Effect of Plastic Mulch Colors on Growth of Pak-choi (*Brassica campestris* L.)

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Summary

Effects of plastic mulch color including aluminum polyethylene, clear, green, red, and yellow plastics on growth of pak-choi (*Brassica campestris* L.) cv. 'Feng Jing' in greenhouse were investigated at three different croppings i.e. September, 2003, November, 2003 and January, 2004. Root temperature under mulches was higher than the non-mulched control during the three croppings. The highest root temperature was shown under aluminum polyethylene and clear plastic which was 2.6 to 3.1^{o}C higher than control at midday. Green, red and yellow plastics had similar effect on root temperature. PPFD tended to be increased on mulch surfaces, except red plastic. The highest PPFD were measured on aluminum polyethylene and yellow plastic which were 6-21% higher than in control at three croppings. The effect of mulch color on plant growth varied among different crops. Yield in Sept. crop decreased in mulched treatments but increased in clear and yellow plastics by 19 and 31%, respectively, in comparing to control in Jan. crop. There were no differences in yield between mulches and control in Nov. crop, however, the differences among mulches were shown with higher yield in yellow plastic compared to aluminum polyethylene. Nitrate content in leaves grown in Sept. crop increased in mulched treatments but decreased in mulching with yellow plastic in Jan. crop. Percentage of leaves injured by diamond-back moth (*Putella xylostella* L.) generally was decreased by mulching during three crops, however, yellow plastic was the most efficient mulch to reduce the leaf injury.

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Introduction

Soil mulching with plastic is one of the devises in plant cultivation (Lamont, 1993; Tarara, 2000; Wittwer and Castilla, 1995). Plastic mulches have been used commercially in the production of vegetable since early 1960’s, and its usage is still increasing throughout the world (Lamont, 1993). Although a variety of vegetables can be grown successfully using plastic mulches, research continues in field and greenhouse evaluation of new formulations of degradable, wavelength-selective, and colored plastic for improving cropping systems (Lamont, 1993).

The mulch color determines it energy-radiating behavior and its influence on microclimate around the vegetable plants via changes in root temperature, light intensity and light quality above the mulch surface (Csizinszky *et al*., 1995; Díaz-pérez and Batal, 2002; Lamont, 1999). A mulch color may have different effects on plant growth and yield at different environment and plant species. In additionally, color of mulch may repel some species of insect while it may extract other insect species (Csizinszky *et al*., 1995; Lamont *et al*., 1990).

Color mulching has been studied and applied for several vegetable crops such as tomatoes, pepper, muskmelons, watermelon, squash and cucumber due to its efficiency in yield increase and pest control. However, few studies on effects of color mulching on leaf vegetable production were found.

In the present study, the experiments were laid out to study effects of plastic mulch color on growth of leaf lettuce and pak-choi at different environments in seasons of the year. These were to demonstrate that some plastic mulch colors improve yield and quality of leaf vegetable in specific climate.

Materials and Methods

Plant material

Pak-choi (*Brassica campestris* L.) cv. 'Feng-jing' (小白菜'鳳京'品種) from Tokia Co., LTD. was used in three experiments. Plants were grown in plastic trays filled with bio-mix medium (Tref Substrates Schoonebeek B.V Manufacture) and biofertilizer tianyao No.1 (田藥一號, 田酪股份有限公司) at 4:1 ratio in volume. Two kg chemical fertilizer Taifei No. 43 (台肥43號 15:15:15) was added to this mixture. At 2Kg/m^3 size of the tray was in 60 cm long, 30cm wide, and 3 cm deep. Three rows of 18 plants were grown per tray, plants being spaced 9 cm x 9 cm. Mulches were perforated with 3 cm x 3 cm in size for growing plant.

Treatments

Effects of five mulches including aluminum polyethylene, clear, green, red, and yellow plastics were tested in three seasons that seedlings were transplanted on 25^{th} Sept., 2003 (Sept. crop), 23^{rd} Nov., 2003 (Nov. crop), and 5^{th} Jan., 2004 (Jan. crop). Thickness of aluminum polyethylene and plastic mulches were 0.05 mm and 3 mm, respectively. A treatment without mulch was designed as control. For all treatments, 15-day 128-plug seedlings were transplanted into the plastic trays. Experiments were designed in a completely randomized design (CRD) with three replications and carried out in greenhouse of Horticulture Department, National Chung Hsing University in Taichung city.

Plant growth conditions

After fully developed the first true leaf, the seedlings were fertilized with peters-fertilizer (15:11:13) 1000 ppm in every three days. Plants were sprayed with 2000 ppm of urea at 3-, 6-, 9-, and 12- day after transplant and irrigated as required.

Measurement

Photosynthetic photon flux density (PPFD) was measured by using a sensor (LI-189; LI-COR, Linconln, Neb.) spaced at 5 cm from mulches. Measurements were made between 1200 and 1300 HR on three clear-days from planting until the expanding foliage covered the mulch. Root temperature was measured with an electrical meter (TB-1110, TOBISHI) at 7-, 10-, and 13-days after transplant at 0700, 1300, 1900, and 2400 HR of the day and the measurements were made for 1 hour

Plants were separately harvested at 15 days after transplant. Leaf area was measured with an area meter (LI-3000A, LI-COR, Lincoln, Neb.). Plant dry weight was measured from plants dried at $70^{o}C$ for 48 hours.

The fourth leaf from top plant harvested at was collected for nitrate analysis. The fresh leaf was sampled 0.1 g then the sample was grinded in 5 ml distilled water. Nitrate content was calculated from value read with Merck-Oquant (RQflex plus; 1.16955.0001; Merck) by following formula (Scaife and Stevens, 1983):

$$NO_3^- \text{-N (mg/kg)} = \text{Blank} \times 50 \times 14/62$$

Number of leaves injured by diamond-back moth (*Plutella xylostella* L.) was recorded from leaves that injured area was at least at 10% of leaf area.

Data analysis

Data were subjected to analysis of variance (SAS Institute, Cary, NC). Means were separated by Duncan's multiple range test ($P<0.05$).

Result

Photosynthetic photon flux density and root temperature

Photosynthetic photon flux density (PPFD) measured on mulches showed a significant difference in Sept. crop, but had no significant difference in Nov. and Jan. crops (Table 1). In Sept. crops, PPFD on yellow plastic was 550.9 mol m^{-2} s^{-1} which was 18% higher than in red plastic and 16% higher than in clear and control but was not significantly different compared to aluminum polyethylene and green plastic (Table 1). Aluminum polyethylene increased PPFD in comparison to the red plastic but not in other mulches and control. Although there were differences in PPFD among mulches, PPFD was not affected by the mulching when compared to the control.

Table 1. Photosynthetic photon flux density - PPFD (μ mol m^{-2} s^{-1}) measured at 5 cm above surface mulches and unmulched medium in the Sept., Nov., and Jan. crops

Mulch	Sept.	Nov.	Jan.
Aluminum	544.9 ab [z]	423.2 a	418.3 a
Clear	475.8 bc	418.9 a	398.1 a
Green	482.5 abc	407.0 a	393.8 a
Red	467.5 c	398.2 a	380.1 a
Yellow	550.9 a	445.0 a	412.1 a
Control	475.4 bc	398.2 a	346.2 a

[z] Means in each column followed by the same letter are not significantly different by Duncan’s multiple range test at $P < 0.05$.

Root temperature in Sept. crop was generally higher than air temperature at 5 or 80 cm from mulch surface (Fig. 1A). At 0700 HR root temperature under mulches and control were similar (Fig. 1A). The difference in root temperature among treatments increased with increasing air temperature. At 1300 HR the highest root temperature of 38.1°C was obtained under clear plastic, followed by aluminum polyethylene (36.4°C) and the lowest root temperature was measured in control (35.0°C). Root temperature under green plastic was 35.2°C and that under red and yellow plastics were both 35.5°C. The difference in root temperature was obtained until 1900 HR. This difference, however, decreased at 2400 HR. Air temperatures at 5 and 80 cm from mulch surface were nearly the same.

Air and root temperatures during Nov. crop were lower than Sept. crop (Fig. 1A and B). Diurnal trends in root and air temperatures during Nov. crop were similar in Sept. crop. At 1300 HR the highest root temperature was obtained under aluminum polyethylene and clear plastic which were 29.5 and 28.6^{o}C, respectively (Fig. 1B). Root temperatures at 1300 HR under green, red, yellow, and control were 27.5, 27.4, 27.6, and 26.9^{o}C, respectively. However, the difference in root temperature among treatments decreased at 1900 HR in Nov. crop compared to 2400 HR in Sept. crop (Fig. 1A and B).

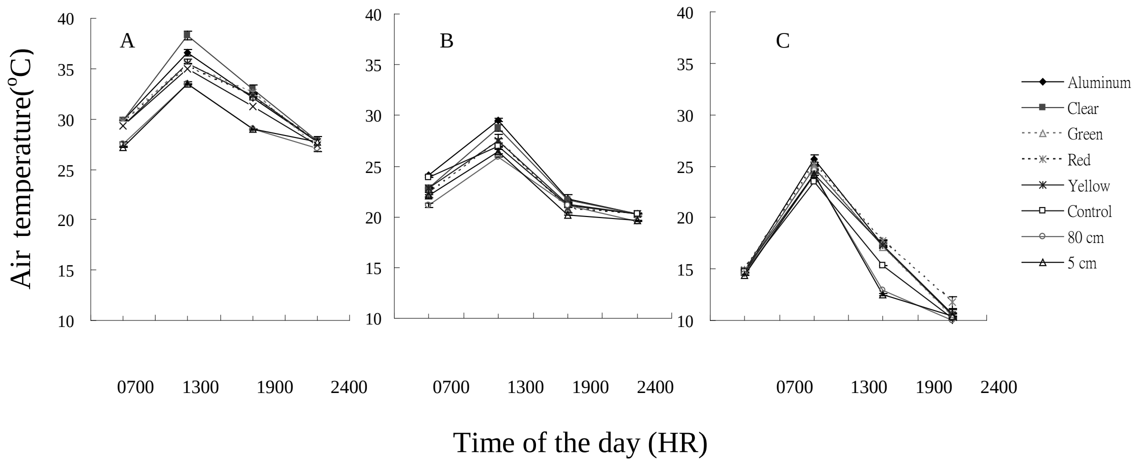

Fig. 1. Air temperature (^{o}C) at 5 and 80 cm from mulch surface and root temperature (^{o}C) under different mulches in Sept. (A), Nov. (B), and Jan. (C) crops.

In Jan. crop air temperature at 80 cm from mulch surface reduced to 24.1^{o}C at 1300 HR and 10.0^{o}C at 2400 HR. Root temperature was higher than the air temperature at 0700, 1900, and 2400 HR but not at 1300 HR in control (Fig. 1C). The highest root temperature was under aluminum polyethylene at 25.7^{o}C, followed by red and clear plastics at 25.2 or 24.9^{o}C, respectively. The lowest root temperature of 23^{o}C was measured in control. The increase in root temperature under mulches compared to control was obtained at 1300 and 1900 HR, and the difference decreased at 2400 HR of the day.

In three crops, air temperature at 80 cm from mulch was similar to that at 5 cm from mulch. Air temperatures above mulches decreased during Sept. to Jan. (Fig. 1A, B, and C).

Plant fresh weight

In Sept. crop, mulching with clear or red plastic decreased plant fresh weight by 21 and 28%, respectively, compared to control (Table 2). Plant fresh weight in red plastic also was

21% lower than in yellow plastic. In Nov. crop, the highest plant fresh weight was shown in yellow plastic with 29% higher than in aluminum polyethylene (Table 2). However, plant fresh weight was not significantly different between control and mulched treatments. In Jan. crop, the positive effect was indicated in yellow plastic (Table 2). This mulch increased plant fresh weight as compared to aluminum polyethylene, green plastic, red plastic and control by 33, 30, 24 and 29%, respectively.

The difference in plant fresh weight among croppings was significant at $P<0.05$. Although there were differences in plant fresh between control and mulches in each cropping, the effect of mulching among three croppings was not shown (Table 2). The interaction between mulch and cropping was not significant.

Plant dry weight

Plant dry weight among treatments was significant differences in Sept. and Jan. but not in Nov. crop (Table 2). In Sept. crop, plant dry weights in clear and red plastics were lower than control and other mulches. There was no significant difference in plant dry weight between mulches and control in Jan. crop, however, the difference between mulches was shown with 8% higher in yellow plastic than in aluminum polyethylene. There was no significant difference in plant dry weight among croppings. Effect of mulching on plant dry weight among cropping and the interactive effect of mulch and cropping on plant dry weight were not significantly different.

Yield

In Sept. crop the highest yield was shown in control which was 21 and 28% higher than in clear and red plastics, respectively (Table 2). The decreased yield in red plastic was also compared to yellow plastic. In Nov. crop the highest yield was shown in yellow plastic with significant higher than in aluminum polyethylene (Table 2). However, there was no significant difference in yield when control was compared to any mulch. In Jan. crop, yellow plastic showed an increase in yield by 24-33% higher than control and other mulches except clear plastic (Table 2).

Yield varied among three croppings and the lowest yield was in Sept. crop. This difference was significant at $P<0.05$. There was no significant effect of mulching on yield among croppings or interaction between mulch and cropping (Table 2).

Total leaf area

Total leaf area was affected by the mulching color in Sept. and Jan. crops but not at Nov. crop (Table 3). In Sept. crop, leaf area was increased in aluminum polyethylene, yellow plastic and control as compared to red plastic by 18-30%. Leaf area in Jan. crop was significantly higher in clear and yellow plastics than in control and other mulches.

Table 2. Effect of color mulches on plant weight, root weight and yield of pak-choi cv. 'Feng-jing' in three crops.

Mulch	Plant fresh weight (g/plant)	Plant dry weight (g/plant)	Yield (kg/1000 m^2)[y]
Sept.			
Aluminum	22.7 abc [z]	1.35 a	1700 abc
Clear	20.3 bc	1.04 b	1523 bc
Green	22.0 abc	1.29 a	1649 abc
Red	18.7 c	1.09 b	1402 c
Yellow	23.2 ab	1.39 a	1742 ab
Control	25.8 a	1.42 a	1934 a
Nov.			
Aluminum	21.7 b	1.22 a	1624 b
Clear	26.0 ab	1.45 a	1949 ab
Green	24.4 ab	1.39 a	1832 ab
Red	25.3 ab	1.47 a	1895 ab
Yellow	27.9 a	1.59 a	2092 a
Control	25.4 ab	1.52 a	1905 ab
Jan.			
Aluminum	23.6 c	1.17 b	1771 c
Clear	28.7 ab	1.57 ab	2150 ab
Green	24.3 c	1.31 ab	1821 c
Red	25.5 bc	1.43 ab	1909 bc
Yellow	31.5 a	1.65 a	2363 a
Control	24.4 c	1.26 ab	1802 c
Significance			
Mulch	ns	ns	ns
Cropping	*	ns	*
Mulch x Cropping	ns	ns	ns

[z] Means in each column followed by the same letter are not significantly different by Duncan's multiple range test at $P < 0.05$.

[y] The yields were obtained with density of 750 plants/1000 m^2

ns, *, ** Nonsignificant or significant at $P < 0.05$, or 0.01, respectively.

Leaf area among croppings was different with significance at P<0.01. There was no significant effect of mulching on leaf area among croppings or the interaction between mulch and cropping at three harvests.

Percentage of leaf number injured by diamond-back moth (*Putella xylostella* L.)

Diamond-back moth (*Putella xylostella* L.) visited plants grown in three croppings (Table 3). In Sept. crop percentage of leaves injured by the pest in control was 28.6% which was the highest and followed by red plastic. The lowest percentage of the injured leaves was shown in yellow plastic, followed by clear plastic, aluminum polyethylene and green plastic with increasing in the order. In Nov. crop and Jan. crops, mulching with yellow plastic significantly decreased percentage of the injured leaves compared to control. Other mulches slightly decreased the injured leaves compared to control however this effect was not significant difference.

Plants grown in Jan. crop had higher percentage of the injured leaves than those in Sept. and Nov. crops. The difference in percentage of the injured leaves among croppings was shown during three harvests with significant difference at P<0.01 (Table 3). Effect of mulching on percentage of the injured leaves among croppings was found with significance at P<0.05. There was no interactive effect of mulch and cropping on percent of the injured leaves at three harvests.

Nitrate content in leaves

In Sept. crop nitrate content in leaves was increased in mulched treatments as compared to control (Table 3). Green and red plastics had higher nitrate content compared to clear and yellow plastics. In Nov. crop the nitrate content was decreased in yellow plastic compared to green plastic, however, there was no difference between control and mulched treatments (Table 3). In Jan. crop the lowest nitrate content was measured in yellow plastic and the highest nitrate content was measured in control which was 17-27% higher than in mulched treatments except the aluminum polyethylene mulching (Table 3).

The difference in nitrate content among croppings was significant at P<0.01 with the highest content measured in Jan. crop and the lowest content measured in Nov. crop (Table 3). There was no significant effect of mulching on the nitrate content among croppings or the interaction between mulch and cropping.

Table 3. Effect of color mulches on leaf area, percentage of leaf number injured by diamond-back moth (*Plutella xylostella* L.), and nitrate content in leaves of pak-choi cv. 'Feng-jing' in three crops.

Mulch	Leaf area (cm^2/plant)	Injured leaves (%)	Nitrate (mg/kg FW)
Sept.			
Aluminum	513 a [z]	20.1 bc	395 ab
Clear	497 ab	16.2 cd	346 b
Green	484 ab	20.2 bc	459 a
Red	426 b	25.8 ab	439 a
Yellow	502 a	12.4 d	342 b
Control	555 a	28.6 a	252 c
Nov.			
Aluminum	445 a	19.0 ab	222 ab
Clear	402 a	21.4 ab	244 ab
Green	435 a	19.0 ab	272 a
Red	417 a	24.7 ab	259 ab
Yellow	467 a	16.0 b	203 b
Control	397 a	30.8 a	218 ab
Jan.			
Aluminum	512 b	44.4 a	1155 ab
Clear	631 a	34.7 ab	1031 bc
Green	531 b	44.2 a	1054 bc
Red	559 b	36.6 ab	1024 bc
Yellow	639 a	31.2 b	974 c
Control	537 b	45.8 a	1234 a
Significance			
Mulch	ns	*	ns
Cropping	**	**	**
Mulch x Cropping	ns	ns	ns

[z] Means in each column followed by the same letter are not significantly different by Duncan's multiple range test at P＜0.05.

ns, *, ** Nonsignificant or significant at P< 0.05, or 0.01, respectively.

Discussion

Many color mulches increase light reflection while some others such as black, gray and red mulches may decrease light reflection compared to bare soil (Díaz-Pérez and Batal, 2002; Loughrin and Kasperbaure, 2001). In the present study, although the significant difference in PPFD between mulches and control was found only for yellow plastic in Sept. crop, however, PPFD was constantly increased with color mulching, except red plastic, during three croppings. The highest PPFD in Nov. and Jan. crops was shown in aluminum polyethylene and yellow plastic which were 6-21% or 12-19%, respectively, higher than control (Table 1). Although these increases were not significant yet may be still beneficial to improve plant growth under low light condition.

It is commonly known that soil temperature under mulches is higher than bare soil (Csizinszky *et al*., 1995; Díaz-pérez and Batal, 2002; Ham *et al*., 1993; Loughrin and Kasperbauer, 2001). This is again demonstrated in the present study which indicated that root temperatures under mulches were higher than control in all Sept., Nov. and Jan. crops (Fig. 1). The highest root temperature was shown in aluminum polyethylene and clear plastic during three crops (Fig. 1). Clear plastic normally used to achieve maximum soil temperatures (DeVay, 1991). The efficiency of clear plastic in increasing root temperature was due to the transmission characteristic and appearance of water droplets in this mulch (Lamont, 1999). Clear mulch absorbs little solar radiation but transmits 85 to 95%. The under surface of clear plastic mulch usually is covered with condensed water droplets. This water is transparent to incoming shortwave radiation but is opaque to outgoing longwave infrared radiation. Therefore much of the heat lost to the atmosphere from the bare soil by infrared radiation is retained by the clear plastic mulch (Lamont, 1999). Many reports (Albregts and Chanler, 1993; Csizinszky *et al*., 1995; Díaz-pérez and Batal, 2002) showed that root temperatures under reflective mulches such as aluminum and silver were lower than other color mulches. By contrast aluminum polyethylene increased root temperature compared to green, red and yellow plastics during three crops in present results (Fig. 1). These differences may be attributed to the difference in mulch materials. Difference in materials or components of mulch may induce a large difference in root temperature even mulches are same in color (Díaz-pérez and Batal, 2002; Ham *et al*., 1993). Aluminum polyethylene used was thinner than the plastic mulches, and the polyethylene covered tightly the trays. These increased the accumulation of heat in root zone under the aluminum polyethylene. The increased root temperature under mulches, particularly under aluminum polyethylene and clear plastic may be benefit for plant growth under low temperature conditions such as Jan. crop but may have negative effect in high temperature condition such as

Sept. crop due to the supraoptimal root temperature.

It is apparent that plant growth is inhibited under sub-optimal environment (Aldous and Kaufmann, 1979; Ali *et al*., 1996; Dieleman *et al*., 1998; Ketcheson, 1968). Optimal temperature for pak-choi growth is between 20 and 25^{o}C (William 1957; Williams and Heyn, 1981). These temperatures could be found in Nov. crop rather than in Sept. and Jan. crops (Fig. 1). Therefore yield and growth of plants grown in Nov. crop were higher than in Sept. and Jan. crops which had supra- or sub-optimal temperatures, respectively.

The differences in plant growth and yield observed in the same mulch color between three croppings may be due to several factors. In Sept. crop, plant growth and yield were highest in control despite higher PPFD in mulches, except red plastic mulch. Under high light condition in Sept. crop the effect of color mulching on increased PPFD was not important for plant growth but the influenced root temperature. A decreasing root temperature would have been expected when root temperature in control varied from 28 to 35^{o}C in the day (Fig. 1A). Increasing in root temperature under mulches overcomes their effect on PPFD and reduced plant growth and yield. Therefore aluminum polyethylene and plastic mulches are not recommended for pak-choi production in high temperature conditions. However the slightly decreased yield in yellow plastic in Sept. crop may be compensated by the decreases in percentage of injured leaves (Table 3) which increases vegetable quality.

In Jan. crop when root temperature in control was below optimum, the increase in root temperature under mulches (Fig. 1C) was expected in stimulating plant growth. On the other hand, the increase in PPFD on color mulches, although nonsignificance, may still be a contribution to increase plant growth and yield in Nov. and Jan. crops. The increased yield was more responsive to yellow plastic and followed by clear plastic rather than other mulches. These were attributed to the difference in root temperature (Fig. 1), reflected PPFD (Table 1) and light quality (Csizinszky *et al*., 1995; Decoteau *et al*., 1989; Díaz-pérez and Batal, 2002; Loughrin and Kasperbaure, 2001) above surfaces between mulch colors. In Nov. crop the differences in plant growth and yield among treatments were attributed to changes in reflected light rather than root temperature which was near the optimal range for the growth of pak-choi.

Yellow plastic had the same effect on root temperature as green and red plastics (Fig. 1). However, slightly increased PPFD (Table 1) and low FR/R ratio above yellow plastic (Coufal *et al*., 1984; Csizinszky *et al*., 1995; Decoteau *et al*., 1989; Loughrin and Kasperbaure, 2001) may have increased plant growth and yield in Nov. and Jan. crops. Yellow mulch reflects more red (photosynthetic) but less far-red (photomorphogenetic) light of the spectrum that might result in reduced fruit yield of tomato (Decoteau *et al*., 1989). However these characteristic of yellow mulch may benefit for increasing yield of leaf vegetable such as pak-choi. The increases in yield in yellow plastic may be also explained by the decrease in percentage of leaves injured by diamond-back moth (Table 3).

Aluminum polyethylene had similar effect on PPFD to yellow plastic (Table 1), however, yield was increased in yellow plastics but not in aluminum polyethylene (Table 2). The excessive root temperature at 1300 HR (Fig. 1B) combining higher FR/R ratio in aluminum mulch compared to yellow mulch (Csizinszky *et al*., 1995) may have resulted in the differences in yield between these mulches in Nov. crop. In additionally, aluminum polyethylene appeared to be the best mulch for improving both root temperature and PPFD in Jan. crop (Table 1, Fig. 1C) but yield in this mulch was not different from control and was lower than clear and yellow plastics. These indicate that light quality reflected from color mulch may play an important role in plant growth and yield which agrees with many reports (Csizinszky *et al*., 1995; Decoteau *et al*., 1989; Loughrin and Kasperbaure, 2001). Despite the harmful increase in root temperature at 1300 HR under clear plastic in Nov. crop (Fig. 1B), yield in this mulch was slightly higher than in control (Table 2). In Jan. crop when temperature dropped to below optimum, the increased yield in clear plastic was significant. The efficiency of clear plastic may relate to the characteristic in reflecting light quality but need further studies.

Red mulch has been recommended for tomato and strawberry because of the reflection of FR to growing plants and its subsequent photochrome-medicated regulation of photosynthate allocation to developing fruit (Kasperbaure and Hunt, 1998; Kasperbaure, 2000; Csizinszky *et al*., 1995). However, it had no possible effect on yield of pak-choi (Table 2).

Mulching, generally, decreased percentage of leaves injured by diamond-back moth compared to control (Table 3). However, the best efficiency was shown in yellow plastic. The decrease in the injured leaves may be a contribution to increase leaf area, plant fresh weight, plant dry weight and yield of pak-choi plants grown in yellow plastic. The advantage of yellow mulch in reducing population of some pest species was reported (Csizinszky *et al*., 1995, 1997; Geinenberg and Stewart, 1986). Number of whiteflies and their hatched eggs on foliage of tomato plants grown in yellow mulch were lower than in blue, red, black mulches, and bare soil (Csizinszky *et al*., 1995, 1997). Numbers of whiteflies, thrips, and aphids counted per trap placed on the yellow mulch were lower than the other mulches in tomato. Whereas yellow traps placed in greenhouse or on bare soil in the field attracted whitefly adults (Chu and Henneberry, 1998). The relation has been explained that the yellow color of plastic mulch extracted whiteflies so that reducing population of the pest in tomato plants (Geinenberg and Stewart, 1986). However, yellow color may attract certain insects but repel others (Chu and Henneberry, 1998). The different effects on different insect species at the same color mulch were reported (Csizinszky *et al*., 1995, 1997).

Nitrate content in leaves plants grown in control was lowest in Sept. crop, and was highest in Jan. crop, but was not different from any mulch in Nov. crop. While several reports (Ali *et al*., 1996, 2000; Gent and Ma, 2000) indicated that nitrate content in leaves was reduced at both high and low root temperatures. The decrease in nitrate content at stressed root temperature was due to the decrease in nitrate uptake (Tindall *et al*., 1990). At low root temperature, furthermore, the upward movement of nitrate from roots to top of plant was restricted (Ali *et al*., 1996, 2000; Gent and Ma, 2000). In the present study nitrate accumulated in leaves was also obtained from the nitrate absorption of leaves because urea fertilizer was sprayed on the folia. The difference in nitrate concentration in leaves at high and low root temperature between our study and the other reports may be due to the difference in method of fertilizer supplement. The difference in nitrate content in leaves between control and mulches was not directly caused by the nitrate uptake by roots and upward transfer.

Nitrate content in leaves is determined by nitrate reductase which is affected by root temperature, light intensity and light quality (Ruiz *et al*., 1999; Travis *et al*., 1970; Wyn Joes and Sheard, 1979). Ruiz *et al*. (1999) showed that increasing root temperature to optimal range by mulching increased NR and NiR activities therefore increased amino acid, protein and organic N contents, and reduced nitrate content in leaves as compared to those in bare soil. However other mulches that excessively increased root temperature had no effect compared to the bare soil. Generally, blue light and high intensity light lead to high NR activity (Evans, 1989; Travis *et al*., 1970; Wyn Joes and Sheard, 1979). The supplement of far-red light varied NR activity in barley (Bünning, 1973). The lowest nitrate content in yellow plastic in Nov. and in Jan. crops was due to the increased light intensity and low far-red light. Low nitrate content in control or yellow plastic in Sept. or Jan. crop, respectively, correlated to high growth and yield. These may relate to the increase in nitrate reductase in leaves. Ruiz *et al*. (1999) indicated that the optimal root temperature controlled by color mulching increased leaf dry weight and yield of tuber potato which correlated to the increase in NR activity and the decrease in nitrate content in both leaves and roots.

Nitrate content in leaves varied during croppings. It was lowest in Nov. crop and was highest in Jan. crop. These correlated to variation of light and temperatures, plant biomass and yield during croppings. Results of the present study indicated that color mulching may be potential to resolve excessive nitrate content in leaf vegetable status occurred in several regions. Yellow mulch may increase efficiency of nitrogen supplement to increase yield under low light and low temperature.

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塑膠覆蓋顏色對小白菜(*Brassica campestris* L.)生長之影響

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關鍵字：覆蓋、顏色、小白菜

摘要：本試驗以小白菜(*Brassica campestris* L.) '鳳京' 為材料，比較不同顏色之塑膠布覆蓋對根溫及光合作用光子密度(Photosynthetic photon flux density, PPFD)之變化及同時探討不同栽培時期覆蓋下對小白菜生長之影響。使用之覆蓋顏色分別為鋁色、紅色、黃色、綠色及透明等五種，不覆蓋者為對照組。栽培時間分別為 2003 年 9 月、11 月和 2004 年 1 月。

試驗結果顯示，覆蓋面上之 PPFD，除紅色覆蓋外，皆較對照組高，但只在 9 月達顯著差異。覆蓋處理間之 PPFD 以鋁色及黃色者最高，高於對照組 6 至 21%。覆蓋處理之根溫較對照組高，並以鋁色和透明者最高，於下午 13:00 兩者之根溫較對照組高約 2.6 至 3.1^{o}C。綠色、紅色及黃色覆蓋對根溫具有相同影響。

覆蓋顏色對小白菜生長及產量之影響依不同栽培時期而異。九月栽培期之產量以對照組最高。十一月栽培者之產量以黃色覆蓋較鋁色覆蓋處理高但各個覆蓋及對照組之間並無顯著差異。一月栽培期之產量以透明及黃色覆蓋處理高於對照組 19 與 31%。本研究發現九月栽培之葉片硝酸態氮含量以對照組最低。一月栽培者則以黃色覆蓋處理最低。另外五種覆蓋顏色都會降低小白菜小菜蛾(*Putella xylostella* L.)對葉片之傷害，並以黃色覆蓋最有效。

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