HortScience 60(1):120–125. 2025. https://doi.org/10.21273/HORTSCI18178-24

Strawberry Desiccation and Gloss in Refrigerated Storage Depend on the Interaction between Cultivar and Time after Harvest

Kim S. Lewers

Genetic Improvement of Fruits and Vegetables Laboratory, US Department of Agriculture, Agricultural Research Service, 10300 Baltimore Avenue, Building 010A, Beltsville, MD 20705, USA

Nora M. Bello

Northeast Area Statistics Group, US Department of Agriculture, Agricultural Research Service, 10300 Baltimore Avenue, Building 003, Beltsville, MD 20705, USA

Keywords. Fragaria ×ananassa, fruit breeding, fruit quality, postharvest

Abstract. **The objectives of this study were to characterize strawberry cultivars grown under two production systems for gloss at harvest as a proxy for freshness and assess cultivar differences regarding the loss of gloss and changes in desiccation scores during refrigerated postharvest storage. Nine strawberry cultivars were grown in an annual plasticulture system for 3 years, harvested twice weekly, and packaged for refrigerated storage. Four of these cultivars also were grown in a low tunnel production system and harvested, packaged, and evaluated similarly. In both cases, berry gloss was measured at harvest and again after 1 and 2 weeks of refrigerated storage. Subjective desiccation scores were assigned to the berries during refrigerated storage. For both traits, effects were primarily determined by the interaction between the cultivar and time of measurement relative to harvest. For either gloss or desiccation, there was no evidence of differences in cultivar rankings based on the production system or packaging event. Cordial and Sweet Charlie were among cultivars that did not show loss of gloss or changes in desiccation scores during storage; therefore, they would not be good choices for studies that test alternative postharvest storage protocols. Keepsake and USDA Lumina were among the glossiest cultivars and those with the highest gloss levels and desiccation scores after both 1 week and 2 weeks of refrigerated storage. The variability of these traits among cultivars indicate that improvement can be made when developing new cultivars.**

Strawberries (*Fragaria ×ananassa* Duchesne ex Rozier) are considered highly perishable produce (Mitcham 2002), thus underscoring the importance of freshness to the marketability of this crop. When packaged in containers for market, the freshness of berries can be inferred from several traits, such as fruit gloss, calyx appearance, shriveling, softness, and decay, as reported by Collins and Perkins-Veazie (1993). Macnish et al. (2012) reported that aroma, turgidity, sheen, bruising, water soaking, softening, water loss, and fungal decay are important traits. However, Ares et al. (2009) reported that odor, gloss, fruit color, shriveling, and sepal browning are important traits.

Some studies have developed subjective rating scales for freshness that require rating a group of berries separately for each freshness proxy (Ares et al. 2009), whereas others have combined proxies into a single rating scale (Collins and Perkins-Veazie 1993; Macnish et al. 2012). Berries may be evaluated for freshness using proxies together or separately, but such proxies are not necessarily mutually exclusive or infallibly connected (Ares et al. 2009; Lewers et al. 2019). For instance, anecdotal observations indicated that rotted berries often (but not always) lose integrity and leak juices into the container. Existing approaches to assess berry freshness may be limited, especially those that mix freshness proxies such as gloss and decay on a single scale. However, it is not clear whether subjective scores based on multiple proxies of berry degradation provide an accurate quantification of the freshness continuum.

Glossiness is broadly considered a desirable trait of fresh produce in general and strawberries in particular. Indeed, the glossiness of multiple crop products in the context of postharvest protocols (Gómez-Contreras et al. 2021; Macnish et al. 2012; Velickova et al. 2013) and crop genetics (Cockerton et al. 2021; Huang et al. 2022) has been evaluated. For strawberries, gloss has been rated subjectively (Community Plant Variety Office, Office Communautaire des Variétés Végétales 2009; RosBREED 2010). Furthermore, strawberry gloss, as visualized in cropped black and white as well as color photographs, has been directly associated with freshness by evaluation panels (Arce-Lopera et al. 2012).

Modern development of commercially available gloss meters, rather than the use of subjective scoring, have offered the opportunity to measure gloss objectively (Mitcham et al. 1996). Gloss meters developed for industrial use were adapted for produce after determining how best to measure gloss on curved and relatively matte surfaces. For instance, the initial development used a gloss meter on flattened peelings of fruits and vegetables to determine that a light angle of 60° relative to the object surface was more reliable than 45° (Nussinovitch et al. 1996). Since that discovery, various types and brands of gloss meters using a 60° light angle have been used successfully to measure gloss of the curved surfaces of apples, eggplants, tomatoes, (Mizrach et al. 2009; Ward and Nussinovitch 1996), and strawberries coated with films (Gómez-Contreras et al. 2021).

New strawberry cultivars are usually described as having berries that are "glossy" or "very glossy" at harvest, without any associated metric (Amyotte et al. 2022; Lewers and Enns 2022; Lewers et al. 2017, 2019; Whitaker et al. 2018). In fact, few new strawberry cultivars are released with any information about their freshness characteristics during postharvest refrigerated storage (Lewers and Enns 2022; Lewers et al. 2019; Whitaker et al. 2017). Strawberry research could benefit from the objective evaluation of gloss as a genotypic trait at harvest as well as a freshness proxy during refrigerated postharvest storage. In this study, we leveraged the aforementioned technical developments of gloss meters to quantitatively assess gloss of strawberries as a trait at harvest and as a postharvest freshness proxy. We further assessed a subjective desiccation score as a second freshness proxy. The objectives of this study were to characterize strawberry cultivars grown under two production systems for gloss at harvest and assess cultivar differences in the loss of gloss and changes in desiccation scores during refrigerated postharvest storage as two independent freshness proxies.

Materials and Methods

Field establishment

As part of an established strawberry breeding project, strawberry plants of multiple cultivars

Received for publication 19 Sep 2024. Accepted for publication 25 Oct 2024.

Published online 30 Dec 2024.

This project was funded by the USDA-ARS Projects 8042-21220-257-00D and 8042-21220-260-00D. We thank Phil Edmonds, Turner Smith, Nhi (Amy) Tran, and the BARC Research Farm Services for their contributions to this research. We thank Michael Bukowski, Cheryl Dalid, Jorge Fonseca, and the anonymous reviewers for their critiques. Any mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the US Department of Agriculture and does not imply its approval to the exclusion of other products or vendors that also may be suitable.

K.S.L. is the corresponding author. E-mail: Kim.Lewers@usda.gov.

and breeding selections were grown in replicated plots on the North Farm of the US Department of Agriculture, Agricultural Research Service (USDA-ARS) Henry A. Wallace Beltsville Agricultural Research Center at Beltsville, MD, USA (lat. 39°01′48.42″N, long. 76°56′07.99″W, 49.4 m elevation), on Downer-Hammonton complex loamy sand and Russet-Christiana complex fine sandy loam soils (USDA Natural Resources Conservation Service 2023). Plantings were established annually in pairs of fields using two production systems: an annual plasticulture system (Black et al. 2002) and a low-tunnel system (Lewers et al. 2020). Both systems used raised beds with trickle irrigation lines 7 cm under the plastic mulch. The annual plasticulture system used black plastic mulch, and the low tunnel system used white plastic mulch. The low tunnels were covered with Kool Lite Plus 0.152-mm-thick polyethylene film (Klerks Hyplast Inc., Chester, SC, USA). The fields assigned to a production system in a given year contained three beds each that were used to compare cultivars in replicate (three beds = three replicates). Each bed contained space for multiple plots of six plants per plot. Each cultivar was randomly assigned to be planted in one plot per bed. Plug plants grown from runner tips pegged in early July were planted in early August each year in six-plant plots and fruited the following May. Irrigation was automated to apply water from the trickle irrigation lines during the late afternoon of the harvest day (Monday and Thursday) if the soil moisture was less than 70%. Imidacloprid systemic insecticide (Admire® Pro; Bayer Crop Science, Research Triangle Park, NC, USA) was applied through chemigation one month after planting. Etoxazole acaricide (Zeal® SC Miticide; Valent U.S.A., LLC, San Ramon CA, USA) was applied to the field the first week of November. No pesticides were used in the fruiting year.

Harvest, evaluation, and packaging

Harvest began as early as May the year after planting at a rate of two harvests per week and continued until all berries were harvested, which extended, at most, until mid-June. The start and end of harvest, as well as its duration, varied between cultivars. A harvest event started in early morning, with plots harvested in the same order at each harvest event, and continued until all plots were harvested and data were collected. Some harvests were completed by noon, and others continued for 12 h. At each harvest event, berries were harvested into two containers per plot, one for rotted berries and one for "ripe" nonrotted berries. A "ripe" berry was defined as any berry that would likely be overripe (i.e., showing physical nonpathogenic degradation of flesh or skin) by the next harvest 3 or 4 d later. If the berries from a nonrotted container were considered marketable (Lewers and Enns 2022), then they were visually examined to select individual undamaged berries of excellent symmetry and comparable size, condition, and ripeness. Up to 12 of these were placed in a labeled clear plastic egg carton with the tip up and calyx down. While still in the field, and immediately after selection, the single berry in the top left position of each container was measured to determine gloss with a micro-gloss 60° XS surface gloss meter, which has its own internal light source (BYK Gardner, Geretsried, Germany). The instrument was set to report gloss units (GUs). Each selected berry was measured multiple times at the glossiest part of the berry, specifically on the shoulder and near the calyx; the largest GU reading was recorded. Egg cartons were closed and placed in a heavy-duty plastic egg crate that held up to 15 egg cartons. The crates were protected from the sun, excess heat, and rain until the day's harvest was complete, and again when all harvested berries were packaged. Crates were transported to a walk-in cooler set at 1.5 °C, stacked up to two crates high, and then covered with a clean plastic trash bag. The cooler did not have relative humidity control, and the relative ambient humidity was not measured.

Postharvest evaluation

Berries were evaluated again after 1 week and 2 weeks of refrigerated storage after harvest. At each evaluation, the top left berry in a carton was measured to determine gloss, as described in the previous paragraph. Additionally, all berries in an egg carton were visually examined and assigned a subjective desiccation score at both 1 and 2 weeks after harvest. The desiccation score was recorded using a scale from 9 (no sign of desiccation for any of the berries) to 1 (all berries shrunken and hard). A score of 7 indicated that most berries in the container had some slight wrinkling but still looked attractive enough to be marketable. A score of 5 indicated that most berries were clearly wrinkled, and some showed signs of flesh cell degradation. A score of 3 indicated that most berries were wrinkled and had shrunk from desiccation. If a container had a mix of berries meriting two different scores, then the container was assigned an intermediate score.

Data selection

All gloss measurements and subjective evaluations at and after storage were conducted by the same person every year (K.L.). A subset of data from 3 years (2022–24) and nine cultivars were selected for analyses. Selected cultivars were those with data for at least 2 of the 3 years. Cultivars chosen from the USDA-ARS breeding program at Beltsville, MD, USA, were Cordial (USPP33636; Lewers and Enns 2022), Earliglow (Scott and Draper 1975), Flavorfest (Lewers et al. 2017), Keepsake (USPP30578; Lewers et al. 2019), and USDA Lumina (USPP36100). 'Earliglow', 'Flavorfest', and 'Keepsake' were commercially grown at the time of the study, whereas 'Cordial' and 'USDA Lumina' were recently released and were being propagated by nurseries to increase plant numbers before sales. 'Camarosa' (USPP8708) and 'Chandler' (USPP4481P) from the breeding program at The University of California, 'Galletta' (USPP19763) from the breeding program at North Carolina State University, and 'Sweet Charlie' (USPP8729) from the breeding program at the University of Florida commercially grown in the mid-Atlantic United States were also included. 'Camarosa' was unavailable in 2022. 'Sweet Charlie' was unavailable in 2023. All nine cultivars were evaluated in the annual plasticulture system. 'Camarosa', 'Chandler', 'Flavorfest', and 'Keepsake' were also evaluated in low tunnels.

For each plot, data from the first four packaging dates were used for statistical analyses. As was expected, packaging dates for early-season cultivars Earliglow, Galletta, and Sweet Charlie occurred earlier than those for later-season cultivars Keepsake and Cordial. Overall, packaging dates used for data analyses reflected berry yields of premium quality for each cultivar. Specifically, packing dates ranged from 5 to 31 May in 2022, 11 to 25 May in 2023, and 6 to 23 May in 2024.

Statistical analyses

A general linear mixed model was fitted to each response variable of interest assuming a Gaussian distribution. Specifically, gloss unit data were fitted in the natural logarithmic scale for variance stabilization. Modeling of desiccation score data effectively implemented a normal approximation.

Model specification: Comparison of nine cultivars grown in plasticulture only. For both response variables, the linear predictor in the statistical model included fixed effects of the cultivar, packaging event for the plot (first to fourth for the year), evaluation relative to harvest (i.e., at harvest and 1 and 2 weeks after harvest), and all two-way and three-way interactions. The following linear predictors were also considered: the random effects of year and bed within the year as overarching blocking structures for the cultivar; the random effect of plot (identified by the cross-product of year, bed, and cultivar), which was fitted to identify the experimental unit for the cultivar and the blocking structure for repeated measures on the packaging date recorded at the plot level; and the random effect of berry (identified by the cross-product of year, bed, cultivar, and packaging date) to recognize the unit of repeated measures at evaluation relative to harvest Finally, a random effect of harvest date (i.e., calendar date) was fitted to accommodate a nonorthogonal blocking structure resulting from commonality of environmental conditions at the calendar date of harvest. The statistical model described directly reflected the data generation process, including multiple blocking arrangements and a total of three different sizes of experimental units called for by factors in the treatment structure, namely cultivar, packaging event, and evaluation relative to harvest.

Model specification: Comparison of four cultivars grown in competing production systems. For both response variables, the linear predictor in the statistical model included fixed effects of productions system, cultivar, packaging event, evaluation relative to harvest, and all two-way, three-way, and four-way interactions. The random effect of field (identified by the cross-product between year and production system) was also included in the linear predictor to recognize the experimental unit for production system. The random effect of bed nested within the field was fitted to recognize the blocking structure in which cultivars were planted. The random effect of plot was identified by the cross-product of year, production system, bed, and cultivar, and it identified the experimental unit for the cultivar and the blocking structure for repeated measures for packaging events recorded at the plot level. Furthermore, the random effect of berry was identified by the cross-product of the year, production system, bed, cultivar, and packaging date to recognize the unit of repeated measures for evaluations relative to harvest. This model specification reflects four different sizes of experimental units called for by factors in the treatment structure, namely production system, cultivar, packaging date, and evaluation week relative to harvest.

Model fitting. In all cases, model assumptions were evaluated using studentized residuals obtained from the fitted model. For each response, a few datapoints were flagged as unusually extreme based on studentized residuals of a magnitude larger than the *t* test critical value obtained by an extremely conservative Bonferroni adjustment for the total number of observations considered (Kutner et al. 2005). Upon closer evaluation, these datapoints corresponded to observations of gloss and desiccation scores 2 weeks after harvest and reflected berries that had severely degraded physically in storage. Therefore, these datapoints were excluded from the final analyses.

Variance components were estimated using the restricted maximum likelihood. The Kenward-Roger's approach (Kenward and Roger 1997) was used to estimate the degrees of freedom and adjust the standard error estimates. The estimated least square means and corresponding 95% confidence intervals (CIs) were determined at the appropriate level of inference. Relevant pairwise comparisons between treatment groups were conducted using the Bonferroni adjustment to avoid inflation of the type I error rate caused by multiple comparisons. All statistical models were fitted using the GLIMMIX procedure of SAS (version 9.4; SAS Institute, Cary, NC, USA).

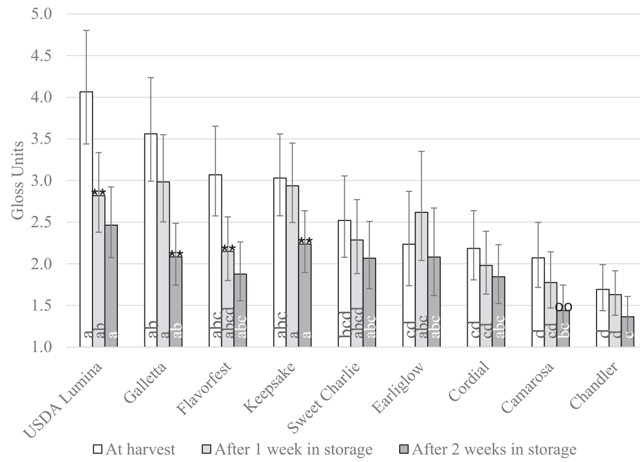

Fig. 1. Estimated gloss units (and 95% confidence intervals) of strawberries from cultivars grown in plasticulture in Beltsville, MD, USA, between 2022 and 2024, measured on the day of harvest and 1 week and 2 weeks after harvest and packaging and refrigerated cold storage. Letters indicate cultivar differences ($P < 0.05$) at harvest (white) or after 1 week (light gray) or 2 weeks (dark gray) of postharvest storage. Asterisks indicate a cultivar-specific significant decrease in gloss units relative to the previous evaluation week. A pair of circles indicates a significant decrease in gloss relative to the harvest date ($P < 0.05$).

Results

Gloss

The glossiness of berries of the nine cultivars grown in plasticulture using black plastic mulch and without low tunnels differed according to a two-way interaction between the cultivar and the evaluation relative to harvest, namely at harvest and 1 week and 2 weeks after refrigerated storage ($P = 0.033$) (Fig. 1). That is, the relative ranking of cultivars differed depending on the timepoint relative to harvest at which berries were evaluated for glossiness. There was no evidence of any effect of packaging event ($P = 0.682$) or for any interaction between packaging event and cultivar ($P = 0.812$), timepoint relative to harvest ($P = 0.496$), and three-way interaction ($P = 0.594$).

A comparison of cultivars on the day of harvest (Fig. 1) showed that berries of USDA Lumina were the glossiest, with an estimated mean of 4.1 GU (95% CI = 3.4–4.8 GU), followed closely by those of Galletta, Flavorfest, and Keepsake, which were estimated at 3.6 GU (95% CI, 3.0–4.2 GU), 3.1 GU (95% CI, 2.6–3.7 GU), and 3.0 GU (95% CI, 2.6–3.6 GU), respectively; however, none of them significantly different from the others. Berries of 'Chandler' were the least glossy, with an estimate of 1.7 GU (95% CI, 1.4–2.0 GU), but its glossiness was not significantly different from that of berries of 'Camarosa', 'Cordial', 'Earliglow', and 'Sweet Charlie', which were estimated at 2.1 GU (95% CI, 1.7–2.5 GU), 2.2 GU (95% CI, 1.8–2.6 GU), 2.2 GU (95% CI, 1.7–2.9 GU), and 2.5 GU (95% CI, 2.1–3.1 GU), respectively. Cultivars with berries that exhibited glossier skin on the day of harvest generally lost gloss during the 2-week postharvest refrigerated storage (Fig. 1). Specifically, 'USDA Lumina' and 'Flavorfest' berries lost gloss in the first week after storage ($P = 0.001$), whereas 'Galletta' and 'Keepsake' berries lost gloss primarily during the second week of storage ($P = 0.001$ and $P = 0.003$, respectively). Yet, 'USDA Lumina', 'Galletta', and 'Keepsake' berries remained at the top of the cultivar scale for gloss units from harvest and throughout the 2 weeks of refrigerated storage. Additionally, 'Chandler', 'Camarosa', and 'Cordial' berries were consistently ranked at the bottom of the cultivar scale for gloss, both at harvest and throughout postharvest storage. For 'Camarosa' berries, gloss loss was apparent only after 2 weeks of storage ($P = 0.002$). 'Sweet Charlie', 'Earliglow', 'Cordial', and 'Chandler' berries, which were ranked at the bottom of the scale at harvest, showed no significant loss in gloss after harvest and throughout the 2 weeks of refrigerated storage.

A subset of four cultivars, namely, Camarosa, Chandler, Flavorfest, and Keepsake, were also grown in a neighboring field using a low tunnel system (Lewers et al. 2020). However, there was no evidence of any differential effect of production system ($P = 0.119$) or packaging event ($P = 0.207$) on berry gloss for any of the four cultivars considered. A two-way interaction was observed between cultivar and evaluation time period relative to harvest ($P = 0.012$). In addition, regardless of the production system, gloss at harvest was higher for berries of 'Flavorfest' and 'Keepsake', with estimated values of 3.1 GU (95% CI, 2.5–3.8 GU) and 2.8 GU (95% CI, 2.3–3.4 GU), respectively, compared with gloss of 'Camarosa' ($P = 0.002$ and $P = 0.010$) and 'Chandler' berries ($P < 0.001$ and $P < 0.001$), with estimated values of 2.1 GU (955 CI, 1.7–2.6 GU) and 1.9 GU (95% CI, 1.5–2.3 GU), respectively. After 2 weeks of refrigerated storage, 'Keepsake', with an estimated gloss of 2.2 GU (95% CI, 1.8–2.7 GU), still had the highest gloss of all four cultivars ($P \leq 0.041$); however, gloss had decreased for 'Flavorfest' (1.7 GU; 95% CI, 1.4–2.1 GU), which had a value closer to and not significantly different from that of 'Camarosa' (1.5 GU; 95% CI, 1.2–1.9 GU) and 'Chandler' (1.4 GU; 95% CI, 1.2–1.7).

Desiccation

For the nine cultivars grown in annual plasticulture with black plastic mulch and without low tunnels, the desiccation scores of berries in refrigerated storage differed according to a two-way interaction between cultivar and refrigerated storage time after harvest ($P = 0.001$) (Fig. 2). Consistent with our findings for gloss, there was no evidence of any effect of packaging date ($P = 0.290$) or any packaging date interaction with cultivar

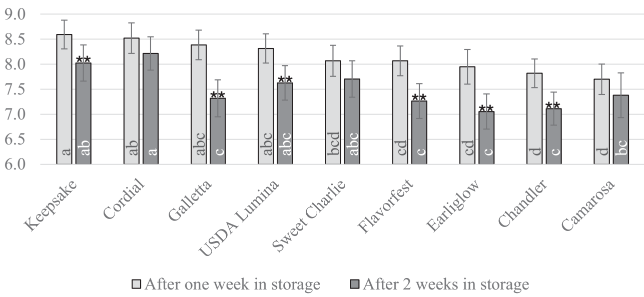

Fig. 2. Estimated desiccation scores (and 95% confidence intervals) of strawberries from nine cultivars grown in plasticulture in Beltsville, MD, USA, between 2022 and 2024. On the harvest day, strawberries were packaged in clear plastic egg cartons for postharvest evaluations at 1 week and 2 weeks after refrigerated storage. Berries in a carton were assigned a pooled subjective desiccation score as follows: 9 = no sign of desiccation; 7 = most berries had slight wrinkling that did not affect marketability; 5 = most berries were clearly wrinkled and some appeared gummy; 3 = most berries were clearly wrinkled and some had shrunk; and 1 = most berries were shrunken and hard. Letters indicate cultivar differences ($P < 0.05$) after 1 week (light gray) or 2 weeks (dark gray) after storage. Asterisks indicate a cultivar-specific significant decrease in the desiccation score relative to the previous week of postharvest storage ($P < 0.05$).

Table 1. Estimated subjective desiccation scores and 95% confidence intervals (CIs) of strawberries of four cultivars grown in plasticulture in Beltsville, MD, USA, between 2022 and 2024. On the harvest day, the strawberries were packaged in clear plastic egg cartons for postharvest evaluations 1 week and 2 weeks after refrigerated storage. All berries in a carton were assigned a subjective desiccation score as a group (9 = no sign of desiccation; 7 = most berries had slight wrinkling that did not affect marketability; 5 = most berries were clearly wrinkled and some appeared gummy; 3 = most berries were clearly wrinkled and some had shrunk; 1 = most berries were shrunken and hard). Cultivar means with different letters within the same evaluation timepoint indicate mean cultivar differences ($P \leq 0.000$).

Cultivar	Estimated mean desiccation score	95% CI
After 1 wk in refrigerated storage		
Keepsake	8.6 a	7.8–9.3
Flavorfest	8.0 b	7.3–8.7
Chandler	7.9 b	7.2–8.6
Camarosa	7.8 b	7.1–8.5
After 2 wk in refrigerated storage		
Keepsake	8.0 a	7.3–8.7
Flavorfest	7.5 b	6.8–8.2
Camarosa	7.4 b	6.7–8.1
Chandler	7.3 b	6.6–8.0

($P = 0.537$), storage time after harvest ($P = 0.128$), or their three-way interaction ($P = 0.547$).

After the first week of storage, berries from the cultivars Keepsake, Cordial, Galletta, and USDA Lumina showed less desiccation than that of all other cultivars, as reflected by higher mean desiccation scores, which were estimated at 8.6 (95% CI, 8.3–8.9), 8.5 (95% CI, 8.2–8.8), 8.4 (95% CI, 8.1–8.7), and 8.3 (95% CI, 8.0–8.6), respectively (Fig. 2). Among these top-ranking cultivars, Cordial berries showed no evidence of further desiccation for the remainder of the postharvest storage period evaluated ($P = 0.2723$). 'Keepsake' and 'USDA Lumina' berries showed further desiccation during the second week of storage ($P < 0.0001$ and $P < 0.0001$, respectively), but still ranked among the least desiccated by the end of the observation period. Finally, 'Galletta' berries showed significant signs of desiccation during the 2 weeks of refrigerated storage ($P < 0.0001$) and lost ranking by the end of the period of refrigerated storage considered.

On the opposite end of the spectrum, 'Camarosa' berries showed the most desiccation by 1 week of refrigerated storage, followed by 'Chandler', 'Earliglow', 'Flavorfest', and 'Sweet Charlie', with estimated values of 7.7 (95% CI, 7.4–8.0), 7.8 (95% CI, 7.5–8.1), 7.9 (95% CI, 7.6–8.3), 8.1 (95% CI, 7.8–8.4), and 8.1 (95% CI, 7.8–8.4), respectively. The second week of postharvest storage revealed no evidence of further desiccation for 'Sweet Charlie' ($P = 0.133$) or 'Camarosa' berries ($P = 0.238$), whereas 'Flavorfest' ($P < 0.0001$), 'Earliglow' ($P = 0.000$), and 'Chandler' berries ($P < 0.0001$) continued to desiccate during the remainder of the storage period considered (Fig. 2).

For the four cultivars grown under alternative production systems, there was no evidence of any differential effects attributable to the production system or packaging event on cultivar desiccation scores during refrigerated storage ($P = 0.179$). Regardless of the production system or packaging event, berries from all four cultivars in this comparison, Keepsake, Flavorfest, Chandler, and Camarosa, showed a decrease in desiccation scores of approximately half of a point from the first week to the second week of postharvest refrigerated storage ($P < 0.0001$). 'Keepsake' berries maintained scores indicative of the least desiccation among the four cultivars throughout the postharvest storage time, with no evidence for any differences between the remaining three cultivars at the end of either storage week (Table 1).

Comparisons of gloss and desiccation scores

Figure 3 shows a scatterplot of estimated mean gloss units and estimated mean desiccation scores for nine cultivars grown in annual plasticulture after 1 week and 2 weeks of postharvest refrigerated storage. The scatterplot is only intended for descriptive purposes to illustrate the relative rankings of cultivars for both gloss and desiccation scores simultaneously, however. 'Keepsake' and 'USDA Lumina' berries showed consistently above-average performance in terms of desiccation scores and GU after both 1 week and 2 weeks of refrigerated postharvest storage. 'Camarosa', 'Chandler', and 'Flavorfest' berries showed desiccation and gloss performance means that were consistently below average at both timepoints. 'Cordial' berries had above-average desiccation scores but below-average mean GUs, whereas 'Earliglow' berries showed below-average desiccation scores and above-average gloss performance throughout the 2 weeks of refrigerated storage. Regarding the remaining cultivars, relative rankings for both outcomes shifted throughout the postharvest refrigerated storage period.

Discussion

It is commonly understood that produce loses freshness during postharvest storage, and that freshness can be assessed with multiple proxies. During this study, we used strawberry gloss and desiccation scores from harvest through refrigerated storage as proxies for freshness to characterize and compare strawberry cultivars grown in two production systems. Our findings indicate that for both gloss and desiccation scores, the effects were primarily determined by the interaction between cultivar and time of measurement relative to harvest. For both traits, there was no evidence of differences in cultivar rankings based on the production system or packaging date.

Overall, the loss of berry gloss during the postharvest period differed by cultivar. As a result, the cultivar ranking for gloss at harvest changed relative to the rankings after 1 week or 2 weeks of storage. Desiccation scores were not measured at harvest; they were measured only after refrigerated storage. However, desiccation scores showed a pattern similar to that of gloss; changes in desiccation scores during refrigerated storage differed between cultivars, and cultivar rankings for desiccation scores differed depending on the number of weeks in storage. There was no indication of any effect of the production system on berry gloss at harvest or desiccation score during refrigerated storage or for any differences between packaging events. Consequently, it may be surmised that field environmental conditions during this study probably had a limited, if any, effect on either berry gloss or desiccation scores.

Observations intended to inform further cultivar development

In particular, cultivars showed substantial variability in their gloss dynamic from harvest (Fig. 4) and during postharvest refrigerated storage. Specifically, cultivars such as Flavorfest and USDA Lumina lost a significant amount of gloss after 1 week in refrigerated storage, whereas others, specifically Galetta and Keepsake, retained their gloss during the first week of storage and lost gloss only

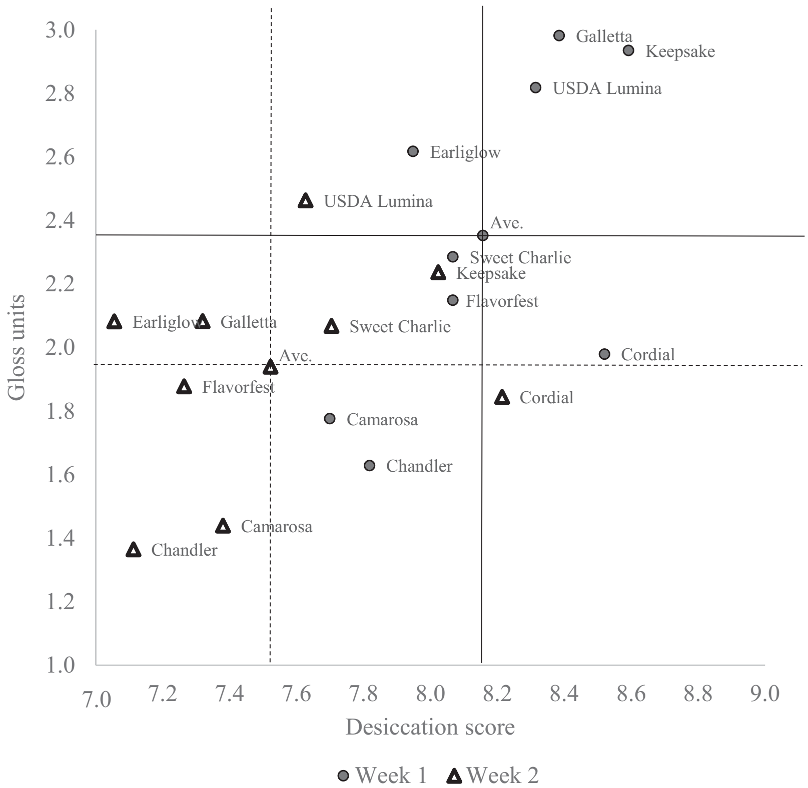

Fig. 3. Descriptive scatterplot of the estimated mean gloss units and estimated mean desiccation scores for nine cultivars grown in annual plasticulture after 1 week (circle) and 2 weeks (triangle) of postharvest refrigerated storage. The estimated cultivar means were averaged across 3 years and multiple harvest/packaging dates each year. For each week of postharvest refrigerated storage, the total average of the cultivar means is depicted (Ave) and emphasized by grid lines (solid for 1 week and dashed for 2 weeks of postharvest refrigerated storage) to better separate quadrants for the simultaneous evaluation of both traits.

during the second week of storage. For other cultivars, including Chandler, Cordial, Earliglow, and Sweet Charlie, berries showed no evidence of gloss loss throughout postharvest storage, but their berries did not have high gloss at harvest. 'Camarosa', 'Cordial', and 'Sweet Charlie' berries showed no evidence of changes in desiccation during their second week in storage. Finally, cultivars such as Keepsake and USDA Lumina showed both high gloss and comparatively limited desiccation during refrigerated storage. Conversely, for 'Cordial' and 'Sweet Charlie', there was no evidence for any gloss loss or for any signs of desiccation throughout the 2 weeks of refrigerated storage after storage. Such phenotypic variability between cultivars suggests the potential for genetic improvement of gloss and desiccation characteristics through breeding efforts. Without selecting for gloss, there may be no increase in gloss in newer cultivars, as was observed in the University of Florida strawberry breeding program (Whitaker et al. 2011). An attempt to genetically map strawberry glossiness using subjective scores for gloss level was unsuccessful (Cockerton et al. 2021). However, advances based on an objective quantification of gloss (i.e., using a gloss meter) are promising and warrant further investigation.

This work supports consumer intuition that gloss indicates the freshness of strawberries (Arce-Lopera et al. 2012), because the results showed that berries from some cultivars lose gloss after harvest. Also, cultivars such as Keepsake and USDA Lumina showed gloss loss yet comparatively limited signs of desiccation in refrigerated storage during this study and may be useful to postharvest studies looking for strategies to maintain freshness. In contrast, cultivars like Cordial and Sweet Charlie showed little, if any, postharvest changes in gloss or desiccation; therefore, they would be less suitable for postharvest studies.

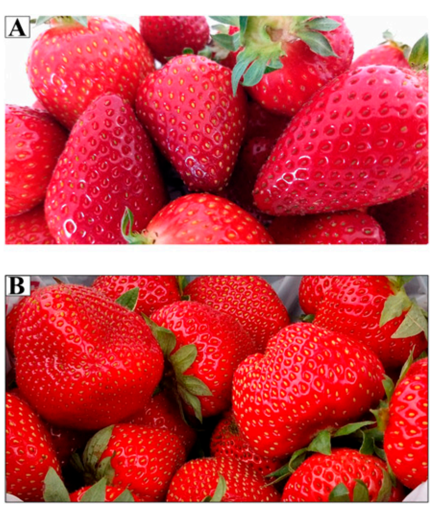

Fig. 4. 'USDA Lumina' strawberries with relatively high gloss at harvest (**A**) with an estimated mean of 4.1 gloss units (GUs) (95% confidence interval = 3.4–4.8 GU) compared with that of 'Cordial' strawberries with relatively lower gloss at harvest (**B**), which was estimated at 2.2 GU (95% CI, 1.8–2.6 GU).

References Cited

Amyotte B, Cole GS, Lewers KS, Karp D, Gasic K. 2022. Register of new fruit and nut cultivars: List 51. HortScience. 57(9):1174–1233. https://doi.org/10.21273/HORTSCI.57.9.1174.

Arce-Lopera C, Masuda A, Kimura Y, Wada K, Okajima T. 2012. Luminance distribution modifies the perceived freshness of strawberries. Iperception. 3(5):338–355. https://doi.org/10.1068/i0471.

Ares G, Barrios C, Lareo P, Lema S. 2009. Development of a sensory quality index for strawberries based on correlation between sensory data and consumer perception. Postharvest Bio Tech. 52:97–102. https://doi.org/10.1016/j.postharvbio.2008.11.001.

Black BL, Enns SC, Hokanson JM. 2002. A comparison of temperate-climate strawberry production systems using eastern genotypes. HortTechnology. 12(4):670–675. https://doi.org/10.21273/HORTTECH.12.4.670.

Cockerton HM, Karlström AW, Johnson B, Li E, Stavridou KJ, Hopson AB, Whitehouse RJ, Harrison A. 2021. Genomic informed breeding strategies for strawberry yield and fruit quality traits. Front Plant Sci. 12:724847–724862. https://doi.org/10.3389/fpls.2021.724847.

Collins JK, Perkins-Veazie P. 1993. Postharvest changes in strawberry fruit stored under simulated retail display conditions. J Food Qual. 16(2):133–143. https://doi.org/10.1111/j.1745-4557.1993.tb00356.x.

Community Plant Variety Office, Office Communautaire des Variétés Végétales. 2009. Strawberry. https://cpvo.europa.eu/sites/default/files/documents/TP/fruits/TP_022-2_Strawberry.pdf. [accessed 21 Oct 2024].

Gómez-Contreras P, Figueroa-Lopez J, Hernández-Fernández M, Cortés Rodríguez R, Ortega-Toro KJ. 2021. Effect of different essential oils on the properties of edible coatings based on yam (*Dioscorea rotundata* L.) starch and its application in strawberry (*Fragaria vesca* L.) preservation. Appl Sci. 11(22):11057–11071. https://doi.org/10.3390/app112211057.

Huang H, Du Y, Long Z, Li Y, Kong W, Wang H, Wei A, Du S, Yang R, Li J, Lin T, Zhang L, Liang B. 2022. Fine mapping of a novel QTL *CsFSG1* for fruit skin gloss in cucumber (*Cucumis sativus* L.). Mol Breed. 42(4):25–32. https://doi.org/10.1007/s11032-022-01291-y.

Kenward MG, Roger JH. 1997. Small sample inference for fixed effects from restricted maximum likelihood. Biometrics. 53(3):983–997. https://doi.org/10.2307/2533558.

Kutner M, Nachtsheim C, Neter J, Li W. 2005. Applied linear statistical models (5th ed). McGraw-Hill Irwin, Chicago, IL, USA.

Lewers KS, Castro PR, Enns JM, Hokanson SC, Galletta GJ, Handley DT, Jamieson AR, Newell MJ, Samtani JB, Flanagan RD, Smith BJ, Snyder JC, Strang JG, Wright SR, Weber CA. 2017. 'Flavorfest' strawberry. HortScience. 52(11):1627–1632. https://doi.org/10.21273/HORTSCI11893-17.

Lewers KS, Enns JM. 2022. 'Cordial' strawberry. HortScience. 57(2):231–235. https://doi.org/10.21273/HORTSCI15808-21.

Lewers KS, Enns P, Castro JM. 2019. 'Keepsake' strawberry. HortScience. 54(2):362–367. https://doi.org/10.21273/HORTSCI13613-18.

Lewers KS, Fleisher DH, Daughtry CST, Vinyard BT. 2020. Low-tunnel strawberry production: Comparison of cultivars and films. Int J Fruit Sci. 20(Suppl 2):S705–S732. https://doi.org/10.1080/15538362.2020.1768616.

Macnish AJ, Padda F, Pupin PI, Tsouvaltzis AI, Deltsidis CA, Sims JK, Brecht EJ, Mitcham MS. 2012. Comparison of pallet cover systems to maintain strawberry fruit quality during transport. HortTechnology. 22(4):493–501. https://doi.org/10.21273/HORTTECH.22.4.493.

Mitcham E. 2002. Strawberry, p 560–561. In: Gross KC, Wang CY, Saltveit M (eds). The commercial storage of fruits, vegetables, and florist and nursery crops. USDA Agric. Handb No. 66. 8 Nov 2002. USDA, Agricultural Research Service, Washington, DC. https://www.govinfo.gov/content/pkg/GOVPUB-A-PURL-gpo87416/pdf/GOVPUB-A-PURL-gpo87416.pdf.

Mitcham B, Cantwell M, Kader A. 1996. Methods for determining quality of fresh commodities. Perishables handling quarterly 85. Division of Agricultural and Natural Resources, University of California.

Mizrach A, Lu M, Rubino R. 2009. Gloss evaluation of curved-surface fruits and vegetables. Food Bioprocess Technol. 2(3):300–307. https://doi.org/10.1007/s11947-008-0083-9.

Nussinovitch A, Ward E, Mey-Tal G. 1996. Gloss of fruits and vegetables. LWT-Food Sci Technol. 29(1–2):184–186. https://doi.org/10.1006/fstl.1996.0025.

RosBREED. 2010. Strawberry phenotyping protocols. https://www.rosbreed.org/breeding/strawberry/Strawberry phenotyping protocols.pdf. [accessed 21 Oct 2024].

Scott DH, Draper AD. 1975. 'Earliglow', a new early ripening strawberry. Fruit Var J. 29:67–69.

USDA Natural Resources Conservation Service. 2023. Web soil survey. https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx. [accessed 30 Aug 2023].

Velickova E, Winkelhausen S, Kuzmanova VD, Alves M, Moldão-Martins E. 2013. Impact of chitosan-beeswax edible coatings on the quality of fresh strawberries (*Fragaria ananassa* cv Camarosa) under commercial storage conditions. LWT-Food Sci Tech. 52(2):80–92. https://doi.org/10.1016/j.lwt.2013.02.004.

Ward G, Nussinovitch A. 1996. Gloss properties and surface morphology relationships of fruits. J Food Sci. 61(5):973–977. https://doi.org/10.1111/j.1365-2621.1996.tb10914.x.

Whitaker VM, NS Boyd, NA Peres, JM Renkema, HA Smith. 2018. Chapter 15. Strawberry production, p 288–307. In: Freeman J, Vallad G, Dittmar P (eds). Vegetable production handbook of Florida, 2016–2017. The University of Florida, Institute of Food and Agricultural Sciences, Gainesville, FL, USA. https://swfrec.ifas.ufl.edu/docs/pdf/veg-hort/veg-prod-guide/2016-17-veg-prod-guide.pdf.

Whitaker VM, Osorio NA, Peres Z, Fan M, Herrington MC, do Nascimento Nunes A, Plotto CA, Sims LF. 2017. 'Florida Beauty' strawberry. HortScience. 52(10):1443–1447. https://doi.org/10.21273/HORTSCI12281-17.

Whitaker VM, Hasing CK, Chandler A, Plotto E, Baldwin T. 2011. Historical trends in strawberry fruit quality revealed by a trial of University of Florida cultivars and advanced selections. HortScience. 46(4):553–557. https://doi.org/10.21273/HORTSCI.46.4.553.