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SHORT COMMUNICATION

Haskap maturity stages and their influence on postharvest berry quality

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Abstract: Limited information is available regarding haskap berry maturity and corresponding postharvest characteristics. We assessed detached berry quality, respiration rate, and ethylene production at five stages of maturity and compared postharvest storage influence on berries harvested at half-blue and softening stages. Ethylene's increase at successive stages suggests its involvement with berry maturation, but concomitant respiration does not support classifying haskap ripening as climacteric. Results indicate harvesting at the less mature half-blue stage is not recommended, as berries had lower fresh weight and inferior quality relative to those harvested at the softening stage, both at harvest and following 14 d storage.

Key words: haskap, postharvest physiology, postharvest quality.

Résumé : On sait peu de choses sur le mûrissement de la camerise et les paramètres post-récolte correspondants. Les auteurs ont évalué la qualité du fruit, son taux de respiration et sa production d'éthylène à cinq stades de maturité, puis ont comparé les effets de l'entreposage après récolte sur les baies cueillies au stade « à moitié bleu » et à celui du ramollissement. La hausse du volume d'éthylène lors des stades successifs laisse croire que le gaz joue un rôle dans la maturation du fruit, mais le taux de respiration concomitant ne permet pas de qualifier le mûrissement de la camerise de climatère. Si l'on se fie aux résultats, on ne recommande pas la cueillette du fruit quand il est à moitié bleu, stade moins mature, car le poids frais des baies est plus faible et la qualité de ces dernières reste inférieure à celle des fruits récoltés au stade du ramollissement, évaluée à la récole et après un entreposage de quatorze jours. [Traduit par la Rédaction]

Mots-clés : camerise, physiologie post-récolte, qualité post-récolte.

Introduction

Fruit respiration patterns during maturation (often reported in terms of carbon dioxide (CO_2) production), as well as the nature of ethylene involvement, is important for fresh fruit production, where this information can influence harvest timing and postharvest management. Fruit species can be classified as climacteric or non-climacteric based on an increase of respiration and ethylene production concomitant with ripening in climacteric fruit (Lelièvre et al. 1997), although this classification does not apply to all species (Paul et al. 2012). The involvement of ethylene in ripening of climacteric fruit often presents an opportunity to prolong storage with the application of ethylene inhibitors (Watkins 2006), although there are exceptions.

Information regarding fresh haskap (*Lonicera caerulea* L.) berry maturation is limited. Research by Jurikova et al. (2009) indicates that closely related species (*Lonicera caerulea* subsp. *edulis* (Turcz. ex Herder) Hultén and *Lonicera caerulea* var. *kamtschatica*) exhibit rapid increases in respiration at the onset of ripening. Immature green haskap berries (*L. caerulea*) can change color and soften at warm temperature storage, with authors concluding that haskap berries can ripen after harvest (Yamamoto et al. 2014). From a practical perspective, as noted by Yamamoto et al. (2014), harvesting at an immature stage when fruit are less prone to damage would be advantageous for fresh market production.

We had two goals in this study: to evaluate fruit quality changes during fruit maturation at specific stages and outline corresponding respiration according to exogenous CO_2 and ethylene assessment, and to determine the effects of harvest stage on postharvest berry quality characteristics.

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Methods

Plant material

We selected two cultivars from our Corvallis, MT, USA (lat. 46°19′45.5 N, long. 114°5′7.4 W), field trial for our experiments: 'Aurora', a mid-season ripening cultivar released from the University of Saskatchewan breeding program (Bors et al. 2015); and 'Tana', a late-season cultivar released by Maxine Thompson (Oregon, USA) (Thompson 2016). The field plot design was a randomized complete block design with three blocks and three plants per cultivar per block and maintained per general haskap management recommendations in Montana (Miller et al. 2021). Further orchard care is detailed by Setzer (2020).

In-field berry selection

We collected 40 berries at each of five maturity stages: young berries, full-green, half-blue, full -blue, and softening berries, with stages based on Huo et al. (2016). At each fruit sampling, equal numbers of berries were randomly collected from all available plants of that variety in the trial, pooled together, and then fruit randomly assigned to treatments or quality measurements. Berries were harvested from all sides and both interior and exterior canopy position of any shrub.

Postharvest berry quality

Berry quality was evaluated on 10 fruit at each maturity stage. Measures included individual fresh berry weight (g), flesh firmness (N), soluble solids content (SSC %), titratable acidity (TA) (g citric acid L^{-1} of solution), and pH. Methods are detailed in Leisso et al. (2021).

Carbon dioxide and ethylene

We used a static accumulation/closed system (Fonseca et al. 2002; Kays and Paull 2004) to assess berry CO_2 and ethylene production. Three samples of 10 berries each were placed in glass jars with an interior volume of 235 cm^3 (wide mouth pint jars, Ball Corporation, Kent, WA, USA). Jars were sealed and remained closed for 1 h. We recorded elapsed time to the second, as well as total fresh berry weight and volume (estimated via water displacement to the nearest half cm^3). After 1 h had elapsed, we measured ethylene and CO_2 production with a handheld device which has an electrochemical sensor for ethylene detection and an infrared sensor/pyroelectric detector for CO_2 (Felix F-950; CID Biosciences, Vancouver, WA, USA). We followed manufacturer's instructions regarding offset/span calibration frequency and sensor lifespan. Measurements were taken in trigger mode. We sampled using a filter to minimize non-ethylene hydrocarbon interference (manufacturer supplied PolarCept filter) with a closed loop system also per manufacturer's instructions; inlet and outlet ports were on opposite sides of the lid to minimize sampling of returned air. All measurements were taken after fruit had acclimated to lab temperature (~25 °C) for 1 h. CO_2 production was calculated per Kays and Paull (2004): [(Change in carbon dioxide (%) × 10) × (free space of container volume (L))] / [(berries fresh weight in (kg)) × (duration container is closed (h)] = mL CO_2 kg berries^{-1} h^{-1}.

We then converted mL CO_2 to mg CO_2 using the volume/mass correction of 556 mL/1000 mg at 25 °C or 511 mL/mg at 1.1 °C (Kays and Paull 2004), and converted gas mass units to moles, and hours to seconds to conform to International System of Units (SI). Ethylene production rates were similarly calculated, with the volume/mass correction of 871 mL/1000 mg at 25 °C.

Maturity influence on postharvest berry quality

We harvested 80 additional berries at each of the stages half-blue and softening. We evaluated berry quality, as above, on 40 berries at harvest for each stage. Preliminary data for haskap berries harvested at half-blue indicated that berry shrivel (desiccation) limits storage to 2 d at room temperature (~22–25 °C). Therefore, we stored the remaining 40 berries in a cold room maintained at 1.1 °C and 95% relative humidity for 14 d followed by berry quality evaluations.

Statistics

We analyzed data with the SAS Statistical Package version 9.4 (SAS Institute, Cary, NC, USA) in analyses of variance (ANOVA) via PROC GLM, with cultivar, storage duration, and maturity as factors. For all analyses, post hoc means separations were established per Fisher's least significant difference at $P < 0.05$.

Results

Maturity influence on berry quality and exogenous gas production

Maturity stage influenced fresh berry quality (Table 1). Berry weight and SSC continued to increase at each successive stage, from initial weights of 0.29 g at young berry stage to 1.49 g at the softening stage. At the softening stage, 'Aurora' berry weights were higher than 'Tana' (1.59 g and 1.39 g, respectively). Mean initial SSC of 6.8% increased to a final SSC of 14.9%, and the interaction of maturity with cultivar was not statistically significant. Flesh firmness decreased at each successive stage, from 4.87 N at young berry stage to 0.20 N at softening. At the young berry stage, 'Tana' had a higher flesh firmness (5.32 N vs. 4.43 N) but by the softening stage, differences were not statistically significant. Fruit respiration, based on exogenous CO_2 production, was highest in the young fruit stage (2463.4 nmol kg^{-1} s^{-1}) and lowest at the softening stage (693.0 nmol kg^{-1} s^{-1}). However, CO_2 production was higher at the half-blue stage (1781.1 nmol kg^{-1} s^{-1}) relative to stages before (the full-green stage) or after (the full-blue stage). Cultivar influenced CO_2 production statistically, but overall trends were relatively similar.

Table 1. Haskap fresh berry quality, respiration (carbon dioxide (CO_2)), and ethylene production according to maturity stage at room temperature (~ 25 °C) in 2020.

Factor	Maturity stage	Cultivar	Date	Weight (g)	SSC (%)	Flesh firmness (N)	Carbon dioxide (nmol CO_2 kg^{-1}·s^{-1})	Ethylene (pmol·kg^{-1}·s^{-1})
Maturity	Young			0.29 ± 0.01D	6.8 ± 0.1E	4.87 ± 0.17A	2463.4 ± 128.8A	3267.5 ± 2109.0CD
	Full-green			0.79 ± 0.04C	7.2 ± 0.1D	2.38 ± 0.23B	1049.0 ± 97.8C	406.0 ± 198.1D
	Half-blue			0.92 ± 0.05C	8.4 ± 0.2C	0.63 ± 0.11C	1781.2 ± 48.6B	2841.8 ± 544.6BC
	Full-blue			1.25 ± 0.04B	13.2 ± 0.3B	0.25 ± 0.03D	1132.3 ± 120.6C	7277.7 ± 693.1A
	Softening			1.49 ± 0.08A	14.9 ± 0.3A	0.20 ± 0.02D	693.0 ± 69.2D	3802.2 ± 623.8C
Maturity × cultivar	Young	'Aurora'	18 May	0.28 ± 0.02e	6.9 ± 0.15ns	4.43 ± 0.20b	2539.1 ± 208.9a	5069.6 ± 4188.4ns
	Full-green		4 June	0.73 ± 0.04d	7.3 ± 0.19ns	2.38 ± 0.29c	841.3 ± 59.3ef	811.9 ± 178.2ns
	Half-blue		4 June	0.79 ± 0.08d	8.4 ± 0.34ns	0.80 ± 0.20d	1849.3 ± 66.3b	3990.4 ± 336.7ns
	Full-blue		18 June	1.25 ± 0.06b	13.9 ± 0.47ns	0.17 ± 0.05e	1382.9 ± 63.1bcd	7000.4 ± 861.4ns
	Softening		8 July	1.59 ± 0.13a	15.2 ± 0.44ns	0.21 ± 0.03e	550.4 ± 50.5f	3059.6 ± 742.6ns
	Young	'Tana'	22 May	0.31 ± 0.01e	6.7 ± 0.03ns	5.32 ± 0.21a	2387.7 ± 182.4a	1455.5 ± 1227.8ns
	Full-green		10 June	0.85 ± 0.06d	7.1 ± 0.13ns	2.38 ± 0.37c	1257.3 ± 37.2cde	0.0 ± 0ns
	Half-blue		10 June	1.04 ± 0.05c	8.5 ± 0.23ns	0.46 ± 0.09de	1712.3 ± 53.6bc	1693.2 ± 227.7ns
	Full-blue		29 June	1.25 ± 0.05b	12.6 ± 0.21ns	0.33 ± 0.03de	881.1 ± 77def	7554.9 ± 1168.4ns
	Softening		20 July	1.39 ± 0.08b	14.5 ± 0.42ns	0.19 ± 0.03e	836.3 ± 17ef	4554.7 ± 980.3ns
P								
Maturity				<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cultivar				0.3445	0.0152	0.2530	0.7848	0.5346
Maturity × cultivar				0.0167	0.1161	0.0228	0.0014	0.1225

Note: Per weekly phenology evaluations, first flower for 'Aurora' was ~8 April; full bloom was ~30 April and first flower for 'Tana' was ~23 April; full bloom was ~5 May. Carbon dioxide and ethylene were measured first in static jars (no air flow) on three groups of 10 berries followed by weight (n = 10), firmness (n = 10), and SSC (n = 10) on individual berries; means are followed by the standard error. Cultivars assessed were 'Aurora' and 'Tana'. Means followed by different letters are different according to the main effect maturity stage (capital letters) and maturity stage × cultivar (lowercase letters) at $p < 0.05$ (Fisher's least significant difference).

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Table 2. Effects of fruit harvest maturity and 2 wk storage on fresh berry qualities in two haskap cultivars.

Cultivar	Harvest maturity	Storage days	Weight (g)	SSC (%)	Flesh firmness (N)	pH	TA (g L^{-1} citric acid equivalents)[a]
'Aurora'	Half-blue	0	0.84 ± 0.03c	8.0 ± 0.2e	0.82 ± 0.09a	3.03 ± 0.01e	35.64 ± 0.32b
		14		9.7 ± 0.2d	0.25 ± 0.03c	3.11 ± 0.01d	26.67 ± 0.84c
	Softening	0	1.48 ± 0.04a	15.5 ± 0.2a	0.35 ± 0.03c,d	3.33 ± 0.02b	17.97 ± 0.51d
		14		15.1 ± 0.2ab	0.25 ± 0.04c	3.44 ± 0.01a	13.68 ± 0.34e
'Tana'	Half-blue	0	0.88 ± 0.03c	7.3 ± 0.2f	0.58 ± 0.03b	2.82 ± 0.00g	48.76 ± 2.74a
		14		8.1 ± 0.1e	0.35 ± 0.03c	2.94 ± 0.00f	34.42 ± 1.02b
	Softening	0	1.39 ± 0.04b	14.4 ± 0.2c	0.25 ± 0.02c	3.29 ± 0.01c	17.76 ± 0.11d
		14		14.7 ± 0.2b,c	0.12 ± .01d	3.42 ± 0.01a	14.40 ± 0.26e
P							
Cultivar			0.2923	<0.0001	0.0042	<0.0001	<0.0001
Maturity			<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Storage			0.0005	<0.0001	<0.0001	<0.0001	<0.0001
Cultivar*maturity			0.0045	0.0982	0.5217	<0.0001	<0.0001
Cultivar*storage			0.2719	0.5719	0.0148	<0.0001	<0.0001
Maturity*storage			0.2166	<0.0001	<0.0001	<0.0001	<0.0001
Cultivar*maturity*storage			0.2201	0.0018	0.0042	<0.0001	<0.0001

Note: For weight, SSC, and flesh firmness, n = 40 berries per mean; pH and titratable acidity (TA), n = 4 (each replication consisting of the juice of 10 berries); means are followed by their standard error. Means followed by different lowercase letters are different according to the interaction effect cultivar*maturity stage*storage at $p < 0.05$ (Fisher's least significant difference). For weight, as the interaction of cultivar*maturity*storage was not significant, means and post hoc comparisons for the interaction of cultivar*maturity are presented.

[a]Titratable acidity is in terms of citric acid; 1 g·L^{-1} = 0.1%.

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Ethylene levels were higher at young berry stage (3267.5 pmol kg^{-1} s^{-1}) than at the next stage (full green; 406.0 pmol kg^{-1} s^{-1}), followed by a significant increase at half-blue (2841.8 pmol kg^{-1} s^{-1}). Levels peaked at full-blue at 73.5 ug kg^{-1} h^{-1} and were reduced in the softening stage (3802.2 pmol kg^{-1} s^{-1}). The interaction of maturity stage × cultivar was not statistically significant.

Maturity influence on stored fruit quality

Maturity stage of fruit and storage affected fruit quality parameters and were also influenced by cultivar (Table 2). 'Aurora' berries weighed more at harvest at the softening stage than 'Tana'; both cultivars weighed more at the softening stage than at half-blue stage, but the interaction of cultivar, maturity, and storage was not statistically significant. SSC in storage was affected by both maturity and cultivar: SSC increased in storage for fruit harvested at the half-blue stage, but not for fruit harvested at the softening stage. However, berries harvested at the half-blue stage never attained SSC as high as berries harvested at the at the softening stage, with levels also differing according to cultivar (9.7% vs. 15.1% for 'Aurora', and 8.1% vs. 14.7% for 'Tana'). Effects of storage on flesh firmness of half-blue fruit was similar in the two cultivars. In storage, these less mature fruit softened to levels similar to more mature fruit (softening stage) at harvest, however, the decrease in firmness with storage was greater in 'Aurora' than 'Tana'. When berries were harvested at the softening stage, berries from 'Aurora' retained their firmness during storage, while fruit from 'Tana' softened and were much less (50%) firm than 'Aurora' at the end of the storage period. Effects of 14 d storage on TA and pH depended on harvest stage but responses were unique for each cultivar. In general, less mature fruit had higher TA, 14 d storage reduced TA, and 'Tana' berries had higher TA than 'Aurora'; however, 'Tana' berries harvested at half-blue stage were consistently more acidic than 'Aurora' before and after storage. When 'Tana' berries were picked at the softening stage, pH was lower than, but TA was similar to, 'Aurora' at the beginning of storage. The effect of 14 d storage on pH was greater in 'Tana' than 'Aurora'.

Discussion

To our knowledge, this is the first report of exogenous ethylene and CO_2 levels in relation to haskap maturation stages for North American haskap cultivars. We demonstrate that ethylene levels rise concurrently with increasing SSC and decreasing firmness at the full-blue stage, which suggests that ethylene plays a role in haskap berry maturation. As respiration (as measured by CO_2 evolution) failed to exhibit a concomitant marked increase with ethylene, we cannot classify haskap as a climacteric fruit based on these data. Ethylene is known to be involved in fruit ripening for many non-climacteric species (Paul et al. 2012); however, we measured ethylene exogenously and on discrete detached fruit at each stage, which limits the extent of interpretation. Additional complementary data, e.g., internal ethylene and corresponding molecular validation (Rogiers et al. 1998) or suppressing ethylene perception (e.g. Zhang et al. 2020), to further elucidate ethylene involvement in maturation will provide additional insight regarding the potential for ethylene manipulation in postharvest management of haskap.

The second goal of this study was to determine whether berries harvested at the half-blue stage would exhibit postharvest quality changes in cold storage to support the practice of harvesting at half-blue stage, when the firmer berries may be more resistant to damage during harvest. Results do not favor this practice, as berry size was lower, SSC was lower, and TA was higher at harvest, as well as at 14 d postharvest cold storage, than berries harvested at the softening stage and stored for the same duration. While less mature (half-blue) harvested berries soften in cold storage, they do not increase in SSC or decrease in TA to levels of later harvested fruit. Furthermore, the decrease of TA in cold storage while SSC remained relatively constant could result in a more favorable SSC to TA ratio; higher SSC to TA ratios result in greater consumer preference for other fruits (Harker et al. 2002). As haskap berries shrivel rapidly at room temperature, we advise caution in attempting postharvest ripening at warmer storage temperatures.

Conclusions

Results support the involvment of ethylene in haskap maturation but CO_2 evolution from detached fruit do not suggest classic climacteric ripening. We presently do not recommend harvesting at the half-blue stage; even though these fruit are firmer and potentially more resilient to damage, they have smaller fruit size, lower SSC, and higher TA at this stage both at harvest as well as after 14 d of cold storage than later harvested fruit.

Competing interests

The authors declare there are no competing interests.

Contributors' statement

R. Leisso: conceptualization, methodology, formal analysis, investigation, writing – original draft, supervision, and funding acquisition. B. Jarrett: investigation, writing – reviewing and editing, supervision, and resources. R. Richter: investigation, writing – reviewing and editing, and visualization. Z. Miller: writing – reviewing and editing, formal analysis, resources, and funding acquisition.

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Data availability statement

Data are available upon request.

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