]Any difference, no matter how small, would yield a 100% divergence, and would therefore, be meaningless.

the N fruit whether based on 6 or on 2 locations. However, hourly values (Table 2) substantially varied from 80%. The same means and variations were obtained in 1971, when only 2 locations (Fig. 3) were used.

Cumulative net heat gain. Curves for cumulative G (Fig. 4) most clearly illustrate the faster heating of the N than of the W fruit, and show that 1 curve can express all the energy changes that occurred during a given period. Such a curve is a summation of the measured temp changes for the entire fruit, expressed in calories. However, the protective value of the whitewash is shown most strikingly in a comparison of curves for locations b (Gnb and Gwb). Gwb ranged from 60% of Gnb early in the day to 76% at about 14:15.

Discussion and Conclusions

G can be calculated for a dense fruit, like a cantaloupe, just as for a head of lettuce (3). Temperatures from 2 properly chosen locations in cantaloupe fruits give nearly the same values of G during warming as those based on more locations. For nearly mature fruits of avg size exposed to solar radiation, without whitewashing, one thermocouple at the center of the fruit and another about halfway (1.5 cm) into the flesh at the top, northeast side, are suitable locations. For whitewashed cantaloupe fruits, halfway into the flesh on the top southwest side and the lower northeast side seem best.

Calculations of G permit comparisons of the effectiveness of radiation-reflecting paints, or of other modifications in the radiant environment, in terms (cal g^{-1} hr^{-1}) that quantitatively can be compared more readily than a set of temp. The quantitative results may then be related to the incidence of sunburn and possibly to other radiation-induced defects that impair the market quality of cantaloupes and related muskmelons (4). Further, when results are given in terms of calories, the contribution of respiratory heat to G can be calculated by converting mg CO_2 produced to calories. Net energy changes can be determined by standard methods of meteorology, but such measurements are time-consuming and require much more elaborate instrumentation than the method described here. Although the former are more precise, calculations of G as presented here seem sufficiently precise for the purposes indicated.

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