Mulch Color Affects Radicchio Quality and Yield

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Abstract. Interest in the production of the specialty vegetable radicchio (*Cichorium intybus* L. var. *silvestre* Bisch.) has increased among vegetable growers in the northeastern United States due to the popularity and consumption of premixed prepared salads. Growing environments with moderate daytime temperature and high light level have been associated with dense, deep red heads. Production problems include the low percentage of plants producing marketable heads and labor costs associated with hand-weeding. Traditional bareground culture was compared with several colored mulches (white, silver, red, black, and blue) for their effects on head formation, size, yield, and color of two Italian cultivars. Field studies were conducted in Freeville (upstate), N.Y., in 1997 and 1998. The percentage of heads harvested ranged from 32% to 82% over the 2 years of experiments and was lowest in black and red plastic mulch treatments. Yields were significantly higher, heads larger, and harvest earlier for plants grown over silver and white mulch compared to the control and other mulch treatments in 1998. In addition, average head weight was greater in all mulch treatments except blue when compared with the control. Cultivar differences were measured for the number and weight of heads, the percent bolting and marketable heads, and head color in 1998. Air and soil temperatures varied significantly around these mulches; however, these differences in microclimate had no effect on head color quality. Despite relatively moderate temperatures in upstate New York, radicchio responded positively to mulches that lowered average soil temperatures (white and silver) compared with the other treatments.

Growers in the Northeast are continuously searching for new or niche crops to diversify production. Radicchio is one such specialty crop, with expanding markets due to its use in “mesclun” salad mixes. The leaves have a deep red color with white veins and a distinctive bitter flavor. Challenges to expanding production observed in New York (J. Dygert, personal communication) and in northern Europe (Grevsen, 1992) have included the lack of uniformity of head quality and size, the timing of head development, and the low percentage of plants producing marketable heads. Minimum marketable size for radicchio ranges from 0.18 kg per head (Carrasco et al., 1998) to 0.23–0.34 kg per head, to allow 12 to 15 heads per 3.9-kg box (Champlain Valley Specialties, N.Y.). Heads must also have uniform dark red appearance and bright white veins. In general, radicchio varieties have shown a high degree of variability for head formation. About 50% of plants produced heads in Italian trials (Gianquinto and Pimpini, 1989), 4% to 70% of plants in New England trials (Hill, 1987), and 30% to 60% of plants in New York production fields and trials (unpublished data). Growers in New York desire 80% of plants headed and harvested with two passes through the field.

Bolting percentages of radicchio grown in a northern U.S. climate ranged from 8% to 70%, depending on the cultivar (Hill, 1987). Long days (>13 h) controlled flower induction. Low temperatures early in the season (<10 °C) stimulated plant photoinducibility and reduced the number of long-day cycles required for flower induction (Gianquinto, 1997; Pimpini and Gianquinto, 1988). Consequently, the total percentage of harvestable heads was reduced. As radicchio plants age, they are more susceptible to low-temperature vernalization and more resistant to high-temperature devernization. Plants grown under short days (<12 h) did not flower, regardless of early season temperatures (Gianquinto, 1997). The growth stage when radicchio plants were sensitive to long days depended upon early season temperature conditions.

Interest in use of colored mulches has increased, as researchers have reported improved yields, improved crop quality, or reduced insect pressure compared with conventional black plastic mulches (Csizinszky et al., 1995; Decoteau et al., 1989, 1990). Colored mulches affected crop development and yield by manipulating the light quality around plants and changing the red : far red ratio (Decoteau et al., 1989, 1990). In addition, colored mulches may have different transmission of infrared radiation, resulting in differences in soil temperatures (Decoteau et al., 1989, 1990; Ham et al., 1993). Separation of light quality from temperature effects of colored mulches on growth remains difficult to assess. In addition, productivity over mulches varies among geo-

graphic regions and crops (Giacomelli et al., 2000). However, most results suggest that these mulches, combined with drip irrigation, could enhance the quality and yield of radicchio and reduce labor costs associated with weed management. We investigated the impact of colored plastic mulches on head color, quality, and yield of radicchio during two summers in upstate New York. Improvements to radicchio uniformity and yield could justify use of colored mulches in production of this specialty crop.

Materials and Methods

Plant material. Seeds for two Italian radicchio cultivars, ‘Rosso di Chioggia no. 1’ and ‘Rosso di Chioggia Medio no. 3’, were seeded into cell flats filled with peat-lite growing medium on 20 May 1997 and 15 May 1998. These have been standard cultivars used in Italy (Gianquinto and Pimpini, 1989) and produce excellent quality heads when grown in New York (unpublished data). Greenhouse conditions were 25 °C day/20 °C night temperatures, with 16-h photoperiod and supplemental metal halide lighting to provide 350 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PPFD during the day. These temperatures during seedling production did not induce bolting and flowering of transplanted radicchio (Gianquinto and Pimpini, 1989). After 4 weeks, seedlings were placed in a cold frame for 5 d prior to field transplanting.

Field experiments. Both field experiments were conducted at the Homer C. Thompson Vegetable Research Farm, Freeville, N.Y., on a Howard gravelly loam (loamy-skeletal mixed semic Glossoboric Hapludalf). A split-plot experimental design with three replicates was used, with mulch treatments as main plots and cultivar as subplots. In 1997, preplant fertilizer was broadcast and incorporated to provide 80N–61P–88K kg·ha⁻¹, and an additional 17 kg·ha⁻¹ N was applied via the drip system 3 weeks after planting. In 1998, the preplant fertilizer rate was 64N–20P–38K kg·ha⁻¹ and 34 kg·ha⁻¹ N was applied via drip.

In 1997, four mulch treatments were tested for effects on radicchio quality and yield. Raised beds (10 cm high and 70 cm wide) were formed, drip tape laid into the beds (2.5 cm below and 5 cm to right of center) and plastic mulch (122 cm wide and 0.0254 mm thick) applied over the beds. Beds were spaced 1.8 m apart, center to center. Plastic mulches (all same thickness and width) included a red (Sonoco Selective Reflecting Mulch or SRM-Red, Hartsville, S.C.), a white on black, and a black mulch (Climagro, St-Laurent, Que.), and the control had no plastic mulch. The SRM-red mulch was formulated based upon research results (Decoteau et al., 1990; Hunt et al., 1989) to reflect a higher ratio of far red to red light than incident sunlight and to transmit a high proportion of infrared radiation to the soil. Transplants were set in a single row on the beds on 19 June, using an in-row spacing of 20 cm between plants. The total plot length was 3 m (15 plants per plot). Heads were harvested on 12 and 18 Aug. 1997, 54 and 60 d after transplanting, respectively.

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In 1998, all previous mulch treatments (same lots as in 1997) were repeated using a split plot design, with the addition of a blue (Rochelle Plastics, Rochelle, Ill.) and a metalized silver on black mulch (Clark's Agricultural Plastics, Greenwood, Va.). This silver mulch was a black plastic coated with aluminum during extrusion and was very reflective. Silver mulch has also been reported to repel aphids and thrips from vegetable crops (Csiszinszky et al., 1995). Beds were spaced 2.6 m between rows to facilitate mechanical cultivation between beds. Transplants were set into the beds on 15 June, using a double staggered row configuration with 30 cm between plants and 38 cm between rows. The total plot length was 3 m, with buffer plants at each end (24 plants per plot). Heads were harvested on 5 and 10 Aug. 1998, 51 and 56 d after transplanting, respectively.

Head yield and quality assessments. Harvested heads were sorted as marketable or unmarketable (misshapen, bolting). Marketable head weight and diameter were recorded (1997) or heads were sorted as small (<9.5-cm diameter) or large (>9.5 cm) and weighed (1998). Mulch treatments affect on head color quality (lightness, hue, and chroma) was assessed using a Minolta CR-100 Chroma Meter (Ramsey, N.J.) with an 8-mm aperture, which provided data in the L^* , a^* , and b^* color system. Three marketable heads were selected per treatment on the first harvest date and three color readings were taken per head, halfway up the length and 1 cm lateral to the central vein of the wrapper leaf. Measurements were taken under diffuse illumination and a viewing angle of 0° (McGuire, 1992). The a^* and b^* readings were used to calculate chroma and hue angle, prior to statistical analysis (McGuire, 1992). For lightness (L^*), the range was 0 for black to 100 for white; for chroma, the range was from 0 for least intense or gray to 100 for most intense color. For hue angle, 0° was red-purple, 90° was yellow, 180° was blue-green, and 270° was blue.

Temperature measurements. In 1998, soil (10 cm deep) and air (10 cm above mulch) temperatures around the mulches were recorded once per hour using copper-constantan thermocouples linked to a data logger (Campbell CR-7; Campbell Scientific, Logan, Utah). Thermocouples monitoring air temperature were shielded with aluminum foil to reduce direct or reflected solar warming. Readings from two thermocouples per treatment were averaged. Temperatures from three 24-h periods (selected based upon clear skies and warm air temperatures) were recorded (11, 22, and 26 July) during the period when heads were forming, to identify maximum temperature differences among treatments. These data were used as replicates for statistical analysis.

Statistical analyses. Yield, temperature, and color data were subjected to analysis of variance (ANOVA) using the SAS statistical package (SAS Institute, Cary, N.C.). Single degree of freedom contrasts were used to compare head measurements from lighter colored mulch treatments (white, silver, bareground) to darker colored treatments (black, blue, red).

Results and Discussion

Air and soil temperatures. Air temperatures over the various mulches were not consistently higher or lower for the 24-h periods measured (Fig. 1A). Temperatures at night were similar over treatments; however, during the day (6 AM to 8 PM), the black mulch had significantly higher air temperatures than all treatments except blue. The 24-h mean air temperature (3 d) for black mulch (22.1°C) was higher ($P \leq 0.001$) than all other treatments. Blue mulch (20.3°C) was significantly warmer than white (19.7°C), bareground (19.7°C), and silver (19.2°C) treatments. Red mulch was intermediate for air temperatures (20.0°C).

Soil temperatures under black mulch averaged significantly higher than under all other treatments except blue mulch (Fig. 1B). Average soil temperatures (24 h) were higher ($P < 0.001$) under black (23.1°C) and blue (22.7°C) mulches compared with white (21.2°C),

silver (21.4°C), and bareground treatments (20.0°C). Soil temperature under the red mulch (21.3°C) was intermediate compared with other mulches. Previous research found soil temperatures under the SRM red mulch (same manufacturer as used here) to be higher than black plastic (Mbugua, 1996). Differences in soil type, climate, sampling date, or mulch batch may have contributed to reduced soil warming under this mulch in our studies compared to previous research.

Yield and head size. In 1997, cultivar had no significant effect on any measurements, and therefore means were presented as an average of both cultivars (Table 1). Total yield and number of heads harvested were similar between the bareground control and white mulch treatments. The number of heads harvested from the black and red mulch treatments was significantly lower than the control (Table 1). Contrasts indicated higher yields ($P < 0.01$) and number of harvested heads ($P < 0.001$) from lighter treatments (white and

Fig. 1. (A) Air and (B) soil temperatures averaged across three 24-h periods (11, 22, and 26 July 1998). Air temperature was recorded 10 cm above mulch, and soil temperature recorded 10 cm deep. Significant differences in average air temperature over mulches were detected from hours 7 to 19. Significant differences in soil temperature under mulches were detected at all measurement times. Vertical lines represent SE of the means.

Table 1. Marketable yield characteristics, head weight, and percentage of heads harvested of radicchio grown on four mulch treatments in upstate New York in 1997.

Treatment	Total yield		Yield per date (kg)		Harvested (%)	Culls ² (%)	Avg head wt (kg)	Avg head diam (cm)
	kg	no.	12 Aug.	18 Aug.				
Bareground	2.60 a ²	9.2 a	0.7	1.9 a	68 a	0 b	0.28 c	10.3 b
White	2.27 ab	6.8 ab	1.0	1.3 ab	55 ab	5 ab	0.34 ab	10.9 a
Red	1.47 b	4.2 c	0.7	0.8 b	32 c	12 a	0.36 a	11.3 a
Black	1.73 ab	5.3 bc	1.0	0.8 b	42 bc	10 a	0.32 bc	10.7 ab

²Culls included those heads with tipburn, green color, or misshapen/bolting.

³Mean values within the same column followed by the same letter were not significantly different. $P < 0.05$ using Fishers protected LSD.

bareground) than darker treatments (black and red), and more culls from darker treatments ($P < 0.001$).

In 1998, cultivar had a significant effect on the number of harvested heads (Table 2), but there were no significant interactions among cultivar and mulch treatments. Higher yields were produced on silver and white mulches than on all other treatments, and lowest yields were recorded from bareground and black mulch treatments (Table 2). No treatment had lower yields than the control, in contrast to the 1997 experiment. However, using black plastic mulch did not improve yields of this crop over the control. Lighter colored, cooler mulches (white, silver) had higher yields ($P < 0.001$) and total number of harvested heads ($P < 0.001$) than the darker, warmer mulches (black and blue) and the red mulch.

Plastic mulches increased radicchio head weight over the control by 13% to 18% in 1997 and 25% to 39% in 1998. More uniform soil moisture may have contributed to this increase (Tanner, 1974). The average head weight ranged from 0.19 to 0.34 kg (Tables 1 and 2), which conformed to the sizes desired by growers. Fewer heads developed on the red mulch; however, those heads that did develop on the red and white mulch had a higher average weight and diameter than other treatments in 1997 (Table 1). In 1998, average head weight increased with all treatments except blue mulch when compared with the control (Table 2). The blue and bareground treatments had 57% of harvested heads classified as small, which was more small heads than other treatments (Table 2). More large heads were harvested from white and silver mulch treatments than from black, blue, and bareground treatments ($P < 0.001$). This may have been due to the increased light reflected off the white and

silver mulches (Decoteau et al., 1990) as well as reduced heading due to higher air and soil temperatures observed for the black and blue mulch treatments (Fig. 1).

Percentage of harvested heads. Cultivar and mulch treatments did not consistently affect the percentage of harvested heads. No difference between cultivars was noted in 1997 (Table 1). In 1998, more heads were harvested from 'Rosso di Chioggia Medio no. 3' than 'Rosso di Chioggia no. 1' and a higher percentage of bolting plants were measured from 'Rosso di Chioggia no. 1' (Table 2). In 1997, mulch treatments resulted in 35% to 55% harvested heads (Table 1). Contrasts indicated that the percentage of harvested heads was greater from white and the control treatments than red and black treatments ($P < 0.05$). In 1998, the percentage of harvested heads ranged from 49 to 82 (Table 2), but differences were nonsignificant. However, those treatments with cooler air and soil temperatures (white, silver, bareground) increased the number of plants forming heads ($P < 0.0001$) compared to other mulches (black, blue, and red).

A higher percentage of plants bolted from the black (23%) and red (25%) treatments at the end of the experiment in 1998 (Table 2) than on lighter mulches ($P < 0.001$). Under long days, radicchio flowering induction occurs (Gianquinto, 1997). Red mulch would increase the far red : red light ratio in the plant canopy, creating "long-day" type conditions. Therefore, red mulch could increase bolting; however, no difference was measured between red and black mulch, suggesting that red color did not affect bolting by modifying light quality.

Earliness. In 1997, none of the treatments resulted in earliness of head formation compared with bareground culture (Table 1). At

the first harvest (12 Aug.), there were no significant differences among treatments for yield; however, the bareground treatment produced significantly higher yields than the black or red mulches at the second harvest (18 Aug.) (Table 1). In contrast, yields were higher ($P < 0.05$) on the first than on the second date from silver, blue, and red mulches in 1998, indicating that these treatments enhanced the earliness of head formation. From 75% to 85% of the total heads harvested from these treatments were taken on the first date (5 Aug.). Significantly higher yields were recorded for silver and blue mulch compared with white, black, and the bareground treatment at the first harvest (Table 2). On the second harvest, yields were similar for all treatments except the blue mulch (Table 2).

Head color quality. Color is an important quality trait of radicchio, and none of the mulch treatments affected head color intensity or hue (Table 3). The two tested cultivars did vary significantly in hue angle and lightness over the 2 years (Table 3). 'Rosso di Chioggia Medio no. 3' had a more intense, deeper red-purple color than the other cultivar.

Most vegetable crops grown on plastic in the Northeast use black plastic mulch. There has been much interest in the use of colored mulches, especially red, for production of fresh-market crops. However, our results with radicchio demonstrated that specialty crops might require different mulch treatments than those commonly selected by growers. Head formation of radicchio appeared sensitive to the modified climate provided by the mulches. The use of black, red, or blue mulch would not be recommended for radicchio grown in the Northeast. These treatments had yields that were 60% of white or silver mulch treatments. Red mulch did not increase the percentage of harvested heads or the yield of radicchio, as described for other crops (Decoteau et al., 1989, 1990). Red mulch color may have affected heading by manipulating the far red : red light ratio (Decoteau et al., 1989), but results did not permit separation of changes in spectral quality from temperature. Black mulch had significantly higher soil and air temperatures than red mulch, and also caused a high degree of bolting. Blue mulch was tested in only 1 year. The results suggested that this color increased the number of small heads

Table 2. Yield measurements from two radicchio cultivars grown on five mulch treatments and bareground in upstate New York in 1998.

	Total yield		Yield per date (kg)		Avg head	Bolting	Harvested	Small heads ^z		Large heads ^z	
Treatment	kg ^y	no.	5 Aug.	10 Aug.	wt (kg)	(%)	(%)	kg	%	kg	%
<i>Cultivar</i>											
Chioggia no. 1 ^x	3.2	11.3 b	2.1	1.2	0.28 a	21 a	58 b	0.9	35	2.4	65
Medio no. 3	3.5	13.4 a	2.2	1.3	0.26 b	14 b	72 a	1.0	39	2.5	61
<i>Mulch treatment</i>											
Bareground	2.6 c	12.8	0.9 b	1.7 ab	0.19 b	9	68	1.1	57 a	1.5 b	43 b
Silver	4.8 a	15.7	3.5 a	1.3 ab	0.30 a	9	82	1.3	35 ab	3.5 a	65 ab
White	4.0 ab	12.8	2.0 b	2.0 a	0.31 a	18	68	0.5	20 b	3.4 a	80 a
Red	3.1 bc	11.3	2.3 ab	0.8 ab	0.28 a	25	57	0.7	30 ab	2.4 ab	70 ab
Blue	3.1 bc	12.2	2.6 a	0.5 b	0.25 ab	18	63	1.5	57 a	1.6 b	43 a
Black	2.6 c	9.3	1.5 b	1.1 ab	0.28 a	23	49	0.5	25 b	2.1 b	75 a

²Small heads measured <9.5 cm and large heads were >9.5 cm in diameter.

³Mean values within the same column and factor (cultivar or mulch treatment) followed by the same letter were not significantly different at $P < 0.05$ using Fishers protected LSD. There were no significant interactions detected among cultivar and mulch treatments.

³Chioggia no. 1 = 'Rosso di Chioggia no. 1' and Medio no. 3 = 'Rosso di Chioggia Medio no. 3'.

Table 3. Color of wrapper leaves from two cultivars of radicchio grown in 1997 and 1998 in upstate New York.

Cultivar ^z	1997			1998		
	Lightness ^y	Chroma ^x	Hue angle ^w	Lightness	Chroma	Hue angle
Chioggia no. 1	41.2	12.4	69.5	40.7	17.0	66.8
Medio no. 3	35.4	12.2	29.4	33.4	14.6	24.2
	**	NS	*	**	**	**

^zChioggia no. 1 = 'Rosso di Chioggia no. 1' and Medio no. 3 = 'Rosso di Chioggia Medio no. 3'.

^yExpressed on a scale extending from 0 for black to 100 for white.

^xExpressed on a scale from 0 for gray to 60 for most intense color.

^wHue angles for primary colors are red, 0°; yellow, 90°; green, 180°; blue, 270°.

NS, *, ** Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

(<9.5 cm) produced in two cultivars of radicchio. Additional studies are required to determine if blue mulch color would consistently result in smaller heads.

Despite the generally moderate temperatures in the Northeast, the modified soil and air temperature microclimate of the white and silver mulches resulted in equal or better yields, head size, and percent harvested heads of radicchio compared with the bareground control. In addition, improved water management and weed control offered by mulches over bareground culture suggested an overall improvement to the production system. Silver mulch was especially promising for radicchio production. Eighty percent of plants produced marketable heads, which was higher than any other treatment, and these heads formed earlier on silver mulch than the control, white, and black mulch treatments. However, costs of this silver mulch are higher than for white mulch. Target market, labor costs associated with weeding and hand harvests, and number of harvests required to remove the majority of heads would affect the economics of produc-

tion and the selection of mulch type. Growers must assess their own markets and production system to determine if improved yield, uniformity, and earliness of radicchio grown on silver mulch would be economically justified compared with white mulch.

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