Original article

Influence of row covers and mulching interaction on leaf physiology, fruit yield and albinism incidence in 'Sweet Charlie' strawberry (*Fragaria* x *ananassa* Duch.)

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Influence of row covers and mulching interaction on leaf physiology, fruit yield and albinism incidence in 'Sweet Charlie' strawberry (*Fragaria* x *ananassa* Duch.).

Abstract — Introduction. Under the sub-tropical climate of India, 'Sweet Charlie' strawberry is being grown on a large scale. However, under such climatic conditions, it is not possible to transplant runners before mid-October, because the environmental temperature is very high, and planting after mid-October is also not good because then winter sets in and affects growth, development, flowering and fruiting of strawberry. Under such circumstances, covering of strawberry beds with row covers and mulching with plastic mulch can be useful for early and high production by way of modifying the leaf physiology and producing marketable berries in high number. **Materials and methods**. Row covers of transparent polyethylene (100-µm thickness) were erected over beds after one month of transplanting of the runners. Mulching (black polyethylene, white polyethylene and paddy straw) was also applied after one month of transplanting of the runners; it was removed only after fruiting was over. Observations on different leaf physiological parameters were made. **Results**. Row covers and mulching individually or in combination significantly influenced plant physiology, growth, berry yield attributes and albinism incidence. Plants showed better growth and physiological attributes under row covers than without row covers. Plants had the best growth and physiological attributes under black polyethylene mulch. Berry weight and yield were the highest in plants under row covers and black polyethylene mulch. Although the [row covers × mulching] interaction showed the highest incidence of albinism, berry yield per plant (excluding albino fruit) was significantly the highest with that combination. **Conclusion**. Erection of row covers and mulching in winter is highly useful for better growth and production of strawberry under a sub-tropical climate.

India / *Fragaria ananassa* / mulches / plastic film / straw mulches / growth / plant physiology / leaves / yields / albinism

Influence de l'interaction entre couverture des rangs et paillis sur la physiologie des feuilles, le rendement en fruits et l'incidence de l'albinisme chez le fraisier 'Sweet Charlie' (*Fragaria* x *ananassa* Duch.).

Résumé — Introduction. Sous le climat subtropical indien, le fraisier 'Sweet Charlie' est cultivé à grande échelle. Cependant, dans de telles conditions climatiques, il n'est pas possible de transplanter les marcottes avant mi-octobre car la température ambiante est très élevée, et une plantation après mi-octobre n'est pas efficace non plus car, alors, l'hiver intervient et affecte la croissance, le développement, la floraison et la nouaison du fraisier. Dans de telles circonstances, la protection de lits de fraisiers à l'aide d'une couverture de rangs et d'un paillis de plastique pourrait être utile pour une production précoce et élevée, induite par une modification de la physiologie des feuilles et une récolte de davantage de fruits commercialisables. **Matériel et méthodes**. Des couvertures de rangs en polyéthylène transparent (100 µm d'épaisseur) ont été érigées au-dessus des lits de fraisiers un mois après la transplantation des marcottes. Un paillage (polyéthylène noir, polyéthylène blanc, paille de riz) a été également appliqué un mois après la transplantation des marcottes ; il a été enlevé seulement après la production des fruits. Des observations ont été faites sur différents paramètres physiologiques des feuilles. **Résultats**. La couverture des rangs et le paillage utilisés seuls ou en combinaison ont influencé significativement la physiologie de la plante, sa croissances, son rendement en fruits et l'incidence de l'albinisme. Les plants ont montré une meilleure croissance et des caractéristiques physiologiques améliorées sous couvertures des rangs par rapports aux plants menés sur rangs nus. Cette croissance et ces caractéristiques physiologiques ont été les meilleures sous paillis de polyéthylène noir. Le poids des fruits et leur rendement ont été les plus hauts pour les plants sous couverture de rangs et sous paillis de polyéthylène noir. Bien que l'interaction [couverture de rang × paillis] ait entrainé le taux d'albinisme le plus élevé, le rendement en fruits par plant (à l'exclusion des fruits albinos) a été significativement le plus fort avec cette combinaison. **Conclusion**. La pose de couvertures de rangs et de paillis en hiver est vivement recommandée pour induire une croissance et une production de fraises optimales sous climat subtropical.

Inde / *Fragaria ananassa* / mulch / film plastique / paillis / croissance / physiologie végétale / feuille / rendement / albinisme

1. Introduction

Strawberry is known as one of the most delicious and refreshing fruit of the world. Compared with other fruit crops, it gives early and high returns per unit area, as the crop is ready for harvesting within 6 months after planting [1]. Although it is an important fruit crop of temperate climates, it grows profitably well in the tropical and sub-tropical climates of India, and a phenomenal increase in its area has been observed during recent years. Under a sub-tropical climate, the 'Chandler' cultivar is grown extensively, but recent studies indicate that 'Sweet Charlie' performs better than 'Chandler' and its popularity is increasing among growers day by day [1]. However, under such climatic conditions, it is not possible to transplant runners before mid-October, because the environmental temperature is very high, which affects the proper establishment of runners. Similarly, planting after mid-October is also not considered good, because then winter sets in, which also affects the growth and development of strawberry plants adversely, and thus delays flowering and fruiting. Further, low temperature and frost during winter damage or curtail the production of flowers; as a result, low yields of poor quality are produced. Under such circumstances, covering of strawberry beds with row covers can be quite useful for early and higher production [2, 3]. Row covers modify the microclimate, which helps with better establishment and development of the runners, and initiation of early flowering and fruiting by influencing the leaf physiology, and producing marketable berries in higher number [4].

Mulching is considered as the most important cultural practice in strawberry, which provides better weed control, modifies soil hydrothermal regimes and thus influences plant growth and development, and productivity of strawberry [5, 6]. For mulching, different materials are used but black polyethylene is preferred throughout the world and, in India, paddy straw is easily and cheaply available. Hence, our studies were undertaken to determine if row covers and different mulching materials influence leaf physiology, plant growth, fruit yield and albinism incidence, a serious disorder in the 'Sweet Charlie' cultivar.

2. Materials and methods

2.1. Experimental site and material

Our studies were conducted at the experimental farm of the Division of Fruits and Horticultural Technology, IARI, New Delhi, India, during 2003 and 2004. The soil of the experimental farm was sandy-loam, low in organic carbon, medium in available phosphorus and high in potash, with pH 8.5. Soil was thoroughly ploughed and leveled, and raised beds of 25 cm height and 1 m width were prepared, spaced 50 cm apart. Runners of 'Sweet Charlie' were procured from the IARI Regional Research Station, Shimla, India, and planted on the raised beds at a planting distance of 25 cm × 25 cm during the second week of October. Mulching materials, *viz.* black polyethylene, white polyethylene and paddy straw, were applied 30 days after planting, and no mulch was applied to beds under control. Each treatment consisted of five beds, replicated three times.

2.2. Erection and removal of row covers

Row covers of transparent polyethylene (100 µ) were deployed over some beds after 30 days of planting, whereas other beds were left uncovered (control). Row covers were removed by the end of February when the environmental temperature started rising. All necessary cultural practices and plant protection measures were uniformly followed for all the plots and treatments during the entire experimentation period.

2.3. Observations recorded and methodology

Observations on the plant growth parameters, such as crown height, plant spread, number of leaves and leaf area, were recorded in ten randomly-selected plants per bed. Standard procedures were adopted for recording these parameters.

Leaf physiological parameters, such as photosynthetic rate, stomatal density and total chlorophyll content, were measured in five fully mature leaves from ten randomly-selected plants per bed. The photosynthetic rate of the leaves was measured by portable IRGA and represented as µmol $CO_2 \cdot m^{-2} \cdot s^{-1}$. Stomatal density was measured by the quick-fix method as described by Sharma *et al*. [7]. Total leaf chlorophyll contents were determined from uniform-sized leaves: eight 0.32-cm leaf discs were removed from each leaf; discs were washed with distilled water in the laboratory before being placed in 10 mL of 80% methanol, and kept in darkness at room temperature for 48 h. The discs appeared yellow and the chlorophyll content was determined from absorption values obtained at 642 nm and 664 nm with a Bausch and Lomb spectronic 21 spectrophotometer [8] and represented as µg of chlorophyll·cm^{-2}.

Albinism incidence was recorded in ten randomly-selected plants per bed. For this, total healthy (normal) and albino fruit were counted in the selected plants and albino fruits represented as a percentage of total fruit. Berry yield was taken from ten randomly-selected plants per bed. For this, fruits of marketable acceptability (excluding albino fruits) were taken into account from primary, secondary and tertiary flowers only, but the fruits of late flushes were ignored.

2.4. Statistical procedures and analysis of data

The whole experiment was laid out in a split-plot design with four replications, keeping row covers as main effect and mulching treatments as sub-effects. The pooled data obtained from different parameters were analyzed statistically, following a split-plot design [9].

3. Results

3.1. Leaf physiological parameters

Row covers, mulching and their interaction significantly influenced the leaf physiology of 'Sweet Charlie' strawberry (*table I*). Under row covers, leaves had a significantly higher rate of photosynthesis (7.28 $CO_2 \cdot m^{-2} \cdot s^{-1}$), stomatal density (16.3 stomata per unit leaf area) and total chlorophyll content (34.5 µg·cm^{-2}) compared with those grown without row covers (*table I*). Irrespective of row covers, the photosynthetic rate was significantly higher in plants mulched with black polyethylene (7.69 $CO_2 \cdot m^{-2} \cdot s^{-1}$), which was progressively lesser in plants mulched either with white polyethylene (6.76 $CO_2 \cdot m^{-2} \cdot s^{-1}$) or paddy straw (6.51 $CO_2 \cdot m^{-2} \cdot s^{-1}$), or control (6.18 $CO_2 \cdot m^{-2} \cdot s^{-1}$). A similar trend was also observed for stomatal density and leaf chlorophyll content, which were significantly higher in plants mulched with black polyethylene, and progressively lesser in plants mulched with white polyethylene, paddy straw or when no mulch was applied (*table I*). The interaction [row cover × mulching] was also significant as plants grown under row covers and mulched with black polyethylene had a significantly higher rate of photosynthesis (8.36 $CO_2 \cdot m^{-2} \cdot s^{-1}$), stomatal density (18.6 stomata per unit leaf area) and total chlorophyll content (39.6 µg·cm^{-2}) than those grown without row covers and mulched either with white polyethylene or paddy straw (*table I*).

3.2. Plant growth parameters

Row covers, mulching and their interaction significantly influenced the plant growth parameters of 'Sweet Charlie' strawberry (*table II*). Irrespective of mulching, plants grown under row covers had significantly better crown height (8.86 cm), plant spread (18.78 cm), number of leaves (22.88) and leaf area (42.52 cm^2) than those grown without covers. Similarly, plants mulched with black polyethylene had significantly higher crown height (10.02 cm), crown spread (21.23 cm), leaf number (24.77) and leaf area (48.55 cm^2) than those mulched either with white polyethylene or with paddy straw. However, plants grown without mulch (control) had the least crown height (6.96 cm), crown spread (14.51 cm), leaf number (17.94) and leaf area (32.46 cm^2) (*table II*). Further, the interaction [row cover × mulching] was also significant for all the growth parameters, as plants under row covers and

Table I.
Effect of row covers with transparent polyethylene (100 µ) and mulching on leaf physiology of 'Sweet Charlie' strawberry plants.

Treatment	Photosynthetic rate ($CO_2 \cdot m^{-2} \cdot s^{-1}$)			Stomatal density per microscopic field (10×)			Leaf chlorophyll content ($\mu g \cdot cm^{-2}$)		
	Row covers	Without covers	Mean	Row covers	Without covers	Mean	Row covers	Without covers	Mean
Black polyethylene	8.36	7.02	7.69	18.6	16.4	17.5	39.6	34.3	36.9
White polyethylene	7.32	6.21	6.76	16.8	14.9	15.8	35.4	31.9	33.6
Paddy straw	7.01	6.01	6.51	15.3	14.1	14.7	32.7	30.5	31.6
Without mulch	6.42	5.94	6.18	14.6	13.2	13.9	30.4	28.7	29.6
Mean	7.28	6.29	–	16.3	14.6	–	34.5	31.3	–
Least significant difference (0.05)	Row cover = 0.34 Mulching = 0.31 [Row cover × mulching] = 0.52			Row cover = 1.12 Mulching = 0.89 [Row cover × mulching] = 2.13			Row cover = 1.21 Mulching = 1.17 [Row cover × mulching] = 3.24		

Table II.
Growth parameters of 'Sweet Charlie' strawberry plants as influenced by row covers with transparent polyethylene (100 µ) and mulching.

Treatment	Crown height (cm)			Crown spread (cm)			Leaf number			Leaf area (cm^2)		
	Row covers	Without covers	Mean	Row covers	Without covers	Mean	Row covers	Without covers	Mean	Row covers	Without covers	Mean
Black polyethylene	10.82	9.22	10.02	22.32	20.15	21.23	26.42	23.12	24.77	52.45	44.65	48.55
White polyethylene	9.32	8.25	8.78	19.72	18.20	18.96	23.86	20.43	22.14	44.72	37.52	41.12
Paddy straw	8.10	7.11	7.61	17.45	16.12	16.78	21.74	17.25	19.49	38.21	32.71	35.46
Without mulch	7.22	6.71	6.96	15.64	13.37	14.51	19.52	16.37	17.94	34.70	30.23	32.46
Mean	8.86	7.82	–	18.78	16.96	–	22.88	19.29	–	42.52	36.28	–
Least significant difference (0.05)	Row cover = 0.27 Mulching = 0.35 [Row cover × mulching] = 0.56			Row cover = 1.21 Mulching = 1.43 [Row cover × mulching] = 2.76			Row cover = 1.27 Mulching = 1.78 [Row cover × mulching] = 2.45			Row cover = 3.42 Mulching = 2.91 [Row cover × mulching] = 6.74		

Table III.
Influence of row covers with transparent polyethylene (100 μ) and mulching on berry weight, yield and albinism incidence for 'Sweet Charlie' strawberry plants.

Treatment	Berry weight (g)			Fruit yield (g per plant)			Albinism incidence (%)		
	Row covers	Without covers	Mean	Row covers	Without covers	Mean	Row covers	Without covers	Mean
Black polyethylene	12.24	11.37	11.81	104.5	87.5	96.0	19.6	18.2	18.4
White polyethylene	11.72	11.02	11.37	92.1	79.2	85.7	14.2	12.8	13.5
Paddy straw	11.13	10.64	10.89	80.4	65.4	72.9	10.2	8.7	9.5
Without mulch	10.42	10.04	10.23	68.6	58.3	63.5	24.3	21.2	22.7
Mean	11.38	10.77	–	86.4	72.6	–	17.1	15.2	–
Least significant difference (0.05)	Row cover = 0.34 Mulching = 0.53 [Row cover × mulching] = 0.74			Row cover = 7.83 Mulching = 8.46 [Row cover × mulching] = 12.7			Row cover = 1.17 Mulching = 1.73 [Row cover × mulching] = 3.21		

mulched with black polyethylene had better crown height (10.82 cm), plant spread (22.32 cm), leaf number (26 42) and leaf area (52.45 cm^2) than those grown without covers and mulched either with white polyethylene or paddy straw, or when no mulch was applied (*table II*).

3.3. Berry weight and yield

Row covers, mulching and the [row cover × mulching] interaction significantly influenced the individual berry weight and fruit yield of 'Sweet Charlie' strawberry (*table III*). Irrespective of mulching, plants under row covers produced better-sized fruit (11.38 g) and had higher fruit yield (86.4 $g \cdot plant^{-1}$) than those grown without row covers. Similarly, plants mulched with black polyethylene produced better-sized fruit (11.81 g) and had higher yield (96 $g \cdot plant^{-1}$) than those mulched either with white polyethylene or paddy straw, or when no mulch was applied (*table III*). The [row cover × mulching] interaction was also significant as plants under row covers and mulched with black polyethylene produced fruit of the best size (12.24 g) and had maximum yield (104.5 $g \cdot plant^{-1}$) compared with those grown without covers and mulched either with white polyethylene or paddy straw, or when no mulch was applied (*table III*).

3.4. Incidence of albinism

Row covers, mulching and the [row cover × mulching] interaction influenced the occurrence of albinism disorder in 'Sweet Charlie' strawberry. Plants raised under row covers produced albino fruit in higher percentage (17.1%) than those which were left uncovered (15.2%). Further, among different mulches, plants under black polyethylene produced albino fruit in higher percentage (18.4%) than those mulched either with white polyethylene (13.5%) or when paddy straw was used as mulch (9.5%), but lesser than those grown without any mulch. Interestingly, plants grown without mulch produced albino fruit in higher percentage (22.7%) than those mulched with either black polyethylene, white polyethylene or paddy straw (*table III*).

4. Discussion

4.1. Leaf physiological attributes

Plants under row covers had better physiological attributes than those without row covers, which may primarily be because of modification in the temperature inside the covers. During winter, the temperature is

quite low in the open fields under sub-tropical climatic conditions, which affects the leaf physiology, establishment and growth of strawberry runners under open fields. Pollard [10] has also reported alteration in some leaf physiological parameters of strawberry (*e.g.,* carbon assimilation) under row covers. Differential influence of mulch materials on leaf physiological parameters may be due to their differential behavior in modifying hydrothermal regimes, weed population and suppression of their growth, and nutrient supply [6]. Further, plants mulched with black polyethylene had a higher photosynthetic rate, stomatal density and chlorophyll content than those mulched with other materials. It may be due to the fact that black polyethylene is considered as the most ideal mulch material for strawberry, which modifies the microclimate more efficiently than other mulches [6, 11, 12]. Further, the interactive influence of [row cover × mulching] is indicative of their synergistic effect in modifying the leaf physiology of strawberry [6, 13, 14].

4.2. Plant growth parameters

Plants under row covers had better growth than without row covers, which may probably be due to modification in seasonal low temperatures [2, 10, 15]. Moreover, plants under row covers have better physiological attributes, which might have favored better growth and development of the plants under row covers than without row covers. Similarly, plants mulched with black polyethylene had higher crown height, crown spread, number of leaves and leaf area than those mulched either with white polyethylene or paddy straw, or when no mulch was used. This significant and positive influence of mulching on plant growth may be due to better conservation of moisture, regulation of temperature and suppression of weeds under black polyethylene [11, 16–18]. Further, the [row cover × mulching] interaction for all the growth parameters was also significant, indicating that the use of both row covers and mulching in 'Sweet Charlie' strawberry synergistically improved the plant growth, mainly by modifying the microclimate [13, 14].

4.3. Berry weight and fruit yield

Production of better-sized fruit and higher berry yield by strawberry plants under row covers than by those without covers may be due to better growth of the plants attained due to development of a favorable microclimate inside the row covers. Gast and Pollard [13, 14] and Pollard *et al.* [15] have also reported higher yield of strawberry under row covers than without row covers. Further, plants mulched with black polyethylene produced better-sized berries and, consequently, produced higher yield than other mulches or control. It may primarily be due to better growth of the plants under black polyethylene, which helped the plants to produce higher yield [6, 10, 13, 19]. The interaction [row cover × mulching] was also significant, indicating the interactive influence of row covers and mulching on yield increase, which may probably be due to better growth and development of the plants by using row covers and black polyethylene mulch.

4.4. Incidence of albinism

Plants under row covers produced albino fruit in higher percentage than those without row covers, which may be due to vigorous growth of the plants, resulting from better mobilization of the nutrients [6, 18, 20]. Our findings also supported these results, as the leaf physiological and growth parameters of 'Sweet Charlie' strawberry were significantly the highest in the plants grown under row covers. Plants mulched with black polyethylene produced albino fruit in higher percentage than those with other mulches, probably due to better growth of plants under black polyethylene mulch [6, 21]. Further, the vigorous growth of plants is not the only factor which favors albinism in strawberry; there are several other factors such as field heat, soil heat or direct contact of berries with soil which can act on this character [1, 19–21]. Interestingly, un-mulched plants produced maximum albino fruit although they were not vigorous, which reveals the importance of mulching in strawberry. It has been demonstrated that fruits produced by un-mulched plants

come into direct contact with hot soil: as a result, they turn albino. It indicates that growing of strawberries without mulch in warm localities is not desirable as a very high percentage of fruit may turn albino, or rot excessively [16, 19]. Although albino fruits were also produced in higher proportion with black polyethylene mulch than with other mulches, the total higher fruit yield and quality over other mulches favor the use of black polyethylene even under a sub-tropical climate.

5. Conclusions

Our studies indicated that use of row covers and black polyethylene mulch in 'Sweet Charlie' strawberry during winter is very useful for better growth and development of runners, which help to achieve better-sized fruit and higher yield per plant under the sub-tropical climate of India.

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Influencia de la interacción existente entre cubierta de las hileras de plantación y acolchado sobre la fisiología de las hojas, el rendimiento en frutos e incidencia del albinismo en la fresa 'Sweet Charlie' (*Fragaria* x *ananassa* Duch.).

Resumen — Introducción. Bajo el clima subtropical indio, la fresa 'Sweet Charlie' se cultiva a gran escala. No obstante, en tales condiciones climáticas, no es posible transplantar los esquejes antes de mediados de octubre, ya que la temperatura ambiente es muy elevada; y, una plantación después de mediados de octubre tampoco es eficaz, debido a que entonces interviene el invierno y afecta el crecimiento, el desarrollo, la floración y la fructificación de los frutos de la fresa. En tales circunstancias podría resultar útil para una producción precoz y elevada, inducida por una modificación de la fisiología de las hojas y una cosecha de más frutos de comercialización, la protección de tongadas de fresa con la ayuda de una cubierta de las hileras de plantación y de un acolchado. **Material y métodos**. Se erigieron cubiertas de filas de polietileno transparente (100 µm de grosor) encima de las tangadas de fresa un mes después del transplante de los esquejes. Asimismo se aplicó un acolchado (polietileno negro, polietileno blanco, paja de arroz) un mes después del transplante de los esquejes, el cual se retiró únicamente tras la producción de los frutos. Se llevaron a cabo observaciones sobre diferentes parámetros fisiológicos de las hojas. **Resultados**. La cubierta de las hileras de plantación y el acolchado, empleados juntos o por separado, influyeron significativamente la fisiología de la planta, sus crecimientos, su rendimiento en frutos y la incidencia del albinismo. En comparación con las plantas tratadas en hileras al desnudo, las plantas mostraron un crecimiento mejor, así como características fisiológicas mejoradas bajo cubiertas de hileras de plantación. Dicho crecimiento y dichas características fisiológicas han sido mejores bajo acolchado de polietileno negro. El peso de los frutos y su rendimiento han sido más altos para las plantas bajo cubiertas de hileras de plantación y bajo acolchado de polietileno negro. A pesar de que la interacción [cubierta de hilera de plantación × acolchado] haya conllevado el índice de albinismo más elevado, el rendimiento en frutos por planta (a excepción de los frutos albinos) fue significativamente más fuerte con esta combinación. **Conclusión**. Se recomienda la colocación de cubiertas de hileras y de acolchados en invierno para inducir un crecimiento y una producción de fresas óptimas bajo clima tropical.

India / *Fragaria ananassa* / material orgánico de cobertura / película plástica / cobertura con paja / crecimiento / fisiología vegetal / hojas / rendimiento / albinismo