Southern Region Small Fruit Consortium

Final Report Research

Title: Evaluating edible coatings to extend postharvest storage of fresh-market muscadine grapes

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Name, Mailing and Email Address of Principal Investigator(s):
Principal Investigator:
Dr. Renee Threlfall, Research Scientist, Food Science Department, 2650 N. Young Ave., University of Arkansas System Division of Agriculture (UA System), Fayetteville, AR 72704, rthrelf@uark.edu
Co-Principal Investigator:
Dr. Margaret Worthington, Associate Professor, Department of Horticulture**,** 316 Plant Science Building, UA System, Fayetteville, AR 72701, mlworthi@uark.edu
Dr. Ali Ubeyitogullari, Assistant Professor, Food Science Department & Biological and Agricultural Engineering Department, 2650 N. Young Ave., UA System, Fayetteville, AR 72704, uali@uark.edu
Safoura Ahmadzadeh, Post Doctoral Fellow, Food Science Department, 2650 N. Young Ave., UA System, Fayetteville, AR 72704, safouraa@uark.edu
Walker Bartz, Graduate Student, Food Science Department, 2650 N. Young Ave., UA System, Fayetteville, AR 72704, mbartz@uark.edu

Public Abstract
Major advances in U.S. breeding efforts between subgenera *Vitis* and *Muscadinia* that have resulted in new, unique fresh-market muscadine grapes (*Vitis rotundifolia* Michx.). Thus, this research from the University of Arkansas System Division of Agriculture (UA System) evaluated edible coatings, including nanocomposite films, to extend postharvest shelf life of fresh-market muscadine grapes. Three muscadine cultivars (Carlos, Noble, and Summit) were harvested in September-October 2023 in Arkansas into clamshells and transported to the UA System Department of Food Science in Fayetteville, AR. For each cultivar, grapes were placed on six stainless steel trays, one for each coating treatment including a control (no coating), a solution with 1% cellulose nanofibers (CNF), a solution with 1% CNF/1% chitosan (CNF/CHT), a solution with 1% CNF/0.5% sodium alginate (CNF/SA), an industry (IND) commercial product, NatuWrap®, and a solution with carnauba wax. After coatings were applied using fine mist spray bottles and coatings dried, the grapes were sorted into 470 g (1-pint) vented clamshells in triplicate for each cultivar, coating, and storage day. Physical, color, composition, and marketability attributes were evaluated at harvest (day 0) and during postharvest storage at 2 °C for 14 and 28 days. In addition, microscopic analysis was performed on the grapes to evaluate how coatings were spread on the surface. At harvest, the berries varied in size, color, firmness, and composition attributes but were typical for each cultivar. Skin color, firmness, and marketability attributes for muscadines grape cultivars with different coatings were evaluated

during storage. Cultivar and storage had more of an impact than coating treatments, so the impact on coating treatments during storage was evaluated by cultivar. In general, as storage increased berries got darker, had more weight loss, and more unmarketable berries. For Carlos, grapes coated with CNF (2.83%) had more weight loss than the control (2.45%), carnauba (2.43%), CNF/CTN (2.35%), and IND (2.37%). The coating x storage interaction was significant for L* and skin firmness showing at 14- and 28-days storage, skin firmness of the grapes coated with CNF were less than the control. For Noble, grapes coated with CNF, CNF/CTN, CNF/SA, and IND had less darkening than grapes not coated. The coating x storage interaction was significant for weight loss and unmarketable berries showing that at 14- and 28-days storage, all Noble grapes coated had less weight loss than the control. For Summit, coatings did not impact any of the attributes, but the coating x storage interaction was significant for weight loss showing that grapes coated with CNF had less weight loss than the control grape at 14 d storage. Microscopic analysis of the surface grape coatings revealed a more uniform CNF coating compared to the other treatments, which had uneven and nonuniform distribution. At 28 days storage at 2 °C, compared to the control, Carlos coated with carnauba and CNF/SA, Noble coated with CNF, and Summit coated with carnauba, CNF/CTN and IND had less unmarketable berries in a clamshell. This project provided initial data to establish the potential for edible coatings to extend marketability of fresh-market muscadine grapes and guide future research.

Introduction

Muscadine grapes (*Vitis rotundifolia* Michx.) are a disease-resistant specialty crop native to the southeastern United States. There have been major advances in U.S. breeding efforts between subgenera *Vitis* and *Muscadinia* that have resulted in new, unique fresh-market muscadine grapes. The U.S. market presence for the muscadine industry as a southern region crop can be strengthened by evaluating and extending postharvest storage potential of this fruit. This research from the University of Arkansas System Division of Agriculture (UA System) will **evaluate edible coatings, including new technologies in nanocomposite films, to extend postharvest shelf life of fresh-market muscadine grapes** by evaluating physicochemical and postharvest marketability attributes. **This project is important because it will help establish the potential for the use of edible coatings to extend marketability of fresh-market muscadine grapes.**

<u>Growing Muscadine Grapes.</u> Muscadine grapes are native to the United States and have been cultivated for several hundred years. The top commercial muscadine-producing states are North Carolina (2,600 acres), Georgia (1,700 acres), and Florida (1,200 acres) (USDA Agricultural Census 2012). Muscadines differ from bunch grapes because they have smaller clusters, the berries abscise (shatter) at maturity, and the tendrils are unbranched. Muscadine clusters contain 6-24 berries and are classified by color, with bronze or black as the two prevalent color types (Conner 2010, Mortensen 2001). Muscadine grape production can be profitable for commercial growers (Noguera et al. 2005) but is dependent on consumer markets.

<u>Muscadine Grape Breeding.</u> There are public and private muscadine breeding programs across the southern United States that result in better quality for consumers and increased cultivar options for growers. The southeastern U.S. muscadine breeding efforts are focused on improving traits for fresh-market and processing muscadine genotypes (cultivars and breeding selections), resulting in an expansion of the germplasm base used in muscadine breeding. The UA System Fruit Breeding Program began a muscadine breeding program in 2007 that includes many fresh-market breeding selections with unique flavor and texture profiles.

Nutraceutical Components of Muscadines. Muscadines offer a healthy fruit choice for consumers and a marketing opportunity for producers. Muscadine grapes contain many health-promoting phenolic compounds including, resveratrol, ellagic acid, anthocyanins, and proanthocyanidins (Barchenger et al. 2014, 2015a, 2015b, Ector et al. 2001, Felts et al., 2018; Pastrana-Bonilla et al. 2003, Striegler et al. 2005,Threlfall et al. 2005).

Postharvest Storage of Muscadine Grapes. Non-optimal storage temperatures, humidity levels, and times in storage can affect quality attributes of muscadine grapes resulting in visual deterioration, reduced firmness, and reduced acidity. The storage life of muscadine grapes is 3-4 weeks (28 days) when held near 0° C and 90-95% relative humidity. Bronze muscadines can shift to a brown color after storage and mold can appear especially near areas of injury such as torn stem scars (Himelrick, 2003). Shahkoomahally et al. (2021) evaluated Triumph and Supreme muscadines stored at 4 °C with 95 % relative humidity in regular atmosphere, regular controlled atmosphere or controlled atmosphere with extreme carbon dioxide levels for up to 42 d and found that both controlled atmosphere treatments had muscadines with less weight loss and reduced decay incidence. Walker et al. (2001) found that muscadine grapes stored in polyethylene bags had reduced decay.

Edible Coatings. Use of edible coatings, ecofriendly biodegradable compounds based on organic materials such as polysaccharides (chitosan, pectin, starch), other biopolymers featured and some of gums can be applied to fruits to preserve quality. Edible coatings are widely used in fruits and vegetables to optimize gas exchange, water loss, and extend shelf life (Hagenmaier and Baker 1993; Jafarzadeh et al. 2021; Mannheim and Soffer 1996). In addition, coatings can reduce the need for non-biodegradable packaging materials (Campos et al. 2010; Diaz-Mula et al. 2011). Maintenance of fruit quality has been achieved by using edible coatings such as chitosan in peaches and cherries (Li and Yu 2001; Ruoyi et al. 2005), methylcellulose in avocados (Maftoonazad and Ramaswamy 2005) and in apricots (Ayranci and Tunc 2004), hydroxypropylmethylcellulose in plums (Navarro-Tarazaga et al. 2008), whey protein in plum (Reinoso et al. 2008), and alginate in cherries (Jayakody et al. 2022, Zeng et al. 2022). Recent research has evaluated the potential use of metal nanoparticles in bioplymeric coatings and packaging (Jafarzadeh et al 2021; Kanikireddy 2018). These nanoparticles make use of the ionic interaction between positively charged metal ions (commonly silver or zinc) to bind with oxygen and increase antimicrobial activity (Fig 1).

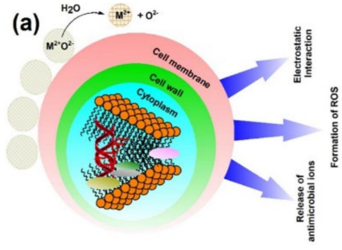

Figure 1. Antimicrobial activity for nanocomposite films on fruits (Jafarzadeh et al. 2021).

Using a coating that specifically addresses fruit requirements is imperative for extending the storage. The use of such coatings has not been evaluated in muscadine grapes, however, many different cherry species have postharvest stressors that are similar to muscadines and therefore should serve as a good foundation for analysis.

Objectives

1. Evaluate physicochemical attributes of fresh-market muscadine grapes with edible coatings at harvest/during storage

Measure physicochemical attributes (berry size, color, firmness, and composition) of fresh-market muscadines with different edible coatings at harvest and during storage

2. Evaluate postharvest marketability attributes of fresh-market muscadine grapes with edible coatings

Measure postharvest marketability attributes (stem scar tear, decay, and weight loss) of fresh-market muscadines with different edible coatings

3. Develop recommendations for edible coatings to use on fresh-market muscadine grapes

Develop recommendations for edible coating to use on fresh-market muscadine grapes based on data generated from Objectives 1 and 2.

Materials and Methods

Blackberry cultivars and harvest

Three muscadine cultivars (Carlos, Noble, and Summit) were harvested in September-October 2023 from a commercial grower in Altus, AR. The fruit were harvested at optimal ripeness and free of major visible blemishes, flaws, or damage. Approximately 18 kg of berries were harvested into 846 g (1-quart) vented clamshells for each cultivar. The clamshells of grapes were placed in an ice chest chilled with ice packs and transported to the UA System Department of Food Science in Fayetteville, AR.

Muscadine coatings

Six coating treatments were evaluated for this study including a control (no coating), a solution with 1% cellulose nanofibers (CNF), a solution with 1% CNF/1% chitosan (CNF/CHT), a solution with 1% CNF/0.5% sodium alginate (CNF/SA), an industry (IND) commercial product, NatuWrap®, and a solution with carnauba wax.

TEMPO-oxidized cellulose nanofiber (TCNF), and cellulose nanofibers (CNF) were purchased from the University of Maine (Orono, ME). Sodium alginate (SA) with medium viscosity was obtained from MP Biomedicals (Santa Ana, CA). Tween 80 and anhydrous citric acid were obtained from Fisher Scientific (Pittsburgh, PA). Chitosan powder (90%+ deacetylated) was purchased from Chemsavers (Bluefield, VA). Native corn starch with 25% amylose content was kindly received from Ingredion (Westchester, IL). Olive oil was purchased from the local market. NatuWrap® was obtained from NABACO® (SanMarcus, TX). Carnauba wax (CW) was obtained from Modernist Pantry (Eliot, ME).

Coating suspensions

The optimum concentrations of cellulose nanofiber, sodium alginate, chitosan, corn starch, Tween 80, carnauba wax, and olive oil were determined based on the preliminary experiments.

Carnauba wax-starch. The coating suspension (CW/S-C) was prepared using the procedure described by Chiumarelli et al. (2014) with some modifications. A 3% (w/w) suspension of native corn starch in distilled water was gelatinized at 90 °C while continuously stirring for 30 minutes. Tween 80 (0.1%, w/w) was then added into the gelatinized starch. CW (0.4%, w/w) and olive oil (1.6%, w/w) were heated at 85 °C and homogenized into the corn starch paste at 13,500 rpm for 2 minutes in a glass container using a high-shear homogenizer (VWR VDI 25, PA, USA). The homogenization temperature was 85 °C. Finally, the generated emulsions were kept at room temperature (23 °C) until further use.

TEMPO-oxidized cellulose nanofiber. The TEMPO-oxidized cellulose nanofiber (TCNF-C) coating suspension was made by mixing TEMPO-oxidized nanocellulose (1.5%, w/w) with DI water along with 0.1% (w/w) Tween 80. The mixture was homogenized for 2 minutes at 13,500 rpm using the high-shear homogenizer.

Sodium alginate-TEMPO-oxidized cellulose nanofiber. The procedure described by Lee et al. (2022) with some modifications, was used to prepare polysaccharide-based coating solutions. The coating suspension (SA/TCNF-C) was made by dissolving sodium alginate (0.5 g) in 98.5 mL of deionized water for 4 hours with continuous stirring, and then TEMPO-oxidized nanocellulose (1 g) and 0.1% Tween 80 were added to the SA solution using the high-shear homogenizer at 13,500 rpm for 2 minutes.

Chitosan-cellulose nanofiber. To prepare a 1% chitosan solution (solution A), 1 g of chitosan was added into 99 g of 1% citric acid solution and stirred continuously overnight. Then, the solution was centrifuged at 1,000 rpm for 10 minutes to remove undissolved particulates, and the supernatant was collected. Solution B (1% CNF) was made by dispersing CNF in DI water and homogenizing it for 2 minutes at 13,500 rpm. Finally, the coating suspension was prepared by combining solution A and solution B in a 1:1 ratio and mixing for 2 minutes at 13,500 rpm with the homogenizer.

Muscadine coating application

After harvest, the grapes were sorted randomly placed on six stainless steel full sheet baking trays (lined with paper towels) per cultivar. Fans were used to dry the berries for 30 min, then the paper towels were removed, and berries were dried for an additional 15 min. The coatings were applied using 2 oz/50 ml fine mist spray bottles. The coatings were applied to the berries, 21 sprays per tray x 4 applications, shifting the berries gently on the trays between each application. After coatings dried (about 1 hour), the grapes were sorted into 470 g (1-pint) vented clamshells in triplicate for each cultivar, storage day, coating, and replication. After physical and marketability analysis at harvest (day 0), grapes were stored at 2 °C (85% to 89% relative humidity) for 14 and 28 days.

Scanning Electron Microscopy (SEM)

A Focused Ion Beam (FEI) NovaNanolab200 Dual-Beam system equipped with a 30 kV SEM Field Emission Gun (FEG) column and a 30 kV FIB column (FEI Company, OR, USA) was used to examine the microstructure of the uncoated and coated samples. Samples of freeze-dried grapes with and without coatings were cut into thin cross-sections to create specimens, which were then placed on top of conductive carbon tape on aluminum stubs. The specimens were then prepared for imaging by sputter-coating them with a gold layer (EMITECH SC7620 Sputter Coater, MA, USA). Finally, SEM imaging was performed at a 15 kV acceleration voltage and a current of 10 mA.

Physical attributes

Five berries per cultivar, storage day, coating and replication were evaluated for physical attributes. The physical attributes (berry size, color, firmness, and stem scar tear) of each of the fresh-market muscadines were evaluated at the UA System Food Science Department. All physical attributes were measured at harvest (day 0) and during storage (14 and 28 days at 2 °C).

After physical attributes were analyzed, the samples for composition were placed in zip-type bags and stored at -10 °C until analysis.
Berry size. Size attributes of the muscadines evaluated included individual berry weight, length, and width. Each berry was weighed (g) on a digital scale, and the width (mm) and length (mm) of each berry was measured with digital calipers.
Color. The color of the grape skins was analyzed using a Konica Minolta CR-400 Chroma Meter (Konica Minolta, Inc., Ramsey, NJ). The L*, a, b, chroma, and hue angle were evaluated using Commission Internationale de l'Eclairage (CIE) Laboratory transmission values of L* = 100, a* = 0, and b* = 0 (CIE, 1986). The CIELAB system describes color variations as perceived by the human eye. CIELAB is a uniform three-dimensional space defined by colorimetric coordinates, L*, a*, and b*. The vertical axis L* measures lightness from completely opaque (0) to completely transparent (100), while on the hue-circle, +a* red, -a* green, +b* yellow, and -b* blue are measured. Hue angle, calculated as $\tan^{-1}\frac{b*}{a*}$, described color in angles from 0 to 360°: 0° is red, 90° is yellow, 180° is green, 270° is blue, and 360° is red. For samples with hue angles <90°, a 360° compensation (hue + 360°) was used to account for discrepancies between red samples with hue angles near 0° and those near 360° (McLellan et al. 2007). Chroma, calculated as $\sqrt{a *^2 + b *^2}$, identified color by which a wine appeared to differ from gray of the same lightness and corresponded to saturation (intensity/purity) of the perceived color.
Firmness. Firmness of each berry was measured using a Stable Micro Systems TA.XT.plus texture analyzer (Texture Technologies Corporation, Hamilton, MA). The berries were placed on the texture unit vertically, stem scar to the side, using a 2-mm diameter probe at a rate of 2 mm/s with a trigger force of 0.02 N. Berry firmness was measured as force (g) to penetrate the berry, then converted to Newtons (N). Skin elasticity was measured as the distance (mm) traveled before the berry skin ruptured. Skin firmness was calculated the force required to puncture the skin of the berry divided by the distance traveled before the berry skin ruptured (N/mm).
Stem scar tear. The stem scar tear (tear > 2x diameter of stem scar) of the berries was calculated as (number of torn berries/total berries) × 100 and expressed as percent.

Marketability attributes
The marketability attributes of the grapes included unmarketable berries and weight loss. Unmarketable berries and weight loss were evaluated at 0, 14, and 28 d at 2 °C for each cultivar, coating, and replication.
Unmarketable. The unmarketability (visible mold or rot) of the berries were calculated as (number of decayed or torn berries/total berries) × 100 and expressed as percent.
Weight loss. The weight loss of the muscadines in the clamshell were calculated as the total weight decrease of the grapes in the clamshell expressed as percent.

Composition attributes
Five berries per cultivar, storage day, coating, and replication were evaluated for composition attributes. Berries were thawed placed in cheesecloth, and the berries were squeezed to extract the juice from the berries. The juice from the berry samples was used to determine composition attributes. The composition (soluble solids, pH, titratable acidity, and soluble solids/titratable acidity ration) attributes of the fresh-market muscadines were evaluated at the UA System. The composition attributes were measured at harvest (day 0 or upon arrival after shipping) and during storage (14 and 28 days at 2 °C). Samples for composition were placed in zip-type bags and stored at -10 °C until analysis.

Soluble solids. Soluble solids (expressed as percent) of the juice were measured using an Abbe Mark II refractometer (Bausch and Lomb, Scientific Instrument, Keene, NH).

pH. The pH of juice was measured using a PH700 pH meter (Apera Instruments, Columbus, Ohio). The pH was measured after the probe had been in the sample for 2 min.

Titratable acidity. The titratable acidity of the juice was measured using a Metrohm 862 Compact Titrosampler (Metrohm AG, Herisau, Switzerland) fitted with a pH meter. Titratable acidity was determined using 6 mL of juice diluted with 50 mL of deionized, degassed water by titration with 0.1 N sodium hydroxide (NaOH) to an endpoint of pH 8.2; results was expressed as g/L tartaric acid.

Soluble solids/titratable acidity ratio. The soluble solids/titratable acidity ratio was calculated.

Statistical design and analysis

For physical, composition, and marketability attributes, all cultivars were evaluated in triplicate. The data was analyzed by analysis of variance (ANOVA) using JMP® (version 16.2.0; SAS Institute Inc., Cary, NC). Tukey's Honestly Significant Difference was used for mean separations ($p \leq 0.05$).

Results and Discussion

Fresh-market muscadine cultivars were impacted by an early and late freeze in Arkansas, so fruit availability was limited. We were able to harvest one fresh-market cultivar, Summit, and two processing cultivars, Carlos and Noble.

Physical, color, and composition attributes at harvest

Summitt had the largest berry weight (10.53 g) and berry length (25.02 mm). Noble had the highest stem scar tear (33.55%), which can cause shorter postharvest storage. Carlos had the highest berry firmness (9.06 N) and skin elasticity (8.74 mm). Skin color attributes varied as would be expected for the bronze cultivars (Carlos and Summit) and black cultivar (Noble), with Nobel having the lowest L* (darkest color). In terms of composition attributes at harvest, Summit had the highest soluble solids (19.71%), pH (3.54), and soluble solids/titratable acidity ratio (48.42) and lowest titratable acidity (0.41%). The composition attributes and berry size attributes were not reported during storage since these attributes are not majorly impacted by storage. Skin color, firmness, and marketability attributes for muscadines grape cultivars with different coatings applied after harvest were evaluated during storage (0, 14, and 28 days) at 2°C.

Physical, color, and composition attributes during storage

The main and interaction effects on color, firmness, and marketability attributes for muscadines grape cultivars with different coatings applied after harvest and evaluated during storage (0, 14, and 28 days) at 2 °C (2023) were analyzed (Table 2). Cultivar and storage had more of an impact than the coating treatments. Thus, the impact on coating treatments during storage was evaluated by cultivar (Tables 3-5 and Figures 3-5).

For Carlos, the coating x storage interaction was significant for L* and skin firmness (Figure 3), storage impacted chroma, berry firmness, skin elasticity, weight loss and unmarketable berries, while coating only impacted weight loss (Table 3). In general, for Carlos grapes as storage increased, hue was not impacted, chroma and berry firmness decreased, while skin elasticity, weight loss, and unmarketable berries increased. In terms of coatings on Carlos, weight loss was highest for grapes coated with CNF (2.83%) which was significantly higher than the grapes without coating (2.45%) and grapes coated with carnauba (2.43%), CNF/CTN (2.35%), and IND (2.37%). Regardless of coating, as storage increased L* and skin firmness decreased. At 14- and 28-days storage at 2 °C, skin firmness of the grapes coated with CNF were less than the control.

For Noble, the coating x storage interaction was significant for weight loss and unmarketable berries (Figure 4), storage impacted L*, chroma, berry firmness, skin firmness, and skin elasticity, while coating impacted L*, chroma, berry firmness, and skin elasticity (Table 4). In general, for Noble grapes as storage increased, hue was not impacted, L*, berry firmness, and skin firmness decreased, while chroma and skin elasticity increased. In terms of coatings on Noble, hue and skin elasticity were not impacted, L* was highest for CNF/SA (24.37) and lowest for the control (23.35), the control had the highest chroma, berry firmness, and skin firmness. Interestingly, Noble grapes coated with CNF, CNF/CTN, CNF/SA, and IND had less darkening (higher L*) than grapes not coated. Regardless of coating, as storage increased weight loss and unmarketable berries increased. At 14- and 28-days storage at 2 °C, all Noble grapes coated had less weight loss than the control. The control and grapes coated with carnauba wax had almost no unmarketable berries at 14 days of storage.

For Summit, the coating x storage interaction was significant for weight loss (Figure 5), storage impacted L*, berry firmness, skin firmness, skin elasticity, and unmarketable berries, while coatings did not impact any of the attributes (Table 5). In general, for Summit grapes as storage increased, hue and chroma were not impacted, L*, berry firmness, and skin firmness decreased, while skin elasticity and unmarketable berries increased. Regardless of coating, as storage increased weight loss increased. The grapes coated with CNF had less wight loss than the control grape at 14 d storage.

Marketable berries at 28 days storage

To understand the postharvest potential, the percentage of unmarketable berries in a clamshell for each cultivar was evaluated at 28 days storage at 2 °C (Table 6). Carlos grapes coated with carnauba and CNF/SA had less unmarketable berries as compared to the control without a coating. Noble grapes coated with CNF had less unmarketable berries as compared to the control and the other coating treatments. Whereas Summit grapes coated with carnauba, CNF/CTN, and IND had less unmarketable berries as compared to the control.

Microstructural observations of coating application

Microscopic analysis was performed to gain a better understanding of how the coatings were spread on the surface of the grapes. SEM images illustrate cross-sections and surfaces of both uncoated and coated samples. There were no detachment areas or surface cracks observed for any of the coating materials, indicating their good film-forming capacity. However, the microscopic analysis revealed a more uniform CNF coating on the surface of the grapes compared to the other treatments, which displayed an uneven and nonuniform distribution. This observation supports the findings in that Carlos coated with CNF had skin firmness less than the control at 14- and 28-days storage, Noble coated with CNF had less weight loss than the control at 14- and 28-days storage, and Summit coated with CNF had less weight loss than the control at 14 d storage. Microscopic analysis of the surface grape coatings revealed a more uniform CNF coating compared to the other treatments, which had uneven and nonuniform distribution. Increased chemical homogeneity within the coating material correlates directly with improved uniformity and surface adhesion (Olivera Filho et al. 2023, Chiumarelli and Hubinger 2014). The high stability of the CNFs resulted in a consistent and uniform CNF coat structure. However, the addition of sodium alginate negatively affected the distribution of the coating material, which could be due to an increase in viscosity, which can result in a reduction in spreadability (Lan et al. 2021). The composition of the carnauba wax emulsion affects the average droplet size of the emulsion. Droplet aggregation and flocculation can occur because of this variation, resulting in less uniformity compared to CNF (Chiumarelli and Hubinger 2014, Ziani et al. 2012). Variations in the microstructure of the coating materials could have a significant impact on the functionality of the coating layer and, in turn, affect the shelf-life of the grapes.

Outreach dissemination

Graduate student is presenting the results of this project at the Postharvest/Biotechnology Section at the Annual Conference of the Southern Region American Society for Horticultural Science on February 2-4, 2024 in Atlanta, Georgia

> Evaluating Edible Coatings to Extend Postharvest Storage of Fresh-market Muscadine Grapes. M. Walker Bartz*, Renee T. Threlfall*, Safoura Ahmadzadeh, and Ali Ubeyitogullari, 2650 N. Young Avenue, Food Science Department, University of Arkansas, Fayetteville, AR 72704

Conclusions

In this project, six edible coating treatments (control, CNF, CNF/CHT, CNF/SA, IND, and carnauba wax was evaluated on three muscadine cultivars. Physical, color, composition, and marketability attributes were evaluated at harvest (day 0) and during postharvest storage at 2 °C for 14 and 28 days. Cultivar and storage had more of an impact than coating treatments, but the impact of the coating varied by cultivar. The coatings with nanocomposites like CNF had uniform berry coverage and showed potential to extend postharvest storage. This project provided initial data to establish the potential for edible coatings to extend marketability of fresh-market muscadine grapes and guide future research. More research needs to be done on fresh-market grapes to evaluate the formulations of the coatings and coverage, in addition to how the coatings impact quality.

Impact Statement

Advances in U.S. grape breeding efforts between *Vitis* and *Muscadinia* have resulted in new fresh-market muscadine-type hybrids with a potential for expansion in commercial markets. While some research has been done on edible coatings for muscadines, there has been no research on nanocomposite films to extend postharvest shelf life. In this study, cultivar and storage had a major impact on physical, color and marketability attributes, but the impact of coating treatments varied by cultivar. Nanocomposites with cellulose nanofibers had uniform berry coverage and showed potential to enhance postharvest storage. This project was important because it provided initial data to establish the potential for edible coatings to extend marketability of fresh-market muscadine grapes and guide future research.

Table 1. Means and standard deviations of physical, skin color, and composition attributes for muscadines grape cultivars at harvest (Altus, AR 2023)

Attribute[z]	Carlos	Summit	Noble
Physical			
Berry weight (g)	4.90 ± 0.72	10.53± 3.28	3.05 ± 0.46
Berry length (mm)	18.53 ± 1.07	25.02 ± 2.71	16.11 ± 0.73
Berry width (mm)	18.92 ± 1.30	18.53 ± 1.07	18.53 ± 1.07
Stem scar tear (%)	5.32 ± 3.26	10.86 ± 6.69	33.55 ± 9.60
Berry firmness (N)	9.06 ± 1.73	8.95 ± 2.96	6.64 ± 1.42
Skin firmness (N/mm)	1.05 ± 0.23	1.24 ± 0.45	0.96 ± 0.28
Skin elasticity (mm)	8.74 ± 1.13	7.44 ± 1.41	7.18 ± 1.23
Skin color			
L*	45.56 ± 1.95	38.37 ± 3.65	24.21 ± 0.68
a*	4.88 ± 1.91	7.18 ± 4.02	0.98 ± 0.44
b*	15.00 ± 2.90	11.31 ± 2.54	0.47 ± 0.27
Hue	71.55 ± 8.13	57.29 ± 14.29	26.23 ± 10.87
Chroma	16.08 ± 3.10	13.78 ± 2.86	1.10 ± 0.47
Composition			
Soluble solids (%)	15.59 ± 1.15	19.71 ± 0.54	18.61 ± 0.78
pH	2.96 ± 0.07	3.54 ± 0.14	3.27 ± 0.10
Titratable acidity (% tartaric)	0.90 ± 0.08	0.41 ± 0.05	0.53 ± 0.06
Soluble solids/titratable acidity ratio	17.62 ± 2.77	48.42 ± 7.17	35.19 ± 3.87

[z] Cultivars were evaluated in triplicate.

Table 2. P-values of main and interaction effects on skin color, firmness, and marketability attributes for muscadines grape cultivars with different coatings applied after harvest and evaluated during storage (0, 14, and 28 days) at 2 °C (Altus, AR 2023)

Effects[z]	**L***	**Hue**	**Chroma**	**Berry firmness (N)**	**Skin firmness (N/mm)**	**Skin elasticity (mm)**	**Weight loss (%)**	**Unmarketable (%)**
Cultivar (CU)	***<0.0001***	***<0.0001***	***<0.0001***	***<0.0001***	***<0.0001***	***<0.0001***	***<0.0001***	***<0.0001***
Coating (CO)[y]	0.1027	0.9121	0.0545	***0.0048***	***0.0099***	0.0819	***<0.0001***	0.5717
Storage (ST)	***<0.0001***	***0.0203***	***<0.0001***	***<0.0001***	***<0.0001***	***<0.0001***	***<0.0001***	***<0.0001***
CU x CO	0.1038	0.9430	0.6058	0.4996	0.4059	0.5421	***<0.0001***	0.1396
CU x ST	***<0.0001***	0.2898	***0.0013***	***0.0160***	***0.0052***	0.4078	***<0.0001***	***0.0010***
CO x ST	0.6956	0.5448	0.6270	0.6898	0.5150	0.2985	***<0.0001***	0.9928
CU x CO x ST	0.0714	0.4450	0.0777	*0.2150*	0.2648	0.6746	***<0.0001***	0.2298

[z] Cultivars were evaluated in triplicate ($p<0.05$).

[y] Coating solution treatments included a control (no coating), 1% cellulose nanofibers (CNF), 1% CNF/1% chitosan (CNF/CTN), 1% CNF/0.5% sodium alginate (CNF/SA), an industry (IND) commercial product (NatuWrap®), and carnauba wax.

Table 3. Main and interaction effects on skin color, firmness, and marketability attributes for Carlos muscadines grapes with different coatings applied after harvest and evaluated during storage (0, 14, and 28 days) at 2 °C (Altus, AR 2023)

Effects[z]	**L***	**Hue**	**Chroma**	**Berry firmness (N)**	**Skin firmness (N/mm)**	**Skin elasticity (mm)**	**Weight loss (%)**	**Unmarketable (%)**
Coating (CO)[y]								
Control	43.22	70.24	15.74	8.69	0.95 ab	9.24	2.45 bc	0.59
Carnauba	43.43	69.40	16.47	8.83	1.00 a	9.04	2.43 bc	0.59
CNF	42.66	71.74	15.34	7.85	0.86 b	9.21	2.83 a	1.37
CNF/CTN	43.87	71.82	16.35	8.34	0.90 ab	9.32	2.35 c	0.57
CNF/SA	42.51	71.26	15.89	8.24	0.89 ab	9.41	2.71 ab	0.37
IND	42.25	70.98	15.35	8.07	0.91 ab	9.07	2.37 c	0.94
P-value	0.0517	0.5291	0.4299	0.1052	***0.0347***	0.3904	***<0.0256***	0.4934
Storage (ST)								
0 days	45.56 a	71.55	16.08 a	9.06 a	1.05 a	8.74 b	0.00 c	0.00 b
14 days	43.08 b	71.03	16.79 a	8.37 b	0.90 b	9.44 a	2.64 b	0.27 b
28 days	40.33 c	70.13	14.70 b	7.58 c	0.79 c	9.46 a	4.92 a	1.94 a
P-value	***<0.0001***	0.3760	***<0.0001***	***<0.0001***	***<0.0001***	***<0.0001***	***<0.0001***	***<0.0001***
CO x ST *(P-value)*	***0.0189***	0.5556	0.0505	0.1400	***0.0351***	0.3035	<0.3776	0.4428

[z] Cultivars were evaluated in triplicate. Means with different letters for each attribute are significantly different (p<0.05) within effect using Tukey's Honestly Significant Difference test.

[y] Coating solution treatments included a control (no coating), 1% cellulose nanofibers (CNF), 1% CNF/1% chitosan (CNF/CTN), 1% CNF/0.5% sodium alginate (CNF/SA), an industry (IND) commercial product (NatuWrap®), and carnauba wax.

Table 4. Main and interaction effects on skin color, firmness, and marketability attributes for Noble muscadines grapes with different coatings applied after harvest and evaluated during storage (0, 14, and 28 days) at 2 °C (Altus, AR 2023)

Effects[z]	**L***	**Hue**	**Chroma**	**Berry firmness (N)**	**Skin firmness (N/mm)**	**Skin elasticity (mm)**	**Weight loss (%)**	**Unmarketable (%)**
Coating (CO) [y]								
Control	23.35 d	25.80	1.38 a	6.36 a	0.88 a	7.33	2.56 a	1.06 ab
Carnauba	23.67 cd	22.66	1.20 abc	5.89 ab	0.78 ab	7.70	2.00 c	1.29 ab
CNF	23.86 bc	22.68	1.09 bc	5.19 ab	0.74 ab	7.30	2.18 bc	0.72 b
CNF/CTN	23.95 bc	22.16	1.34 ab	4.84 b	0.64 b	7.96	2.25 b	3.46 ab
CNF/SA	24.37 a	21.30	1.02 c	5.59 ab	0.77 ab	7.48	2.01 c	3.31 ab
IND	24.08 ab	27.35	1.19 abc	4.77 b	0.66 b	7.59	2.08 bc	4.34 a
P-value	***<0.0001***	0.9289	***0.0013***	***0.0006***	***0.0022***	0.1651	***<0.0001***	***0.0074***
Storage (ST)								
0 days	24.21 a	26.23	1.10 b	6.64 a	0.96 a	7.18 b	0.00 c	0.31 b
14 days	23.74 b	26.76	1.21 ab	5.67 b	0.73 b	7.90 a	2.51 b	0.55 b
28 days	23.69 b	18.00	1.29 a	4.01 c	0.55 c	7.52 ab	4.03 a	6.24 a
P-value	***<0.0001***	0.0988	***0.0295***	***<0.0001***	***<0.0001***	***0.0004***	***<0.0001***	***<0.0001***
CO x ST *(P-value)*	0.6956	0.4186	0.4148	0.0537	0.2960	0.5912	***<0.0001***	***0.0234***

[z] Cultivars were evaluated in triplicate. Means with different letters for each attribute are significantly different ($p<0.05$) within effect using Tukey's Honestly Significant Difference test.

[y] Coating solution treatments included a control (no coating), 1% cellulose nanofibers (CNF), 1% CNF/1% chitosan (CNF/CTN), 1% CNF/0.5% sodium alginate (CNF/SA), an industry (IND) commercial product (NatuWrap®), and carnauba wax.

Table 5. Main and interaction effects on skin color, firmness, and marketability attributes for Summit muscadines grapes with different coatings applied after harvest and evaluated during storage (0, 14, and 28 days) at 2 °C (Altus, AR 2023)

Effects[z]	**L***	**Hue**	**Chroma**	**Berry firmness (N)**	**Skin firmness (N/mm)**	**Skin elasticity (mm)**	**Weight loss (%)**	**Unmarketable (%)**
Coating (CO) [y]								
Control	36.64	54.85	14.36	7.47	0.98	7.92	1.79 ab	2.72
Carnauba	37.25	55.04	13.98	7.49	1.00	7.64	1.63 b	2.95
CNF	36.33	57.40	13.03	7.18	0.95	7.83	1.75 ab	4.48
CNF/CTN	36.87	56.90	13.40	7.52	0.96	8.13	1.92 a	2.03
CNF/SA	37.43	59.42	13.18	7.78	0.97	8.19	1.65 b	3.86
IND	36.19	57.35	13.04	7.14	0.94	7.76	1.94 a	2.56
P-value	0.4676	0.5133	0.1703	0.8932	0.9742	0.3962	***0.0004***	.8079
Storage (ST)								
0 days	38.37 a	57.29	13.78	8.95 a	1.24 a	7.44 b	0 c	0.42 b
14 days	36.87 b	58.00	13.79	7.26 b	0.91 b	8.23 a	1.76 b	1.52 b
28 days	35.12 c	55.18	12.94	6.08 c	0.75 c	8.06 a	3.57 a	7.36 a
P-value	***<0.0001***	0.2804	0.0872	***<0.0001***	***<0.0001***	***0.0006***	***<0.0001***	***<0.0001***
CO x ST *(P-value)*	0.7892	0.7825	0.8709	0.8951	0.7030	0.4902	***0.0002***	0.9501

[z] Cultivars were evaluated in triplicate. Means with different letters for each attribute are significantly different ($p<0.05$) within effect using Tukey's Honestly Significant Difference test.
[y] Coating solution treatments included a control (no coating), 1% cellulose nanofibers (CNF), 1% CNF/1% chitosan (CNF/CTN), 1% CNF/0.5% sodium alginate (CNF/SA), an industry (IND) commercial product (NatuWrap®), and carnauba wax.

Figure. 1. Muscadine grapes after harvest were placed onto trays (left), and the different coatings were applied to the grapes using 2 oz/50 ml fine mist spray bottles (right)

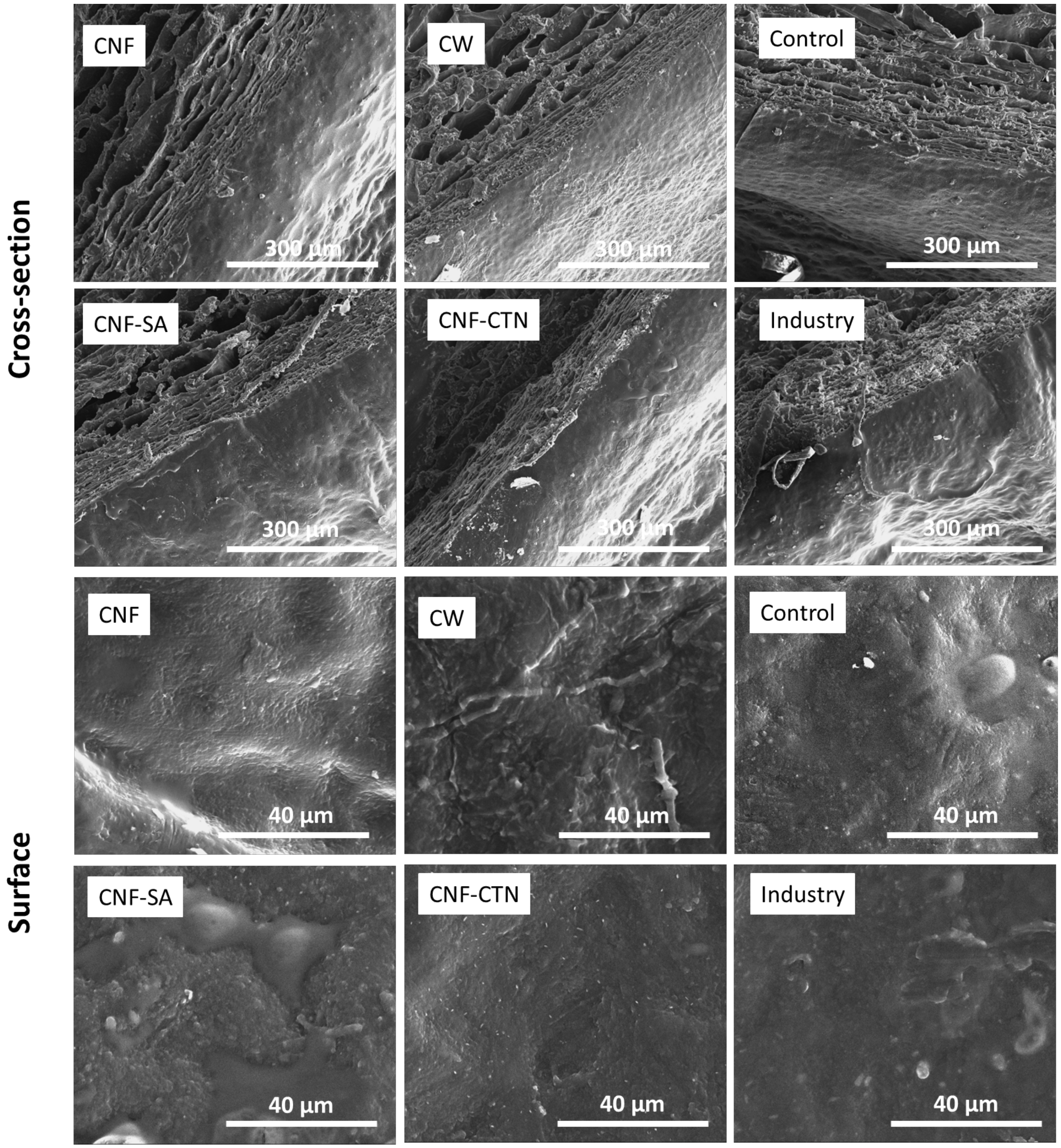

Figure. 2. The Scanning Electron Microscopy (SEM) images taken from surfaces and cross-sections of the coated and uncoated muscadine grapes. CNF: cellulose nanofiber, CW: carnauba wax, CNF-SA: cellulose nanofiber-sodium alginate, CNF-CTN: cellulose nanofiber-chitosan. Coating solution treatments included a control (no coating), 1% cellulose nanofibers (CNF), 1% CNF/1% chitosan (CNF/CTN), 1% CNF/0.5% sodium alginate (CNF/SA), an industry (IND) commercial product (NatuWrap®), and carnauba wax.

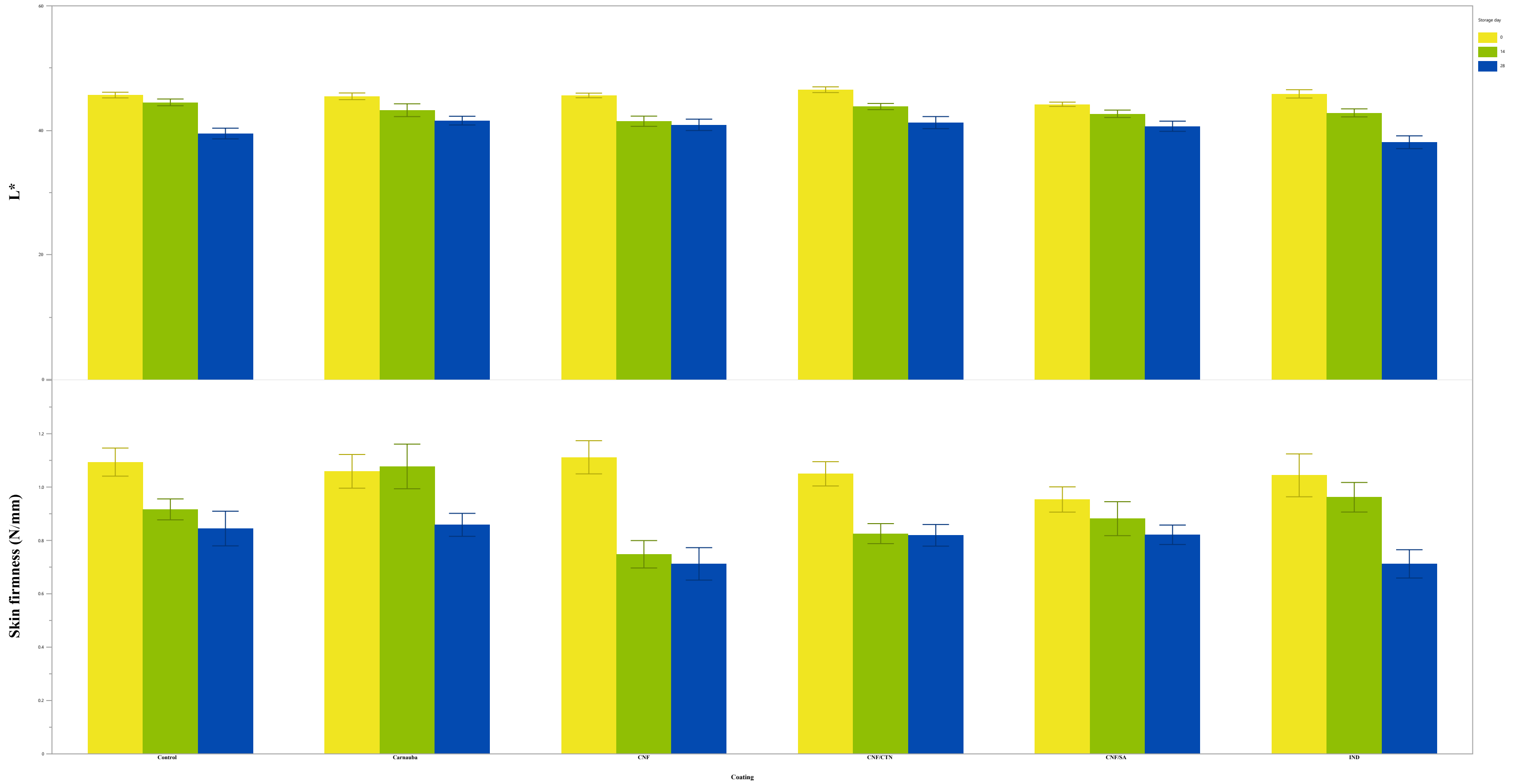

Figure 3. Interaction effects on L* and skin firmness attributes for Carlos muscadines grapes with different coatings applied after harvest and evaluated during storage (0, 14, and 28 days) at 2 °C (Altus, AR 2023)

Cultivars were evaluated in triplicate. Each error bar was constructed using 1 standard error from the mean. Coating solution treatments included a control (no coating), 1% cellulose nanofibers (CNF), 1% CNF/1% chitosan (CNF/CTN), 1% CNF/0.5% sodium alginate (CNF/SA), an industry (IND) commercial product (NatuWrap®), and carnauba wax.

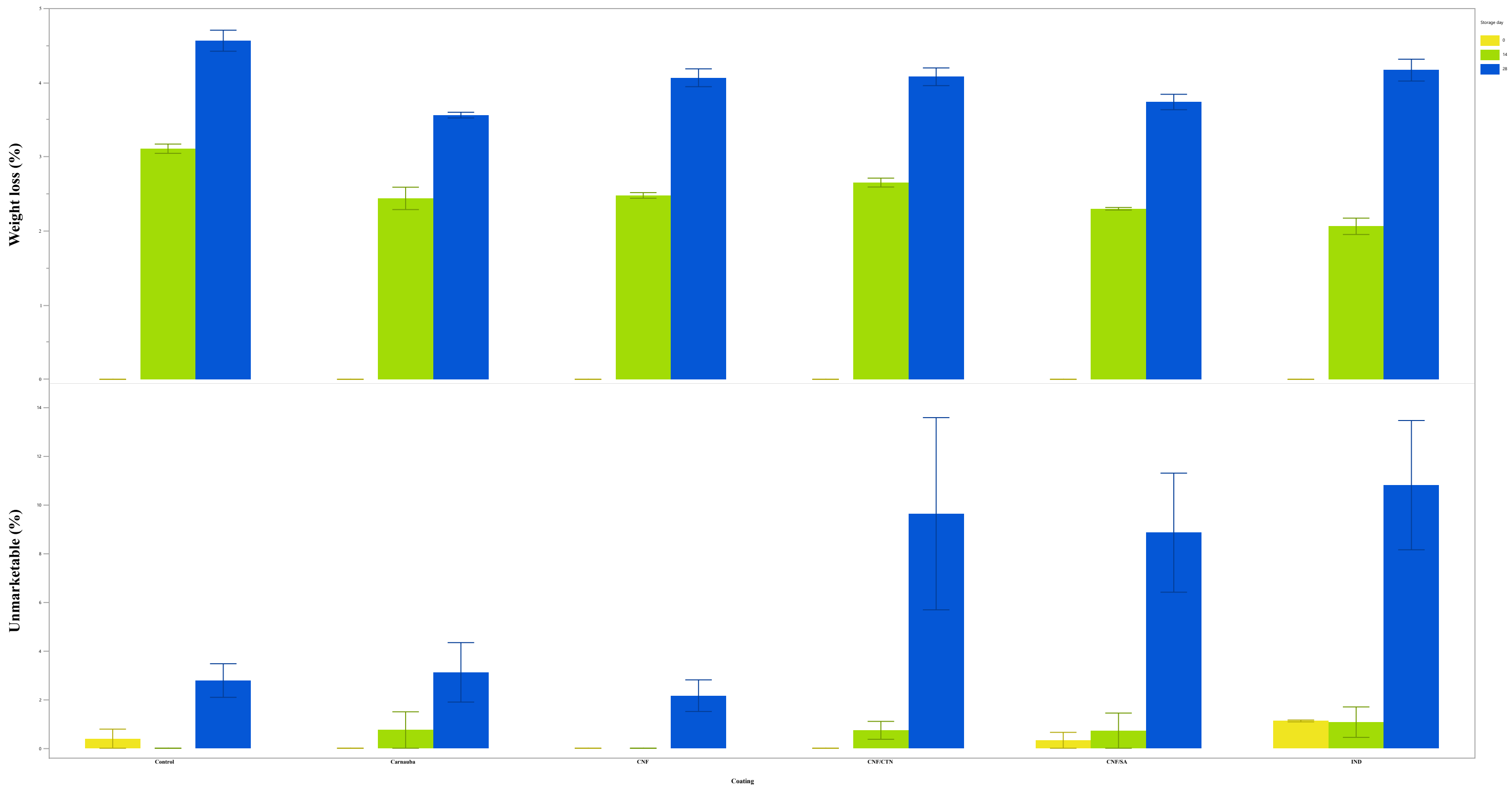

Figure 4. Interaction effects on weight loss and unmarketability attributes for Noble muscadines grapes with different coatings applied after harvest and evaluated during storage (0, 14, and 28 days) at 2°C (Altus, AR 2023)

Cultivars were evaluated in triplicate. Each error bar was constructed using 1 standard error from the mean. Coating solution treatments included a control (no coating), 1% cellulose nanofibers (CNF), 1% CNF/1% chitosan (CNF/CTN), 1% CNF/0.5% sodium alginate (CNF/SA), an industry (IND) commercial product (NatuWrap®), and carnauba wax.

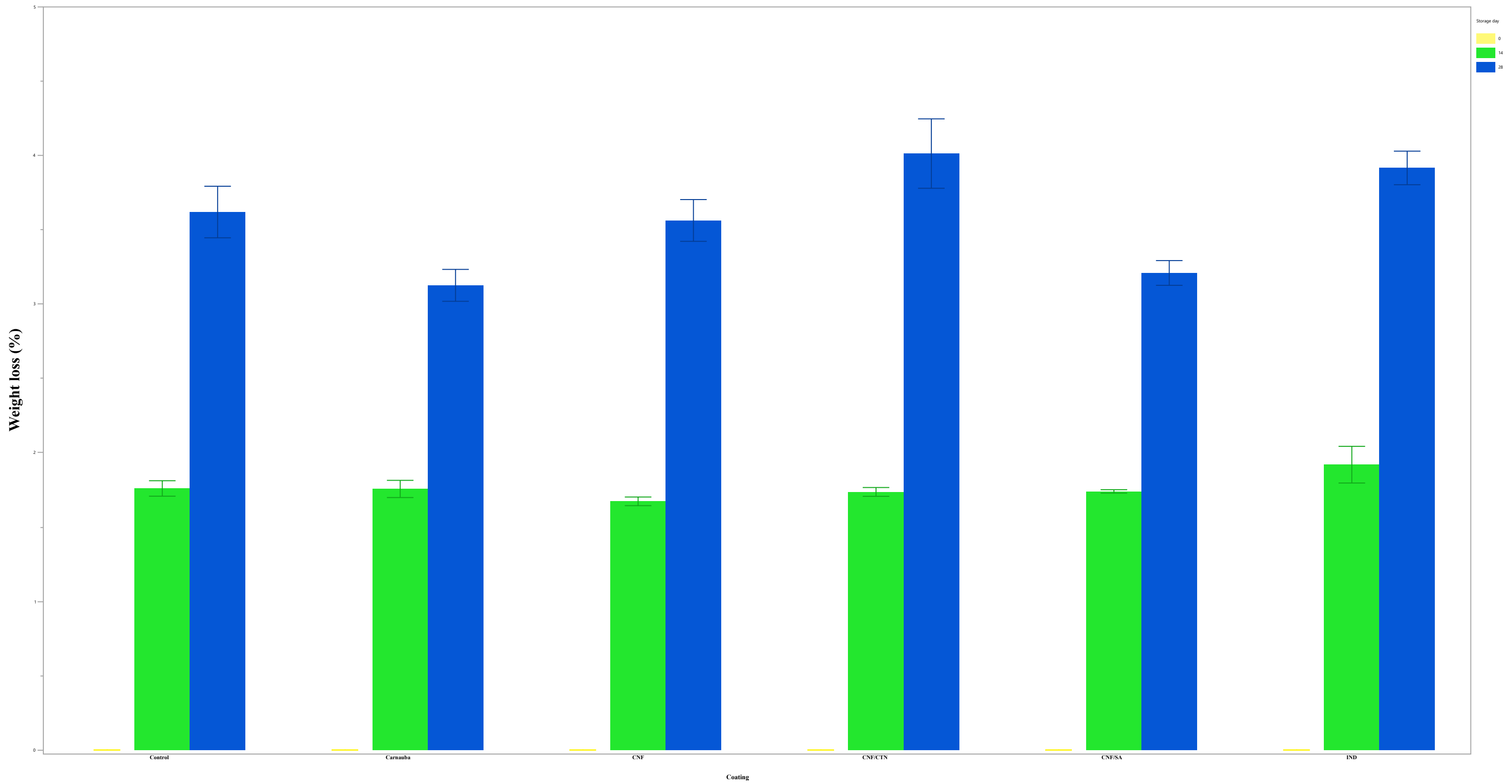

Figure 5. Interaction effects on weight loss attributes for Summit muscadines grapes with different coatings applied after harvest and evaluated during storage (0, 14, and 28 days) at 2 °C (Altus, AR 2023)

Cultivars were evaluated in triplicate. Each error bar was constructed using 1 standard error from the mean. Coating solution treatments included a control (no coating), 1% cellulose nanofibers (CNF), 1% CNF/1% chitosan (CNF/CTN), 1% CNF/0.5% sodium alginate (CNF/SA), an industry (IND) commercial product (NatuWrap®), and carnauba wax.

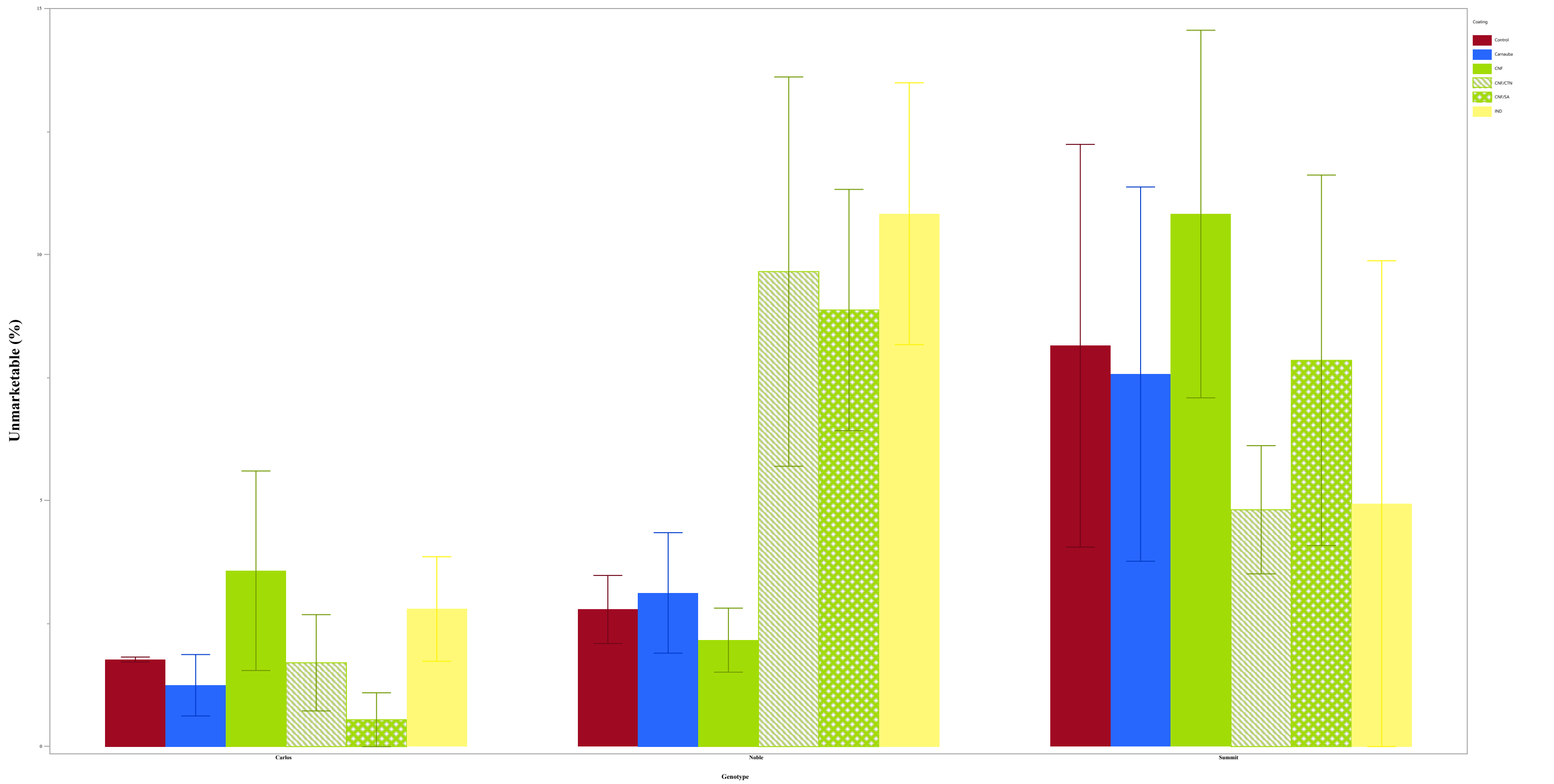

Figure 6. Interaction effects on unmarketability attributes for Carlos, Noble, and Summit muscadines grapes with different coatings applied after harvest and evaluated at 28 days storage at 2 °C (Altus, AR 2023)

Cultivars were evaluated in triplicate. Each error bar was constructed using 1 standard error from the mean. Coating solution treatments included a control (no coating), 1% cellulose nanofibers (CNF), 1% CNF/1% chitosan (CNF/CTN), 1% CNF/0.5% sodium alginate (CNF/SA), an industry (IND) commercial product (NatuWrap®), and carnauba wax.

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