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Plastic cover film on table grapes from field to cold storage

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Abstract. Plastic film covers are commonly used in viticulture to shield table grape vines from harsh weather and minimize the impact of fungal diseases. The type of plastic film affects how it absorbs and reflects solar radiation, which can influence the wavelengths passing through the covering. The interaction of wavelength bands selected by the different covers with the vines underneath could influence grape ripening and yield and consequently influence shelf life. The study investigated the effects of three plastic films on two different table grape varieties IFG Eleven (Sugar Crisp™) and Italia, at harvest, focusing on quantitative parameters such as yield, juice chemical composition (including pH, TSS, and TA), and conducting a berry texture analysis. For the "Italy" variety, there was no statistically significant change in yield when using different plastic films. In contrast, a statistical difference was observed in the yield of the IFG Eleven variety. For the berry carpometric parameters, statistically significant differences were found in bunch length and width only in the IFG Eleven variety with different plastic films. The study also examined the pros and cons of using various plastic films on grape during cold storage, based on an analysis of texture and color parameters. The results indicated that the choice of plastic films impacted the quality and shelf-life of items during cold storage.

1. Introduction

The cultivation of table grapes requires the protection of vineyards with plastic film to protect the vegetation and bunches from external agents and to condition the microclimate. By using plastic, growers extend the harvest period by advancing or delaying grape ripening and improving grape quality [1-2]. Since plastic films are applied to the vineyard at the beginning of the growth cycle, it is important that their radiometric properties do not cause environmental stress to the vines. In fact, plastic films need to have the right levels of absorbed, transmitted and reflected radiation [3-4]. This phenomenon is specific to the radiometric and material properties of the plastic film, but could also interact with local agricultural practices.

Although table grapes are protected to be harvested after physiological ripening, they are usually subjected to a medium cold storage period before being marketed. During cold storage, grapes undergo changes in their visual, mechanical and organoleptic properties, which may affect quality and consumer acceptance [5]. The environmental conditions during the grape growing cycle can affect the cold storage life, and therefore the plastic film covering is a key parameter to understand the different cold storage lives of grapes.

The evaluation of the crop parameters in vineyards covered with plastic film for table grape production and the consequences on the cold storage life is a rather unexplored topic. The present work aimed to fill this gap and therefore, during cold storage, data such as yield, color, crunchiness, pulp consistency and chromatic characteristics were collected and compared for two white grapes cultivated under three different plastic films. The analysis of these factors, which evaluate the quality of the grapes, could be crucial in extending their shelf-life and could indicate which type of plastic film is more suitable for this purpose.

2. Materials and methods

2.1. Field conditions

The study was carried out on two commercial table grape varieties 'Sugar Crisp™' and 'Italia' in vineyards located in southern Italy, (Puglia region, 223 m a.s.l.). After bud break in the last week of March, the two vineyards were covered with three different types of 150µ

thick commercial plastic sheets, A1n, A2n and MA (Figure 1).

In order to limit as much as possible the influence on the atmosphere underneath the different films, especially the temperatures and the light interference, three small plots were planned for each film. Each film plot was complessively 12.5 m wide and 60 m long, consisting of 5 adjacent rows for a total area of 750 m^2.

The films covered the vineyard continuously throughout the flowering, veraison and ripening stages until harvest. The harvest for the 'Sugar Crisp™' and 'Italia' varieties was performed on the 5th September and on the 30th September, respectively. At the time of harvesting, approximately 20 kg of grapes were collected from the vines situated beneath each plastic sheet covered plot. From each quantity, a sample of 15 bunches was randomly selected for yield and technological parameters measurement. After, texture analysis and color measurements were conducted on three replicates of 20 berries each. The remaining grapes were then cold stored in a total of ten 4 kg boxes at 2°C with 95% relative humidity and analyzed after 60 days (T1). The yield was calculated at harvest (T0) and the CIELab coordinates, the texture and morphological parameters of the berries were measured at harvest (T0) and after 60 days (T1) of cold storage.

2.2. Spectro radiometric plastic film measurements

Measurements were taken on several 2 cm x 2 cm film fragments. Prior to measurement, each fragment underwent a cleaning process consisting of 30 minutes of washing in 100 ml of water and 1 ml of Decon Contrad 70 Liquid Detergent (Thermo Fisher Scientific) in an ultrasonic bath. Next, the film was rinsed for approximately 1 minute in a flow of water and then immersed in 100 ml of water in an ultrasonic bath for 15 minutes. The water used in the cleaning process was deionised water obtained from a Millipore Milli-Q system (Aldrich).Then, films were dried in a flow of nitrogen. Each spectrum acquired was the result of 10 successive accumulations, so that the result was not influenced by extemporaneous fluctuations. The transmittance and reflectance spectra at normal incident light was acquired using a double beam UV-Vis-NIR spectrophotometer (Varian Cary 5) in the range of 200–2500 nm, with a data interval of 1 nm and a scan rate of 600 nm/min. Reflectance measurements was performed by using an integrating sphere. All the analyzed spectra were recorded with the zero line/baseline correction (Figure 1). Two kinds of lamps, a Deuterium for measurement in the ultraviolet range and a tungsten lamp for measurement in the visible and near-infrared ranges, are used as the light sources of a spectrophotometer.

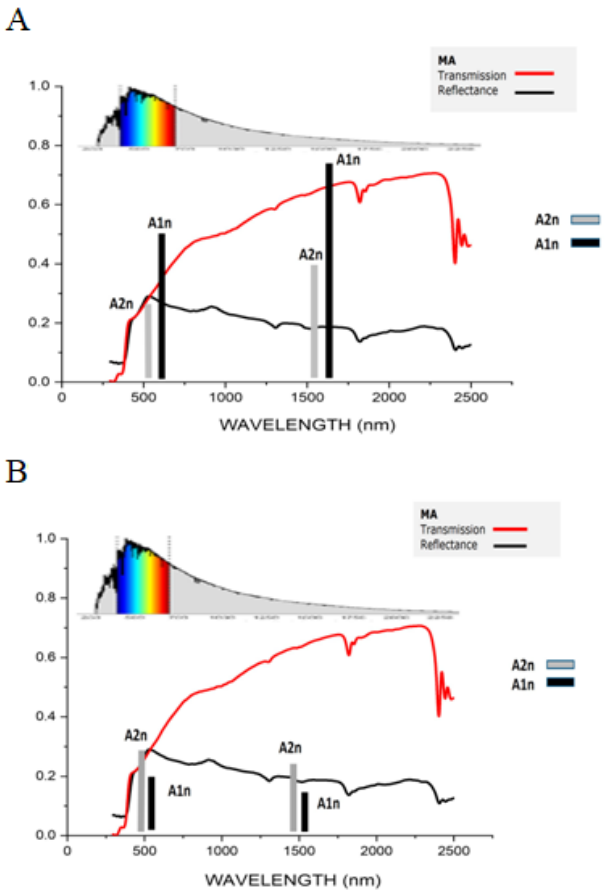

Figure 1. Transmittance (A) and reflectance (B) comparison of the plastic film.

2.3. Texture Analysis

The rheological characteristics of the berries were tested using the Zwick/Roell brand Texture Analyzer mod. BT1-FR0.5TND14 (Zwick GmbH & Co.Gk - August-Nagel-Strasse 11), equipped with a compression load cell with a nominal force of 500 N. The following parameters were determined:

- Berry Hardness (N): maximum force value during the first compression cycle;
- Berry Cohesiveness (-): strength of internal bonds that "reform" the berry structure;
- Berry Springiness (mm): height that the berry recovers during the time between the end of the first cycle and the beginning of the second;
- Berry Gumminess (N): energy required to disintegrate a semisolid food (berry) until it is ready for swallowing;
- Berry Chewiness (mJ): energy required to chew a solid food (berry) until it is ready for swallowing.

The equatorial diameters of the berry were also provided by the software as the distance between the two probes when the second probe touches the surface of the berry.

2.4. CIEL*a*b color measurements

Color is one of the most important characteristic of the skin for table grape cultivars. From the visible spectrum for

each berry the CIELab color coordinates: L* (lightness, ranging from 0 to 100), a* (values ranging from reddish when positive to greenish when negative), b* (values ranging from yellow when positive to blue when negative), were calculated. Standard illuminant C was utilized as the reference. CM-5 - Konica Minolta Corp. spectrophotometer was used to collect visible spectra of all the berries between 360 and 740 nm. Color data were provided as CIELab coordinates, which define the color according to a three dimensional spaces.

2.5. Statistical

The comparison of the means at T0 and T1, were calculated using a one way ANOVA, followed by Tukey's post-hoc test($p < 0.05$) using the STATISTICA software v. 6.0 (StatSoft Inc., Tulxa, OK). In all the tables the p-level was employed for calculating statistical significance, which was indicated by the use of text in bold when $p < 0.05$.

3. Results and discussion

3.1. Spectro radiometric measurements

The spectro-radiometric analysis of the plastic films showed three distinct film sheet typologies (Figure 1). A1n and A2n were characterized by the highest and lowest transmittance, respectively, while MA demonstrated an intermediate behavior. With regard to reflectance, it was observed that both A1n and A2n exhibited a contrasting behavior with respect to the transmittance parameters. Indeed, A2n was the most reflective film, while A1n was the least reflective. Similarly to transmittance, MA exhibited intermediate values for reflectance.

3.2. Yield parameters

The yield parameters and fruit composition of the two grape varieties were subjected to analysis. The two varieties exhibited disparate responses with regard to yield parameters as a consequence of the film sheets covering. Furthermore, a divergent behavior was observed in relation to the harvest time (T0) and after cold storage time (T1) for both varieties.

3.2.1. Sugar Crisp™ variety

At harvest (T0), the Sugar Crisp™ variety (Table 1) displayed considerable differences in yield and total soluble solids (TSS) per vine. The yield was found to be significantly lower for MA (13.35 kg*vine) and A2n (12.44 kg*vine) compared to the highest yield observed for A1n (15.68 kg*vine) ($p = 0.030$). Additionally, the A1n film sheet was found to significantly increase the TSS per vine (kg 3,35). The highest bunch weight was observed with the A1n film sheet (426,56g), which exhibited a significant difference (+19.8 %) compared to the MA film sheet.

Following the cold storage period, a greater number of variables were observed to be significantly affected by the plastic sheets covering (Table 2), with the Sugar Crisp™ variety exhibiting a greater sensitivity than the Italia variety. The A1n was confirmed to induce the most favorable effects on the Sugar Crisp™, as evidenced by a notable increase in bunch weight, berry weight and rachis weight in comparison to the other film plastic. However, the A1n also resulted in a considerable increase of the pH with respect to A2n.

Table 1. Sugar Crisp™ - Yield parameters of grapes at T0.

Variables	Plastic cover			*p*
	A2n	A1n	MA	
TSS (°Brix)	20.12 (0.79)	21.45 (1.18)	20.20 (0.78)	0.157
Titratable acidity (g/L)	4.46 (0.18)	4.03 (0.55)	4.34 (0.28)	0.293
pH	3.48 (0.04)	3.49 (0.06)	3.55 (0.06)	0.225
Bunch weight (g)	401.03 (138.91)^{ab}	426.56 (158.69)^{a}	356.06 (115.96)^{b}	**0.047**
Berry weight (g)	4.66 (2.32)	4.49 (1.15)	3.90 (0.62)	0.400
Bunch lenght (cm)	21.56 (3.84)^{b}	21.84 (3.5)^{ab}	23.25 (2.70)^{a}	**0.032**
Bunch width (cm)	11.62 (2.30)	12.93 (3.17)	12.56 (1.50)	0.278
Berry number	86.06 (30.30)^{b}	94.75 (25.98)^{a}	91.28 (20.22)^{ab}	**0.041**
Rachis weight (g)	8.44 (2.99)	8.66 (3.04)	9.12 (3.27)	0.820
Yield*vine (kg)	12.44 (4.02)^{b}	15.68 (2.42)^{a}	13.35 (1.71)^{b}	**0.030**
TSS*vine(kg)	2.50 (0.69)^{b}	3.35 (0.50)^{a}	2.67 (0.35)^{b}	**0.023**

Different letters among means and SD values in the same line indicate significant differences when $p < 0.05$.

Table 2. Sugar Crisp™ - Yield parameters at T1.

Variables	Plastic cover			*p*
	A2n	A1n	MA	
TSS (°Brix)	17.10 (1.01)	17.46 (0.45)	19.77 (1.56)	0.612
Titratable acidity (g/L)	6.15 (0.04)^{a}	6.23 (0.05)^{a}	5.53 (0.14)^{b}	0.050
pH	3.37 (0.005)	3.41 (0.024)	3.48 (0.03)	0.306
Bunch weight (g)	735.28 (125.05)^{a}	645.85 (192.02)^{ab}	575.16 (203.27)^{b}	**0.032**
Berry weight (g)	8.18 (0.87)^{a}	7.80 (1.11)^{ab}	7.44 (1.08)^{b}	**0.017**
Rachis weight (g)	4.96 (1.35)	5.05 (1.37)	4.53 (1.73)	0.272

3.2.2. Italia variety

With regard to the Italia variety, at T0 no significant differences were observed in the productive parameters such as total soluble solids per vine and yield, among the film sheets (Table.3). The only significant differences were observed on berry weight, bunch weight and rachis weight. The A2n film sheet yielded the best results for all the three variables.

After cold storage for this variety, the majority of the favorable effects observed with the A2n film were confirmed (Table. 4). Indeed, the increases documented at T0 with the A2n film, were repeated for both bunch weight and berry weight. Conversely, the highest optimal and pronounced result at T0 for rachis weight was no longer evident at T1 with any of the plastic films employed in the field.

Table 3. Italia - Yield parameters of grapes at T0.

Variables	Plastic cover			*p*
	A2n	A1n	MA	
TSS (°Brix)	18.37 (1.87)	18.12 (1.87)	17.57 (1.73)	0.814
Titratable acidity (g/L)	5.41 (0.57)	5.45 (0.64)	5.85 (0.34)	0.476
pH	3.51 (0.05)	3.58 (0.11)	3.55 (0.14)	0.739
Bunch weight (g)	816.90 (270.85)^{a}	738.37 (175.66)^{b}	724.49 (178.55)^{b}	**0.034**
Berry weight (g)	9.41 (1.06)^{a}	8.33 (0.78)^{b}	8.5 (0.91)^{b}	**0.013**
Bunch lenght (cm)	24.5 (4.27)	23.025 (3.40)	22.125 (4.24)	0.398
Bunch width (cm)	16.91 (2.96)	15.80 (3.17)	15.33 (2.10)	0.366
Berry number	86.81 (227.89)	88.63 (27.52)	84.93 (18.83)	0.953
Rachis weight (g)	18.59 (7.70)^{a}	15.47 (4.54)^{b}	15.96 (4.99)^{b}	**0.040**
Yield*vine (kg)	26.30 (5.76)	27.11 (2.99)	26.03 (6.01)	0.851
TSS* vine(kg)	4.83 (1.11)	4.91 (0.70)	4.62 (1.48)	0.940

Table 4. Italia - Yield parameters of grapes at T1.

Variables	Plastic cover			*p*
	A2n	A1n	MA	
TSS (°Brix)	22.1 (0.95)	22.5 (0.45)	21.9 (0.26.)	0.617
Titratable acidity (g/L)	3.49 (0.02)	3.53 (0.005)	3.54 (0.04)	0.345
pH	4.91 (0.06)^{b}	5.10 (0.04)^{a}	4.95 (0.06)^{ab}	0.012
Bunch weight (g)	282.95 (65.24)^{b}	437.67 (126.36)^{a}	317.97 (70.26)^{ab}	**0.005**
Berry weight (g)	3.19 (0.58)^{b}	3.71 (0.77)^{a}	3.76 (0.34)^{a}	**0.044**
Rachis weight (g)	2.21 (0.70)^{b}	3.01 (1.04)^{a}	2.15 (0.76)^{b}	**0.031**

3.3. Color parameters

3.3.1. Sugar Crisp™ variety

It is worth noting that the plastic sheets appeared to exert an interesting influence on the color parameters of the berries (Table 5). At the harvest (T0), it was observed that the A1n had a notable impact on the L* parameter, when compared to both the A2n and MA plastic films. By contrast, as regard the a* parameter, the A2n film typology yielded a higher value for the a* parameter, while the A1n and MA plastic films exhibited no notable distinction from one another. Finally, it would appear that none of the plastic films had any effect on the b* parameter.

After sixty days of cold storage (T1), it was observed that the grapes cultivated with the A1n plastic film did not retain the optimal condition of the L* parameter at harvest. Similarly, the a* parameter was also found to be not statistically different among the plastic films. Finally, only the b* parameter, despite the extended cold storage period, did tend to show statistical differences, with the A2n and MA plastic films demonstrating the best values in both of them.

3.3.2. Italia variety

In the case of the Italia variety, the different radiometric characteristics of the plastic films at harvest did not induce statistical differences in the L* parameter and consequently in the brightness of the berry color. Instead, statistical differences in the b* parameter were recorded. The prevalence of negative values in b* showed that the A2n film was able to increase the blue tonality, giving an overall berry aspect more linked to a not fully ripened grape. For this reason, a more positive result must be considered in the b* value registered for the MA plastic film, where a better yellow tonality was developed by the grapes. Similarly to the behavior of Sugar Crisp™, the

cold storage period of the Italia variety caused changes in the L*, a*, b* values compared to the harvest. In fact, even if L* was not significantly different in all three plastic films at harvest, it changed after the cold storage period, showing the highest value in the MA film plastic. Accordingly, a more consistent reduction in luminosity during cold storage was significantly registered in the grapes coming from the A1n film. Furthermore, after the storage period, the differences observed in b* at harvest disappeared, since all the films were not significantly different. For the a* parameter, remained not significantly different among the plastic film treatments although it was observed an homogeneous decrease after the cold storage.

Table 5. Difference among film plastic on color measurement of grapes at harvest time T0 and after 60 days of cold storage T1 on Sugar Crisp™ and Italia variety.

Sugar Crisp™						
Plastic cover	T0			T1		
	L*	a*	b*	L*	a*	b*
A2n	38.86 (2.14)^{b}	-3.17 (0.34)^{a}	8.76 (1.55)	37.39 (3.82)	-2.40 (1.14)	7.74 (1.37)^{a}
A1n	40.13 (1.58)^{a}	-2.53 (0.52)^{b}	9.06 (1.59)	36.26 (3.82)	-2.09 (1.11)	6.61 (1.57)^{b}
MA	38.76 (1.79)^{b}	-2.81 (0.27)^{b}	8.67 (1.04)	37.69 (3.90)	-2.40 (1.11)	7.34 (1.30)^{a}
p	**0.047**	**0.002**	0.522	0.702	0.805	**0.032**
Italia						
Plastic cover	T0			T1		
A2n	35.37 (1.91)	-1.72 (0.26)	4.13 (0.98)^{b}	33.39 (4.81)^{ab}	-1.40 (1.40)	5.12 (1.26)
A1n	34.84 (1.64)	-1.63 (0.26)	4.76 (0.93)^{ab}	33.10 (3.79)^{b}	-1.35 (1.14)	5.27 (1.10)
MA	35.24 (1.93)	-1.67 (0.36)	5.09 (1.38)^{a}	34.51 (4.07)^{a}	-1.41 (1.13)	5.43 (1.38)
p	0.657	0.741	**0.045**	**0.039**	0.540	0.850

Different letters among means and SD values in the same row indicate significant differences when $p < 0.05$.

3.4. Texture analysis

3.4.1. Sugar Crisp™ variety

Previous articles have reported that for some texture parameters the berry weight played a more important role in relation to sugar accumulation [6]. According to these results, none of the texture parameters showed significant differences among the plastic films (Table 6), as also expected from the recorded berry weight values, which were not statistically different at T0 (Table 1).
After the cold storage period (T1), no significant differences appeared due to the plastic film typologies, although a general decrease was observed mainly in hardness and gummines (Table 7).

Table 6. Sugar Crisp™ - Texture analysis of grapes at T0.

Texture variables	**Plastic cover**			***p***
	A2n	A1n	MA	
Equatorial diameter (mm)	17.60 (1.77)	17.06 (1.74)	17.66 (1.04)	0.205
Springiness (mm)	4.14 (0.32)	4.02 (0.36)	4.10 (0.44)	0.316
Gumminess (N)	6.42 (1.12)	6.70 (1.37)	6.76 (1.27)	0.452
Chewiness (mJ)	26.82 (6.25)	27.35 (7.38)	28.15 (7.51	0.739
Cohesiveness (-)	0.40 (0.03)	0.41 (0.03)	0.40 (0.03)	0.450
Hardness (N)	16.13 (3.18)	16.4 (3.33)	16.6 (3.21)	0.834

Table 7. Sugar Crisp™ - Texture analysis of grapes at T1.

Texture variables	**Plastic cover**			***p***
	A2n	A1n	MA	
Equatorial diameter (mm)	16.32 (1.06)	16.79 (1.57)	16.41 (0.98)	0.304
Springiness (mm)	4.06 (0.26)	4.18 (0.39)	4.09 (0.24)	0.355
Gumminess (N)	5.69 (0.89)	5.84 (1.20)	6.13 (1.49)	0.375
Chewiness (mJ)	23.35 (4.82)	24.85 (7.34)	25.11 (5.85)	0.483
Cohesiveness (-)	0.39 (0.04)	0.42 (0.03)	0.41 (0.08)	0.149
Hardness (N)	14.32 (2.05)	13.72 (3.05)	15.03 (2.14)	0.137

3.4.2. Italia variety

The responses to the plastic film covering in the Italia cultivar were found to be relatively in relation to the texture parameters. It is noteworthy that film plastic covering affected the main texture parameter such as, hardness. In particular, the MA film plastic resulted in the highest level of hardness of the berry. In this case, the strength of the plastic film conditioning was confirmed by the p-value (0.00001), which was the lowest of all the compared parameters (Table 8).

The effect of plastic films on gumminess was found to be similar to hardness, and, similarly, it showed the best value on the MA film plastic.

Significant differences were observed for springiness which, unlike hardness, was found highest for A2n and lowest for A1n and MA plastic film. Together to springiness, cohesiveness appeared to reach an higher value on A2n film as compared to MA, where cohesiveness registered the lowest value.

Table 8. Italia - Texture analysis of grapes at T0.

Texture variables	Plastic cover			*p*
	A2n	A1n	MA	
Equatorial diameter (mm)	23.255 (1.31)	22.7425 (1.11)	22.65 (1.39)	**0.079**
Springiness (mm)	3.81 (0.29)^{a}	3.60 (0.29)^{b}	3.51 (0.31)^{b}	**0.0008**
Gumminess (N)	5.18 (0.62)^{b}	5.30 (0.62)^{b}	5.86 (0.98)^{a}	**0.0003**
Chewiness (mJ)	19.84 (3.22)	19.17 (3.14)	20.67 (4.11)	0.1651
Cohesiveness (-)	0.55 (0.04)^{a}	0.54 (0.06)^{ab}	0.51 (0.069)^{b}	**0.0108**
Hardness (N)	9.36 (1.03)^{b}	9.93 (2.12)^{b}	11.65 (2.86)^{a}	**0.00001**

Table 9. Italia - Texture analysis of grapes at T1.

Texture variables	Plastic cover			*p*
	A2n	A1n	MA	
Equatorial diameter (mm)	22.95 (1.77)	22.53 (1.80)	22.95 (1.34)	0.540
Springiness (mm)	3.30 (0.43)	3.39 (0.44)	3.30 (0.40)	0.683
Gumminess (N)	5.77 (1.01)	5.54 (0.84)	5.81 (1.39)	0.613
Chewiness (mJ)	19.32 (4.90)	18.89 (4.12)	18.98 (3.75)	0.936
Cohesiveness (-)	0.50 (0.06)	0.54 (0.07)	0.50 (0.08)	0.145
Hardness (N)	11.54 (2.69)	10.39 (1.72)	12.23 (5.14)	0.141

4. Conclusions

Overall, the two varieties behaved very differently, probably due to the absence of seeds in the Sugar Crisp™ variety, as opposed to the presence of seeds in the Italia variety. At T0, the A2n and A1n plastic films induced more differences in both the Italia and Sugar Crisp™ varieties. These plastic films had a strong influence on the productive parameters of the Sugar Crisp™ variety and on some morphological parameters of the Italia variety such as the weight of the berry, bunch and rachis. The two varieties showed different responses in the berry absorbance values of the visible spectra, L*, a*, b*, when grown under the three types of plastic film.
A low influence of the plastic film on the texture parameters was observed for both varieties. Finally, it should be noted that the plastic films analyzed in the study represent only a small part of the possible film typologies available on the market. So, new studies are requested for a better understanding of the effect of the spectro-radiometric characteristics of the possible different polymers, especially to avoid any undesirable consequences on the yield and the market requirements for the table grapes.

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