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Ripeness stage at harvest influences postha cranberry fruit: physiological and anatomical

Mustafa Özgen [a], Jiwan P. Palta [a,*], Jonathan D.

[a] *Department of Horticulture, University of Wisconsin, 1575 Linden Drive, Madison, W*
[b] *Northland Cranberries Inc., PO Box 8020, Wisconsin Rapids, WI 54495-80*

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Abstract

We investigated the relationship between postharvest life of cranberry (*Vaccinium m* fruit and ripeness stage at harvest. Wet harvested, mature fruit were sorted into four r quality after 4 and 7 weeks of cold storage at 3 °C. In addition, CO_2 and ethylene produ content were measured. After 7 weeks of storage, the marketable fruit among dark-red were 82, 74, 63, and 44%, respectively. The ethylene production was nearly the same However, white, blush, and light-red fruit had significantly higher respiration rates than d that cuticle thickness was significantly higher for red fruit as compared to other ripeness present at the calyx end of the fruit, which became impregnated with wax in red fruit. layer in the calyx opening accumulated anthocyanins in red fruit only. Our studies sugg postharvest life, possibly because (i) red fruit have lower respiration rates, (ii) thicker cu (especially at the calyx end) on these fruit may retard the entry of microorganisms into and may mitigate mechanical injury by harvesting equipment. © 2002 Elsevier Science

Keywords: Anthocyanin; Ripeness stages; *Vaccinium macrocarpon*; Cranberry; Cuticle; Shelf life; F

1. Introduction

Ripening is the terminal phase in the development of fleshy fruits that encompasses a range of physiological and biochemical changes in the tissue. It is frequently signaled by changes in color,

mulation of sugars, deg and destruction of al Rhodes, 1980).

Association of pickin ness stage is important f Fruits are generally div cording to their ripening

softening and thus, short
ore, such fruits are har-
arly stage of ripening for
The majority of tomatoes
en to withstand current
l transportation, whereas
nly good for local mar-
rt postharvest life (Kader
5). Fruits such as straw-
ackberry are also picked
e to prevent postharvest
t al., 1996; Sjulin and
udies aimed at determin-
for harvest have utilized
ied, 1969; Knee et al.,
1989; Skrzynski, 1994),
acteric fruits are limited.
fruits and vegetables can
r for designing storage
nize their longevity
sure to high concentra-
concentrations of O_2 is
lene biosynthesis in cli-
der, 1986). Although no
lable for nonclimacteric
rate is generally thought
stharvest life (Blanpied,

sphere cranberries ripen
velop color in the outer
nse to low temperatures
and Stang, 1983). The
ed with a distinct rise in
the fruit (Abdallah and
s a major cultivar that
fruit, resulting in one of
ver, it suffers from poor
ficant numbers of fruit
nder Wisconsin growing
d for fresh market are
ing of flooded bogs. Wet
stored for 1 or 2 months

lower incidence of physiological breakdown during storage than less colored fruit. This was reported to be true for fruit harvested at three times during the ripening period (early, middle and late). They suggested that highly colored cranberries should be used for cold storage (Ceponis and Stretch, 1983). These studies suggest that cranberries possibly do not behave like other climacteric fruits such as tomatoes and strawberries. Systematic information is not available on the relationship between ripeness stage at harvest and postharvest life in cranberries. We investigated the effect of ripeness stage (fruit color) on postharvest life. We also attempted to understand the physiological and anatomical basis for the influence of ripening stage on postharvest life.

2. Materials and methods

2.1. Plant materials

Cranberry (*Vaccinium macrocarpon* Ait. cv. Stevens) fruit were collected at the processing plant of Northland Cranberries Inc. (Wisconsin Rapids, WI). These fruit had been wet harvested using a Getsinger style fresh fruit harvester (Paul's Machine and Tool, Warrens, WI) on October 13, 1997 from a commercial bed established near Wisconsin Rapids. Fruit were sorted by visual inspection into four ripeness stages: dark-red, light-red, blush, and white. Fruit showing rot, mechanical injury, disease, or flesh softness were discarded. All fruit selected were physiologically mature and similar in size. Fruit lacking any visual chlorophyll are generally considered mature (Salunkhe and Desai, 1984). Maturity of the fruit was also determined using the seed color. As cranberry fruit mature, seed color gradually changes from light-green to light-brown and then dark-brown. Samples of 0.5 kg were placed into 2-l open ventilated plastic containers. Each of the

ing rot and/or flesh softness was designated as 'unmarketable' fruit. The remaining fruit were designated as 'marketable' fruit. In addition, fruit respiration (CO_2), ethylene production, and anthocyanin content were measured after 4 weeks of storage using subsamples of marketable fruit. Remaining fruit were kept in cold storage for an additional 3 weeks and again rated for fruit quality.

2.2. Fruit ethylene production and respiration

Fruit ethylene production and respiration were determined by using a procedure similar to the one used by Farag and Palta (1993). For this purpose, 0.05 kg of intact, healthy fruit were incubated in a 700-ml gas-tight glass jar for 24 h at room temperature (20 °C). All decaying and rotted fruit were removed prior to respiration and ethylene measurements. Headspace gas was sampled and ethylene concentration was determined by injecting 1-ml gas into a gas chromatograph (Shimadzu 9AM, Shimadzu Corporation, Kyoto, Japan) equipped with a flame ionization detector and a 1.2-m stainless steel packed column (80/100 Porapak KQ Supelco Inc., Bellefonte, PA). For quantification of respiration, 0.05 kg of fruit was incubated in the same gas-tight glass jars for 30 min. Headspace gas was sampled and carbon dioxide generated by the fruit was quantified by injecting 1 ml of gas into the same gas chromatograph (used for ethylene measurements). Attachment of a Methanizer (Shimadzu MTN-1) allowed the detection and quantification of carbon dioxide by reducing it to methane gas. Methanizer temperature was set at 450 °C. Five separate measurements were made for each ripeness stage.

2.3. Anthocyanin content

For quantification of total anthocyanins (TAcy) a procedure similar to that of Fuleki and Francis

Delray Beach, FL). Th
tract (TEV) was 175 m
ml slurry (SV) were dil
centrifuge tube with ex
volume, DV = 27 ml).
lowed to diffuse into th
samples were then sti
trifuged (Beckman J2-2
Inc., Irvine, CA) at 68
supernatant was used t
(OD) at 535 nm (Beckı
meter; Beckman Instrur
calculated using the fol
and Francis (1968):

TAcy (mg/kg)

$= OD \times DV \times 100 \times T$

2.4. Cuticle thickness

The equatorial portic
for measuring cuticle
perpendicular to the fr
were made with an Ox
Oxford Co., San Mat
allows thin sectioning c
tion (Palta and Li, 19
was measured by obser
a light microscope (Nil
jective) equipped with a
1821) and television r
with a total magnifica
ments were made using
ness stage and five d
fruit.

2.5. Fruit resistance to

Cuticle strength (r
cranberry fruit was det
eter equipped with p
Synergie 200, MTS Co
cross-head drive, inter

leasurements were made
o sizes (ranges 1.0–1.3
ipeness stages (dark-red

s stage, eight, 0.05 kg
it were crushed, trans-
d squeezed by hand to
luble solids content was
digital refractometer
i Measurements Inc.,

roscopy

y and accumulation of
tal) end were examined
croscopy (SEM). Obser-
nite and dark-red stage
nd cross-sections were
ashed in distilled water,
s with silver paint, and
n thick gold–paladium
mens were viewed with
kyo) at 10 kV.
ion on the fruit calyx
ving thin cross-sections
cope (SZ-PT Olympus;
nts Inc., Minneapolis,
or video camera (Sony
on Instruments Inc.).
t 0.5 mm thick) were
e. Ten berries of each
ed.

significant differences

The storage quality of the fruit was significantly affected by the ripeness stage (Fig. 1(B), Table 1). At 4 weeks after storage, both dark-red and light-red fruit had higher percentages of good fruit than the blush and white fruit. At the end of 7 weeks of storage, the good berries were 82, 74, 63, and 44% in dark-red, light-red, blush, and white groups, respectively (Table 1). At 4 and 7 weeks after storage, the blush stage had a higher percentage of good fruit than the white stage. Between 4 and 7 weeks of storage, the percentage of good fruit declined by 17.5, 14.2, 11.5, and 6.6% in the white, blush, light-red, and dark-red ripeness stages, respectively.

There were large differences in respiration rates among the various ripeness stages (Fig. 1(C)). White berries had the highest respiration rate, which was 71% higher than the dark-red fruit. Dark-red fruit had the lowest respiration rate. The respiration rates of blush and light-red fruit were similar and their respiration rates were significantly higher than the dark-red fruit and significantly lower than the white fruit.

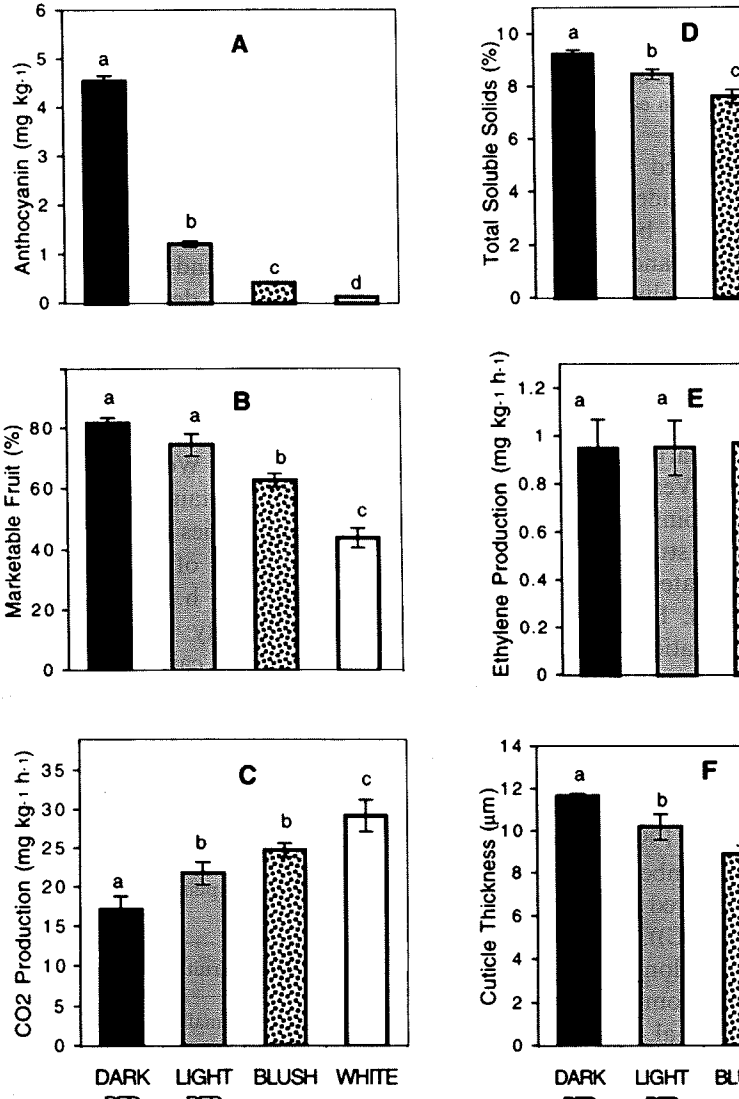
There were significant differences in total soluble solids (%) content among the four ripeness stages. The berries that had higher anthocyanin content also had the highest soluble solids (Fig. 1(D)). Rate of ethylene production by the fruit did not vary significantly among the four ripeness stages (Fig. 1(E)).

Dark-red and light-red berries had significantly thicker cuticles than blush and white berries (Fig. 1(F)). Cuticle thickness was 11.7 ± 0.6, 10.2 ± 0.3, 8.7 ± 0.45, and 8.2 ± 0.5 μm in dark-red, light-red, blush, and white groups, respectively. In addition, resistance of the fruit to puncture was increased as fruit ripened. Dark-red fruit had higher resistance to puncture than white fruit (Table 2). This was true for both large and small size fruit.

Greater wax accumulation was seen in the dark-red fruit than the white fruit (Fig. 2). There

4. Discussion

The results of the present study (Fig. 1, Table 1) clearly show that, in contrast to other perishable fruits such as tomatoes, bananas, strawberries, and raspberries, ripe cranberries have a longer shelf life than
results also support the
by Ceponis and Stretch
highly colored cranberri
cal breakdown during
ripening in classic clima



nberry fruit on shelf life

uit (%) after storage at	Loss of good fruit (%) between 4 and 7 weeks of storage
7 weeks	
81.7a	6.6
74.4b	11.5
62.8c	14.2
44.0d	17.5

7 weeks of cold storage. The values represent mean of five replications. Means were compared by 5) within each column; means followed by the same letter do not differ significantly.

nsidered to be synony-
a prelude to senescence.
have been conducted
ruits and only limited
nonclimacteric fruits
t al., 1989; Skrzynski,
ed postharvest life and
y, it is commonly rec-
acteric fruits when ma-
an early ripeness stage
kins-Veazie et al., 1996;
Robbins, 1987). In con-
our study suggest that
at late ripeness stages
e 1). Furthermore, our
planation for this con-
high respiration is gen-
correlate with short
d, 1969; Tucker, 1993)
ed an indicator in con-
torage to maximize
oko, 1996). Our results
e cranberry fruit had a
mpared with light-red,
g. 1(C)). Thus, reduced
cate longer postharvest
ies compared with less
et al. (1963) found
and poor shelf life of

showed that wax accumulation on the cranberry fruit surface as it ripens, and no stomata, lenticels, or trichomes were found on the fruit surface (Farag and Palta, 1989). In addition, the fruit cuticle was devoid of cracks. We confirmed these observations on the fruit morphology in our studies (data not shown). Furthermore, we found significant changes in the wax accumulation at the calyx end of the fruit during ripening (Figs. 2 and 3). We also found that this portion of the fruit contained stomata (Fig. 2). In Wisconsin, cranberries are wet harvested by flooding the fields. Fruit often remain submerged in water for over 24 h. During this time, there is a high probability that microorganisms (e.g., fungi, bacteria) can enter fruit. The main path of entry of these microorganisms would be through wounds or through stomata at the calyx end of the fruit. The presence of fungal hyphae on this part of the fruit (Fig. 2) supports

Table 2
Fruit resistance to puncture (N) of dark-red and white cranberry fruit

Ripeness stages	Fruit size	
	Small (1.0–1.3 g)	Large (1.7–2.0 g)
Dark-red	5.22a	5.33a

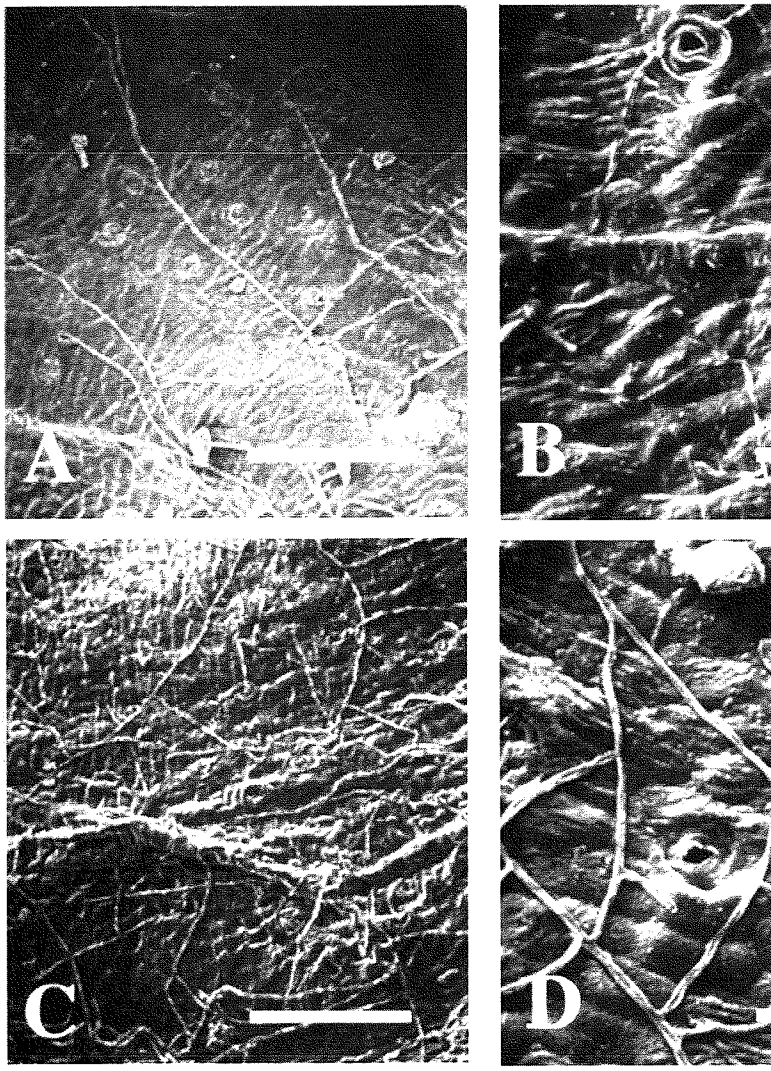
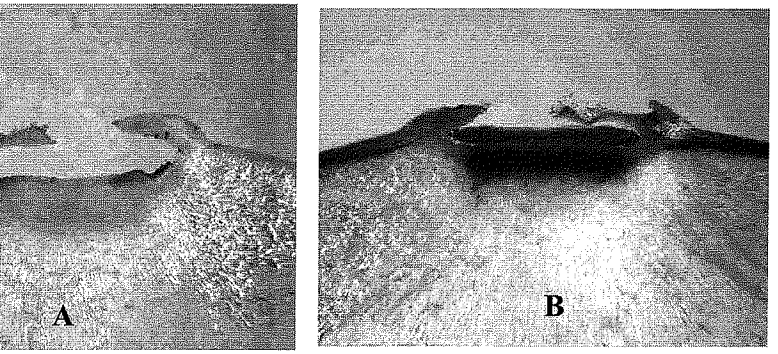


Fig. 2. Scanning electron micrographs of the calyx (distal) end of the cranberry fruit. Fruit ends
at 10 kV. ((A) and (B)) White stage of fruit; ((C) and (D)) dark-red stage of fruit. Bars in (A) a
(D), 30 μm. Notice more wax accumulation in dark-red fruit ((C) and (D)) as compared to white f
and stomata are seen at this (distal) end of the fruit ((B) and (D)).

this idea. These observations suggest that ripe

calyx end of the red



ed under light microscope showing anthocyanin accumulation on calyx end of the fruit (A) white otice accumulation of anthocyanin in the epidermal cells (B) in dark-red fruits (dark layer under ot present in white fruit (A).

ted by the College of ces, University of Wis- the Wisconsin State ank Dr Patricia Mc- nd Chang Hwang for ement of cranberry cu- k Beth Ann Workmas- SEM work.

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of the relationship between storage and the respiratory

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