Production and Quality of White Asparagus Grown under Opaque Rowcovers

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Abstract. Black and white plastic rowcovers were established over field-grown 'Jersey Giant' asparagus (*Asparagus officinalis* L.). Spears were cut for 7 weeks. Season soil temperatures were lowest under white plastic and highest without plastic covering. Night air temperature under plastic covers was $\approx 1.4^{\circ}\text{C}$ higher than without plastic covering (control), but day air temperature was typically 10°C higher under black plastic, with temperatures under white plastic intermediate. Marketable yield ($\text{t}\cdot\text{ha}^{-1}$) was improved with the use of plastics as was total yield ($P = 0.05$), but spear number/ha was similar in all treatments. There was no consistent treatment effect on spear diameter. Average spear weight was higher when under plastic, whereas spear length was reduced compared with uncovered spears. There were no differences among treatments in spear fiber content, but spears grown under plastic covers were higher in soluble solids content, titratable acidity, and nitrate and lower in protein, ascorbic acid, and total phenolics than uncovered spears. Quantitative differences in these constituents were also a function of whether they were from the upper, middle, or lower spear segment. Very little chlorophyll and carotenoids were produced in the absence of light, but there was a chroma (color intensity) difference between spears grown under the two plastics.

White asparagus production is common in Asia and Europe. But fresh white asparagus is rare in major U.S. markets and, when available, costs two to three times as much as green asparagus.

In Germany, clear plastics have been used principally as a soil warming technique in green (Kromer, 1978) and white (Munz, 1970) asparagus production. On Cyprus, 1.5-m-high walk-in plastic tunnels in conjunction with black rowcovers provided maximum yield of white asparagus (Vakis et al., 1975). Black plastic alone did not improve earliness.

When asparagus is grown under conditions that allow spears to develop in darkness, chlorophyll is not synthesized and developing spears appear white. Raw white asparagus has been reported to be similar or higher in fiber, slightly lower in ascorbic acid and protein, but higher in soluble solids content (SSC) than green asparagus (Ketsa and Uthaburt, 1987; Lai et al., 1973).

Traditionally grown white asparagus requires mounding ≈ 0.5 m of soil over the

asparagus crowns. Soils subject to crusting or of high bulk density are not always suitable for white asparagus production. Harvesting is frequently done three times a day. During daylight, spears that have pierced through the soil surface are not saleable as white asparagus. Because of these and other problems (Vakis et al., 1975) associated with white asparagus production, we report on a method using opaque white and black plastic rowcovers as a simple tool for the production of white asparagus and examine the effects that cover types have on spear quality.

The production site consisted of an Enders stoney silt loam (clayey, mixed, thermic Typic Hapludults) that had been planted in Apr. 1986 to 'Jersey Giant' seedlings. Spacing and eventual crown depth were 30 cm and 15 cm, respectively, in rows 1.4 m apart. *N'*-(3,4-dichlorophenyl)-*N,N*-dimethylurea (diuron) and (2,4-dichlorophenoxy)-acetic acid (2,4-D) were applied on 10 Mar. 1989, before spear emergence, at 2 and 9 $\text{kg}\cdot\text{ha}^{-1}$, respectively. Ammonium nitrate was applied at 60 kg N/ha on 16 Mar. Griffolyn (Reef Ind., Houston, Texas), a nylon-reinforced 4-mil (0.1 mm) plastic fabric, which is white on one side and black on the other, was then used to establish either white or black rowcovers (as viewed from the outside). Plot length was 7.3 m. Wire hoops, spaced 1.8 m apart in the row, supported the rowcovers to a height of 0.35 m. Uncovered rows were used for the control treatment to produce green asparagus. The plastic covers were removed

to one side of the row each time the spears were harvested.

Single-ended thermocouples were connected to a CR-10 data logger (Campbell Scientific, Logan, Utah) to measure hourly soil and air temperatures 15 cm below and above the soil surface of one replicate. Spears were cut three times a week from 27 Mar. to 12 May. Immediately after cutting, spears were placed in opaque plastic bags. Objective color determination and subsequent sample preparation were done under diffuse light. After trimming length to 15 cm, spears < 9.5 mm in diameter (butt end) were counted, weighed, and culled. Marketable spears were ≥ 9.5 in diameter after trimming to 15 cm; those used for quality analysis weighed 10 to 20 g per 15 cm length. The spears were cut into three 5-cm segments consisting of upper (tip), middle, and lower (butt) sections, blanched for 3 min in boiling water, and frozen to -20°C after each harvest. Spear segments were pooled by harvest week for each replication of the rowcover treatments.

Spears were harvested after the 7th week of cutting to obtain spear length data, but only weeks 1 through 7 were included in the total season yield. On 26 May, spears 9 cm or longer from all treatments were marked 4 and 9 cm below the tip and remeasured on 29 May to determine length differences after 3 days of growth.

Spear pigments from a 5-cm-long segment 5 to 10 cm below the tip were measured by reflectance and spectrophotometry. Reflectance was measured with a CR100 Chroma Meter (Minolta, Ramsey, N.J.) standardized against a white plate having values for Y, x, and y of 87.4, 0.311, and 0.318, respectively. Chlorophylls and carotenoids from lyophilized mid-spear segments were extracted in 80% aqueous acetone and quantified spectrometrically using published extinction values for chlorophylls and carotenoids previously determined in 80% aqueous acetone (Wellburn and Lichtenthaler, 1984). Soluble solids concentration in juice pressed from the thawed samples before fiber analysis was read with an Atago Nlt hand-held refractometer (Atago Co., Japan). Protein was determined by AOAC automated Kjeldahl method 7.021 (Assn. of Official Analytical Chemists, 1980) and nitrate by specific ion

Fig. 1. Yields of asparagus produced under black or white covers and in the open (control) during 7 weeks of harvest. Letters apply to the respective weekly harvest date. Yields were similar during harvest weeks 1 and 2. $P = 0.05$.

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Fig. 2. Rowcover $\times$ spear segment interactions for percent soluble solids, ascorbic acid and total phenols concentrations, and for pH. Mean separation for segments within each cover treatment (lowercase letters) and treatments within a given segment (uppercase letters) were performed by LSD at $P = 0.05$. Plots covered with white or black plastic rowcovers produced white asparagus; plots without rowcovers produced green asparagus.

Table 1. Performance of row-covered asparagus during a 7-week cutting season.^a

Rowcover	Marketable spears			Cull spears		
	Count (no./ha, thousands)	Wt (t·ha ⁻¹)	Average spear wt (g)	Count (no./ha, thousands)	Average spear wt (g)	Total yield (t·ha ⁻¹)
None	201 a	2.20 b	11.3 b	122 a	3.5 b	2.62 b
Black	205 a	3.10 a	14.7 a	90 ab	4.8 a	3.56 a
White	200 a	2.88 ab	13.2 ab	80 b	4.3 ab	3.27 ab
	NS	**	**	**	*	**

^aMeans of four replications separated by LSD (0.05 or 0.01).

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

Table 2. Effect of rowcovers on spear length and on 3 days of growth of a 5-cm marked spear segment.

Rowcover	Week 9 (19–26 May)	Week 10 (29 May)	
	Spear length (cm)	Spear length (cm)	Segment increase (cm)
None	33.3 a ^z	47.2 a	4.9 a
Black	22.6 b	25.0 b	0.9 b
White	24.7 b	28.5 b	1.1 b
	**	**	**

^zMeans of four replications separated by LSD, $P = 0.01$.

electrode (Amer. Soc. of Agronomy, 1982). Fiber content was determined by the blender method of Smith and Kramer (1947). As-

corbic acid levels were measured by the modified method of Morell (1941) in which 3% metaphosphoric acid was substituted for 1% oxalic acid in the extraction solution. Total phenolics were determined by the colorimetric method described by Swain and Hillis (1959) in which the Folin-Ciocalteu reagent was used. The standard curve was developed with chlorogenic acid. The pH and titratable acidity were determined in a 50-ml filtrate obtained from a blend of 10 g frozen sample in 100 ml deionized water. The filtrate was titrated to pH 8.2 with 0.01 N NaOH.

A trained, blindfolded, 10-member taste panel evaluated spear segments from the three treatments for sweetness and flavor intensity. A scale of 1 (very low) to 6 (highest) was used (Larmond, 1967).

Rowcovers (main unit) were replicated in

the field in four randomized complete blocks. Statistical differences were determined by analysis of variance. When measurements by spear segment were included, the analysis was performed as a split-plot design with spear segments as the subplot treatment. In the sensory evaluation, every rowcover treatment by spear segment combination was evaluated in a random order by each one of the 10 panelists. The effects of rowcovers and spear segment on the sweetness and flavor intensity were analyzed as a split plot where rowcovers were the main plots, segments the subplots, and panelists the replications.

Daily soil temperatures at 15 cm oscillated the most in uncovered soil throughout the cutting season and were generally higher than in plastic-covered soil, with the exception of

Table 3. Effect of rowcover on objective color, chlorophylls, carotenoids, protein, and NO₃-N of sections 5 to 10 cm below the asparagus spear tip.^z

Rowcover	CDM ^y			Hue angle tan (b/a)	Chroma (a ² + b ²) ^{1/2}	Chlorophyll ^x (mg·g ⁻¹)	Chlorophyll a : b ratio	Carotenoids ^x (mg·g ⁻¹)	Protein ^x (%)	NO ₃ -N ^x (ppm)
	L	a	b							
None	50.5 b	-11.3 b	28.2 a	-68.5 b	30.4 a	1.120 a	3.74 a	0.387 a	32.9 a	162 b
Black	74.8 a	1.5 a	15.8 b	30.3 a	16.1 b	0.023 b	2.24 b	0.030 b	28.0 b	263 a
White	75.0 a	2.0 a	13.9 c	63.6 a	14.3 c	0.019 b	1.77 b	0.021 b	26.8 b	241 a
	**	**	**	**	**	**	*	**	**	**

^zMeans of four replications separated by LSDP = 0.05(*) or 0.01(**).^yColor Difference Meter (CDM) values for 'L' = Lightness, 'a' = greenness, and 'b' = yellowness.^xDry-weight basis.Table 4. Effect of rowcover and spear segment on titratable acidity and taste panel evaluation of sweetness and flavor intensity of harvested spears.^z

Main effect	Titratable acidity ^y (mcq/100 g)	Taste panel score ^x	
		Sweetness	Flavor intensity
Rowcover (RC)			
None	0.050 b	2.6 b	3.4 a
Black	0.058 a	3.5 a	3.3 a
White	0.057 ab	3.6 a	3.1 a
	**	**	NS
Segment			
Upper	0.056 ab	2.4 b	4.1 a
Middle	0.059 a	3.6 a	3.0 b
Lower	0.050 b	3.7 a	2.8 b
	*	**	**
RC × segment	NS	NS	NS

^zMeans separated by LSD. Nonsignificant (NS) or significant at $P = 0.05$ (*) or $P = 0.01$ (**).^yFrom spears in harvest week 7.^xFrom spears in week 6, 1 = low and 6 = high.

black-plastic-covered soil very early in the season. Soil under white plastic was coolest. Mean soil/air temperatures for uncovered, white and black plastic were 17.4/17.0, 15.9/17.2, and 16.8/20.2°C, respectively. On 28 Apr., a canopy temperature of 57°C was recorded under black plastic, but no subsequent spear damage was observed. Average air minima were ≈ 1.4 °C higher under both plastics than over bare soil. Opaque plastics reduced the fluctuation in soil temperatures at 15 cm depth (data not shown).

The number of marketable spears (mean diameter of 13 mm at the base) produced was not affected by row covering during the 7 weeks of cutting (Table 1). The weight of marketable spears produced, average spear weights, and total yield were not affected by white covers, while cull spear count was decreased, compared with bare soil (control). In contrast, use of black covers led to increases in the total weight of marketable spears produced and in total yield compared with bare soil, due to increases in average spear weight. Percent marketable yield was not significantly improved by covering spears.

Black covers enhanced harvest yields during the 3rd and 5th weeks of cutting (Fig. 1). Spear yields from white-covered rows were similar to no covers until the 4th cutting week. Yields from all treatments declined after the 5th week of cutting, with spears grown under black plastic showing the greatest percentage decrease.

Spears grown under white or black plastic picked during weeks 9 and 10 were shorter than the control spears (Table 2). After 3 days, the marked 5-cm section of uncovered spears grew ≈ 5 times as much as those covered. Axial breaks and lateral development

of the spear tips appeared to be more advanced or open when grown in the light. We do not know whether these differences existed before the 9th week.

Asparagus spears produced under white and black plastic covers were similar in most objective color attributes except chroma (Table 3). The higher chroma values of the black-covered spears confirmed the subjective observation that these spears were more cream- or yellowish-white than those from under the white covers. The color of both spear populations overlapped as noted by the lack of significant difference between black and white cover treatments in hue (data not shown) and hue angle. The average amount of chlorophyll and carotenoids found in asparagus produced under white and black covers was typically one-fiftieth and one-fifteenth, respectively, that of uncovered asparagus. There was less chlorophyll 'a' relative to chlorophyll 'b' in rowcovered spears but more carotenoids relative to chlorophylls (ratio of carotenoids to chlorophylls) than in uncovered spears. The importance of these amounts and ratios is unclear because of the small amounts detected in crude extracts.

The percentage protein found in mid-spear segments was 15% and 18% lower, respectively, in spears from rows covered with black and white plastic than in uncovered spears (Table 3), indicating that white asparagus had significantly less protein than green. Nitrate levels were 62% and 49% higher in asparagus from black and white rowcovers, respectively, than in green spears. Both protein and nitrate levels changed over the harvest season, with maximum levels generally associated with the peak season yield in harvest week 5 (data not shown). Nitrate and

protein levels were correlated ($r = -0.433$, $P = 0.003$), over harvest weeks 3 through 7. Although the incorporation of NO₃-N into protein and other forms of organic N appears to be reduced in spears grown in darkness, the higher NO₃ levels found in white spears should not be a dietary concern (Maynard and Barker, 1972).

A significant interaction of rowcovers by spear section showed that the middle and lower segments were higher in SSC than the tip (Fig. 2). However, SSC distribution was different in white and green asparagus. In white asparagus the highest concentration of SSC was observed in the middle segment, while the tip had the lowest concentration. In green asparagus (no rowcovers) the middle and lower segments had similar SSC and these were higher than that in the tip (Fig. 2). The higher levels of SSC were detected as a significant difference in sweetness by the panelists (Table 4). This is in agreement with the reported higher accumulation of glucose, fructose, and sucrose in the spear middle and lower sections (King et al., 1988). The difference in SSC may be different in other cultivars and/or areas of cooler day/night temperatures. Ketsa and Uthairurt (1987) reported that SSC in Thailand-grown 'UC-309' white asparagus was higher than in green asparagus by 4.5% (9.7% vs. 5.1%).

The results also showed that upper and middle segments of white asparagus had higher SSC than those of the green asparagus. SSC in the middle segments of spears obtained from under the white cover was higher than that of spears from under the black cover. SSC of upper sections of spears from under white or black covers was similar. No significant differences in SSC were observed between the lower spear segments in either green or white asparagus (Fig. 2). No differences in fiber content were detected (data not shown).

Ascorbic acid (AA) and total phenolics contents of the samples followed similar patterns; highest levels were noted in the upper segment of the spears and they gradually decreased basipetally in white and green asparagus. Green asparagus had significantly higher levels of AA and phenols in all spear segments compared with white asparagus (Fig. 2). Similar distribution of AA has been reported in green 'Registered Washington' asparagus grown in southern Manitoba (Shewfelt and Mohr, 1960). Lai et al. (1973) reported AA values of 38.1 and 19.8 mg/100 g for green and white asparagus, respectively. These values are similar to the ones reported herein.

Maga (1978) suggested that high phenolic content was associated with high flavor intensity. In this study, no difference in flavor intensity between cover treatments was observed. However, the higher flavor intensity observed in upper segment of the spear may be associated with high spear phenolic content (Table 4, Fig. 2).

The phenolic content of green asparagus in the upper, middle, and lower segments was higher than their respective segments in white asparagus. However, a significant interaction between cover treatments and spear segment indicated differences in phenolic content between upper segments of green and white spears. Middle and lower spear sections from spears grown under white and black plastic covers were similar in phenolic content. A decrease in phenolic content was observed between the upper, middle, and lower spear segments in green and white asparagus obtained from the white cover treatment. Phenolic content of the upper segment of white asparagus obtained from the black cover treatment was higher than that in the middle and lower segments, but differences in phenolic content between the middle and lower segments were not significant (Fig. 2).

The pH of green and white spears decreased basipetally. However, a significant interaction between rowcover treatment and spear segment showed that green asparagus (no rowcover) had a higher pH in the upper and middle sections than white asparagus. The lower section of both green and white spears had similar pH (Fig. 2).

Total organic acid components, as measured by total titratable acidity, tended to be higher in white spears than in green; however, only white asparagus produced under black plastic was significantly different from green asparagus. Lai et al. (1973) reported similar levels of titratable acidity for white and green asparagus grown in Taiwan. The middle segment of the spear had a higher titratable acidity than did the lower segment of the spear (Table 4).

On 11 Apr., minima of -6.2, -4.4, and -4.8°C were recorded for the control, black, and white plastic covers, respectively. After 10 h of temperatures <0°C, spear damage was ≈100%, 50%, and 20%, respectively. The higher levels of SSC (sugars) in the white asparagus and freeze protection of the covers may have contributed to this observed low temperature tolerance.

Opaque plastic rowcovers were used successfully to produce white asparagus, a high value crop. High canopy temperatures did not reduce spear quality. In addition to affecting the time of production, plastic barriers to light had an effect on spear quality components. Additional potential benefits of covers include: protection against short duration frost (to about -4°C), higher trimmed spear weights, and, under commercial conditions, less frequent cutting. White asparagus production using opaque plastic covers requires more labor and material inputs than production of green asparagus, but return on investment can be substantial (Makus, 1990).

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