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INTRODUCTION

Year-round temperatures at 3,000- to 4,000-foot elevation in Kula, Maui, closely approach optimum for production of high quality Sim type carnations. Outdoor acreage planted to this crop has grown steadily, with the bulk of the flowers shipped to Honolulu and Hilo for lei-making. For this purpose the fairly high incidence of calyx-splitting, caused by inability of the growers to exactly control temperature, has not been of any consequence. For the stem-flower grower, however, this problem has only been overcome by the labor-consuming process of banding each bud before the calyx opens.

Each year, especially in the winter and the spring months, spells of misty, rainy weather make it very difficult or even impossible for the grower to produce disease free blooms. At this time of the year lei heads commonly arrive in the market severely damaged by botytris petal rots. Blooms appear disease-free when picked but infection has already begun and conditions in the closed shipping container during transit are ideal for rapid invasion of the petals by the fungus. It is nigh impossible to hold lei heads in storage if they were exposed to rain or mist during the last days before picking. As the demand for leis is not uniform many growers need to store the flower heads under refrigeration to meet heavy advance orders. Well grown heads not exposed to rain can be satisfactorily stored for up to one month under ideal conditions.

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Petal disease problems could be largely solved by growing carnations under cover and a few growers tried to use plastic for this purpose prior to 1966. Also, calyx splitting can be controlled by enclosing the plants and controlling the air temperature with exhaust fans and cooling pads. Unfortunately all the materials tried prior to 1966 proved unsatisfactory, because of their short life and/or a rapid decrease in their light transmitting properties. In all cases performance fell short of that expected from similar materials in the warmer parts of the U.S. mainland, probably because of the higher year-round light intensity in the tropics, the exceptionally clear atmosphere over Maui, and the relatively high elevation of the carnation growing areas.

To meet the need for an evaluation of probable performance of plastics in Hawaii a collection of available materials was made and installed in 1966.

EXPERIMENTAL PROCEDURE

The test was installed at the Kula Experimental Farm, at 3,100-foot elevation, on a terrace running approximately North-South. The plastics were mounted on 4 x 8-foot frames constructed of 1 x 3-inch lumber, mounted 5 feet above the ground on posts. Each frame had two cross pieces of 1 x 2-inch lumber, at 32-inch centers, and a single piece down the center. The frames were mounted in sets of three, end to end, over a 24-foot plant bed running east to west, with a slope of 1 in 9 from north to south to facilitate shedding of rain. A 3-foot wide alley was left between beds, putting the beds on 7-foot centers.

The films were attached to the frames with T-50 staples applied with a gun-tacker at not greater than 6-inch centers. Nylon tape, ¾-inch wide, was laid over the line of attachment before tacking. One-inch wide tape was also laid between the frame and all of the Griffolyn films, as specified for these materials, before stapling.

Each plastic was mounted on two frames, with the treatments grouped into two replicates.

After installation, the beds under the plastics were planted half to Petersen's New Red Sim Carnation and half to Harvest Giant chrysanthemum. Only the plant crop of chrysanthemums was harvested. The number and weight of blooms was recorded. The carnations were harvested for one year after planting, number and grade of stem flowers being recorded.

Additionally, 4-inch wide strips of each plastic were mounted both horizontally and vertically so that samples could be taken at intervals to measure light transmittance, both with a Weston Master V, Model 748 light meter and a Beckman DU, Model 2400 spectrophotometer. Percent light transmittance in the visible range was calculated by directing the Weston meter at a white sheet in a room illuminated by diffused cloud light, adjusting the distance of the meter from the sheet until a steady reading of 100 foot candles was obtained, then placing a plastic sample directly over the sensor surface and taking the new reading. As the sample was applied close to the sensor the readings obtained were accurate measures of transmission of combined diffused and directly transmitted light.

Percent directly transmitted light was measured over the range 200-2,000 millimicrons through samples mounted on card frames, using the spectrophotometer. Measurements were made at the time of installation and at 6 months and 12 months after installation. All plastics were carefully washed with a sponge and detergent water before taking measurements. Samples were also stored in the dark so that unexposed and exposed samples could be compared together under identical meter and light conditions.

Note was made of the date plastics started to tear or break down and the date on which they blew out.

PLASTIC LONGEVITY

Plastic Films

Several plastics lasted less than one year. These, together with notes on individual performance prior to disintegration are recorded in Table 1.

Several plastic films lasted more than one year. Their condition after 12 months is recorded in Table 2.

Corrugated Plastics

Four corrugated plastics were included in the exposure test:

Clear fiberglass, "Denverlight 20"
Clear PVC, "Takiron"
White PVC, "Takiron"
Green PVC, "Takiron"

The fiberglass and clear PVC appeared in excellent condition after one year's exposure. Both the green and white PVC were in excellent condition except where they lay tightly against the wooden frame. Here they both had become brittle 10 months after installation. Also, the green plastic became white while the white plastic turned denser white.

Table 1. Performance of plastic films with less than one year's life expectancy

Material	Life (months)	Remarks
Polyethylene, 4 mil	4	Brittle after 3 months.
Visqueen, 4 mil	5	Brittle after 4 months.
PVC film, 3 mil	6-12	Remained pliable but broke away slowly at staple points. (Will blow out in 6 months unless installation is perfect.)
Griffolyn, Type 55, clear	6	Reinforcing threads lost tensile strength within 5 months and film became brittle.
Griffolyn, Type 92	5	Film plies started to separate within 4 months, especially along fold lines. Reinforcing threads and film both had very low tensile strength after 3½ months.
Mylar, 3 mil Mylar, 5 mil	4 7	Brittle after 4 months. Cracked between stapling points and rips resulted during wind.
Mirrophane, 3 mil	3	Upper ply disintegrated in 2 months and aluminum disappeared.

Table 2. Performance of plastic films with greater than one year's life expectancy

Material	Condition
PVC film, 4 mil	Ripped in several places and ready to blow out.
6 mil	Starting to tear at stapling points. Very dirty, cannot be cleaned.
10 mil	No sign of tearing. Very dirty, cannot be cleaned. Lower surface sticky, upper surface pitted.
14 mil	Same as 10 mil above.
16 mil	Same as 10 mil above.
20 mil	Same as 10 mil above.
Griffolyn, Type 91	Both film plies and reinforcing threads still have almost original tensile strength. Film plies have separated along all fold lines and the upper ply is cracking in the center of the separation. Film starting to rip at stapling points.
Amerex UV, green 8 mil	Still in excellent condition. Film surfaces still smooth–easy to wash off dirt. Very slight signs of tearing at stapling points.

LIGHT TRANSMITTANCE

Effect of exposure on total visible light transmittance

Presented in Table 3 is a summary of the visible light transmitted by the different plastics at the time of installation and 12 months after installation, following exposure in both horizontal and vertical positions. Total, direct and diffused visible light are reported. Percent total visible light transmittance was measured with the Weston meter, which actually gives an integrated reading for the approximate range 200-800 $m\mu$, with peak response at 550 $m\mu$ (1). Percent direct visible light transmittance was calculated for the range 400-700 $m\mu$ by integration of the readings taken at 50 $m\mu$ intervals on the Beckman DU, weighting the readings according to the relative response of the Weston photocell to the waveband in question. Diffused light was then calculated by difference. In interpreting the data it should be noted that the light source for the Weston meter readings was cloud light, which has peak intensity at 530 $m\mu$ (2), passed through glass. Different readings would be anticipated from direct sunlight, which increases almost linearly in intensity from 400 to 800 $m\mu$ (2). The differences would be slight for the plastics examined in this study, however, because each showed relatively constant percent transmittance over the range 400-800 $m\mu$.

Loss of transmittance was much greater where PVC films were mounted horizontally than when they were mounted vertically. The vertically mounted films did not develop surface pits or collect dirt and the pasticizer did not migrate through the film, as it did in the horizontally mounted film. The latter became tacky on the underside. The rate at which these PVC films picked up dirt was closely related to film thickness; the thicker the film the quicker it became dirty. This is possibly related to the fact that radiation absorption in the infra-red (700-2,000 $m\mu$) by this type of film is positively correlated with film thickness (see Table 4).

Both the clear and the white vertically mounted corrugated PVC lost 9 percent transmittance due to development of "cloudiness" in the material. The sheets had not picked up dirt. The same clear PVC mounted vertically in full sheets on an adjacent greenhouse did not become cloudy in the same period, neither did the full sheets set horizontally in this test. No explanation for this discrepancy between the performance of full sheets and 4 x 4-inch samples is evident. The green PVC mounted horizontally lost 23 percent transmittance, also due to development of "cloudiness", while the vertically mounted sample became slightly more transparent.

Amerex UV, green, showed a 4-percent decrease in light transmittance although there was no adhered dirt and the exposed and unexposed films seemed identical to the unaided eye.

Table 3. Percent visible light transmittance by various plastics before and after 12 months' exposure

Material	Percent transmittance							Percent loss	
	Before exposure			After exposure					
				Horizontal			Vertical	Horizontal	Vertical
	Total†	Direct††	Diffused	Total	Direct	Diffused	Total		
Visqueen	98	72	26	D			93	D	5
Amerex UV, green, 8 mil	55	26	29	53	23	30	53	4	4
Griffolyn, Type 55, clear	86	57	29	82	39	43	83	5	4
Type 91	88	61	27	88	55	33	88	0	0
Type 92	89	68	21	82	53	29	83	8	7
PVC film 3 mil	98	89	9	92	71	21	98	6	0
4 mil	98	89	9	84	47	37	98	14	0
6 mil	98	89	9	67	10	57	98	32	0
10 mil	98	89	9	66	7	59	96	33	2
14 mil	98	88	10	55	7	48	95	44	3
16 mil	98	88	10	66	8	58	96	33	2
20 mil	98	88	10	82	46	36	98	16	0
Corr. PVC, clear	89	67	22	88	46	42	82	1	9
white	75	17	58	73	10	63	68	3	9
green	76	11	65	62	5	57	78	23	0
Clear fiberglass	93	59	34	92	46	46	92	1	1
Mirrophane	40	15	25	D			96	D	0
Mylar 3 mil	98	90	8	98	84	14	98	0	0
5 mil	98	90	8	98	83	15	98	0	0

† Measured with Weston light meter.
†† Measured with Beckman DU spectrophotometer.
D Disintegrated before test.

Decrease in total visible light transmittance following exposure was almost invariably accompanied by an increase in diffused light. In several cases, e.g., clear fiberglass, the increase in the proportion of diffused light should offset expected plant growth reduction from the loss in total light transmittance because of the more even distribution of diffused than direct light through plants.

Effect of exposure on direct transmittance of infra-red wavelengths

Presented in Table 4 is a summary of the percent direct transmittance of the infra-red (700-2,000 $m\mu$) part of the spectrum by the various plastics at the time of installation and again 12 months later. These figures were calculated by plotting percent transmittance-wavelength curves for each plastic, from readings taken on the spectrophotometer. From the irradiance-wave number curves presented by Gates (2) the percent of the total energy of the waveband 700-2,000 $m\mu$ present within each 100 $m\mu$ increment was calculated for direct sunlight. The percent transmittance of the total energy of direct sunlight within the 700-2,000 $m\mu$ waveband was then calculated for each plastic by multiplying the corresponding waveband transmittances and percent energy together and summing the products. The figures in Table 4 therefore represent the expected percent direct transmittance of infra-red energy from direct sunlight.

For construction of open-sided saw-tooth greenhouse structures the extent to which the covering material transmits the infra-red, or heat, part of the incident sunlight was found to be relatively unimportant under local conditions. The heat flux at the plant surface is rapidly carried away by wind currents and convection. Temperatures were recorded with recording thermographs in standard weather shelters, within and on the windward side of a saw-tooth, 60 x 100-foot open-sided greenhouse (Bynum greenhouse, Makawao) throughout the summer of 1966. This structure was covered with corrugated clear PVC, from the same shipment used in the exposure tests reported in this bulletin. Temperature differences between inside and outside the greenhouse never exceeded 1°F. At the time the readings were made, the plastic was directly transmitting 30 percent of the incident infra-red waveband (see Table 4). For construction of "air-tight" pad-cooled greenhouses, however, the infra-red transmittance of the covering material would be a major consideration, especially if the house is to be used for raising crops such as spring bulbs, which generally require growing temperature below 65°F.

PLANT GROWTH RESPONSE TO VARIOUS PLASTICS

The yield of stem carnations and chrysanthemums grown under the different plastics did not appear to be influenced by the presence of the plastics. As only two replicates were tested, and there was wide variation between most of the plots within treatments, the differences between average yields are not meaningful and are therefore not presented. It is of interest that yield under the films producing the most shade was equal to or better than that from the uncovered plots.

Apparently no yield loss from reduced light intensity need be anticipated from the use of a wide range of plastics if the plastics are to be used only over, not around the beds, and the walkways (alleys) between the beds are not covered. The use of plastics such as Amerex UV, green, which intercept 45 percent of the visible light, would certainly result in yield reduction of carnations if used on a closed-in, pad-cooled house, however, as it is known that carnation yield closely follows light intensity (3).

Table 4. **Percent infra-red (700-2,000 mμ) energy from direct sunlight directly transmitted by various plastics, before and after 12 months' horizontal exposure**

Material	Percent direct transmittance	
	Before exposure	After exposure
Visqueen	66	D
Amerex UV, green, 8 mil	13	12
Griffolyn, Type 55, clear	40	32
Type 91	25	25
Type 92	56	51
PVC Ag-Film, 3 mil	83	62
4 mil	81	41
6 mil	80	9
10 mil	79	6
14 mil	76	5
16 mil	74	6
20 mil	64	33
Corr. PVC, clear	30	24
white	8	7
green	6	2
Clear fiberglass	25	24
Mirrophane	12	D
Mylar, 3 mil	86	38
5 mil	83	38

COST-PERFORMANCE OF PLASTICS

None of the inexpensive plastic films tested had exposure life in excess of six months. Amerex UV, green, 8 mil would cost about 8½ cents per square foot landed in Hawaii, unless it were bought in 2,500-pound lots, in which case it would cost 3 cents per square foot plus freight from California (prices quoted September 1965). Plastic films require much closer spacing of rafters and purlins and a steeper roof pitch than corrugated PVC or fiberglass. They also require very careful installation if rips starting at the staple points are to be avoided. With the recent drastic reduction in the cost of corrugated plastics there appears to be little point in considering the use of films for crop protection in Hawaii.

There is now a wide variety of makes of fiberglass and PVC panels available costing, landed in Hawaii, from 12 cents to approximately 40 cents per square foot. The corrugated clear PVC used in the tests reported herein cost approximately 12½ cents per square foot. It can be expected that the higher priced materials produced by the same manufacturers will have longer exposure life and would have especial application for construction of "permanent" pad-cooled greenhouses. The light transmittance of samples of several brand names of corrugated clear PVC and clear fiberglass was measured and differences of 10 percent in total visible light transmittance were found. Slightly larger differences in the percent of this light transmitted as direct (rather than diffused) light were evident. Samples taken from different batches of the same brand showed differences as high as 10 percent in the percent total light transmitted as direct light. In picking a plastic for greenhouse construction some attention should therefore be paid to the light transmitting characteristics of the material, especially if the greenhouse is to be used for a crop such as carnation, whose production is closely positively correlated with light intensity.

SUMMARY

The performance of 16 plastic films and 4 corrugated plastics is reported.

Of the plastic films only Amerex UV, green, performed satisfactorily. The others either lost strength and blew out or appreciably lost light transmittance.

Of the corrugated plastics, both clear PVC and fiberglass appeared satisfactory after 20 months of trial.

Changes in visible light transmittance and diffusion and heat transmittance during field exposure are reported for each material.

If plastics are to be used only over, and not around beds, and the walkways are to be left uncovered, no loss in yield from reduced light intensity need be anticipated even from plastics which intercept 45 percent of the visible light.

LITERATURE CITED

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