Selection Efficiency for Postharvest Shelf Life Affected by Storage Temperature and Harvest Season for Raspberry Fruit

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As growers capitalize on novelty fruit crops and consumers are told to eat a more colorful diet, different colored raspberries are a growing interest. Increasing the colors of raspberries in the market can benefit both consumers and producers. Red raspberries are the most commonly consumed raspberry, and therefore the most information is known about how this fruit crop performs after harvest. Considerably less information is known about the quality and storability of purple, black and yellow raspberries.

Using an existing planting in Beltsville, Maryland, we developed a postharvest research program to study postharvest pathology and physiology of this perishable fruit crop. Plants were trellised, pruned for double-cropping and treated with herbicides. Since many eastern raspberry growers prefer low-input or organic production of this crop, we chose not to make any insecticide or fungicide applications to this research planting.

The floricane (spring) and primocane (fall) fruits were harvested during two consecutive years. Fruits were picked at commercial maturity directly into CoStar® plates to assess fruit bleed and rot. Larger samples were taken for measurements of firmness, soluble solids content, titratable acidity, anthocyanins and other measures of reactive oxygen species.

Since relatively little postharvest work has been conducted on this crop, we also measured ethylene evolution and respiration rates in selected cultivars. These were harvested and disinfected using alcohol to reduce spoilage and placed in a flow-through system to measure ethylene and respiration rates using a gas chromatograph.

In our study, red raspberries had the lowest ratio of soluble solids to titratable acidity which determines the raspberry flavor expected by consumers. They also had lower anthocyanin and phenolic content levels than either black or purple raspberries. They were intermediate in firmness at harvest but tended to bleed during storage. Red raspberries harvested after overcast rainy days and a humid night bled more. Red fruit rotted more rapidly (Fig 1), especially when harvested after hot, humid days. Red cultivars also produced the most ethylene during ripening.

Yellow raspberries had the lowest levels of anthocyanins and phenolics. Their titratable acidity was lower than red raspberries but their ratio of soluble solids to titratable acidity was closest to those of red raspberry fruit. This bodes well for their consumer acceptance as this is an important indicator of flavor. Yellow raspberries resisted bleeding the best (Fig 1), although they bled more quickly when harvested on overcast days. Yellows were the firmest at harvest but were very susceptible to grey mold, especially after being harvested on overcast, cool, humid days. Their ethylene and respiration rates were similar to red raspberries.

Fresh black raspberries are an increasing presence in local markets, and are very attractive to consumers for their perceived health benefits. Their flavor was less tart than red raspberries, as they had the lowest titratable acidity and highest (best) sugar to acid ratio. Black raspberries were the most susceptible to bleeding which makes their handling in the wholesale, fresh market a challenge. On the other hand, they were the firmest at harvest and also the most decay resistant fruits in this study. Black raspberries also had the lowest ethylene and CO_2 evolution rates, which may indicate why they were the most resistant to decay.

Purple raspberries, which are a hybrid between red and black raspberries, are popular in the northeastern US. They had the third highest anthocyanin and phenolic content, and their flavor was intermediate between black and yellow raspberries. Like black raspberries, their ability to resist bleed was poor (Fig 1). Cool weather tended to exacerbate this problem. While purple fruit were not as firm as black raspberries, they resisted decay well. Humid days before harvest lowered their decay resistance. Their ethylene and CO_2 evolution rates were intermediate between red raspberries and black raspberries which also corresponded with their ability to resist decay.

Phenolic content coupled with low ethylene evolution rates may help explain the low susceptibility of decay for purple raspberries despite a lack of firmness at harvest and rapid bleed postharvest. High total phenolic content has been shown to have antifungal effects in other plant species. A study to determine to test whether total phenolics actually act *in vivo* to reduce decay is needed.

Data from our study also supports the claim that raspberries are not a classical climacteric fruit. They did not have a corresponding increase in CO_2 output coinciding with their increase in ethylene evolution. However, we have shown for the first time that differences between ethylene rates and decay incidence coincide. Berry species and cultivars with the greatest ethylene evolution rates rotted the most rapidly.

It is unclear if the ethylene we measured was liberated by the fungus, produced by the fruit, or by both. Since it has been shown that ethylene is a ripening hormone that promotes senescence and that *B. cinerea* has the ability to sense and respond to exogenous ethylene, it is logical to assume that ethylene is involved in the host-parasite interaction. Our findings have great impact as they open the door for potential disease mitigation strategies that center around lowering ethylene emission rates on berries to reduce decay. Plant breeders can also use this information to screen raspberry germplasm to look for low ethylene liberating berries to use as material for generating more decay-resistant fruit.

Season extension for greater fruit availability is important to farmers looking for an edge on local competition and so harvesting from both floricanes and primocanes is increasingly popular. While primocane fruiting varieties tend to have higher yield, our study showed that the primocane crop is harder to manage after harvest in the Mid-Atlantic region. Both bleed and decay susceptibility were found to be more severe during the primocane season.

For both the red-raspberry and yellow-raspberry genotypes, rankings based on floricane fruit were not similar to rankings based on primocane fruit. Since floricane performance was not a good indicator of primocane performance, it is important to screen genotypes in both fruiting seasons when making breeding selection decisions. Eight genotypes in this study could be used to determine whether postharvest decay and bleed using floricane fruit would be similar to that in primocane fruit. Averaged over all genotypes, time to 25% decay was significantly shorter for primocane fruit than for floricane fruit ($p<0.0001$). Floricane fruit took 10.5 days to reach the 25% threshold whereas primocane fruit only took 8.4 days (Fig 2). However, the decay rate for

each cultivar during the floricane season was not significantly different from its primocane season, except for 'Kiwigold'. In that cultivar, the decay rate was significantly greater for the primocane fruit, while, the primocane fruit of the red raspberry cultivars 'Caroline' and 'Prelude' appeared to have a slower decay rate than the floricane fruit. However, the difference was not statistically significant.

Similarly, for time to 25% bleed, primocane fruit reached that threshold significantly faster than floricane fruit when averaged across all genotypes. Floricane fruit took an average of 13.2 days whereas primocane fruit took an average of 10.3 days to reach that threshold (Fig 3). Again, the bleed rate for each cultivar during the floricane season was not significantly different from its primocane season, except for 'Heritage,' with primocane fruit bleeding significantly faster than floricane fruit.

When cultivars were ranked from best to worse for decay, the rankings for yellow and red raspberry cultivars were not all similar across seasons (Fig. 2). 'Anne' and 'Kiwigold' switched orders from one season to the next, as did the red cultivars. In the floricane season, 'Mandarin' was the best, and 'Caroline' was the worst, while in the primocane season, their ranks were reversed. For bleed rankings, only the red raspberries were dissimilar for the two fruiting seasons (Fig. 3). Similar to the decay rankings, 'Mandarin' was the best and 'Caroline' the worst during the floricane season, but their ranks reversed in the primocane season. These findings indicate that fruit of primocane-fruiting genotypes should be evaluated from both the floricane- and the primocane-fruiting seasons.

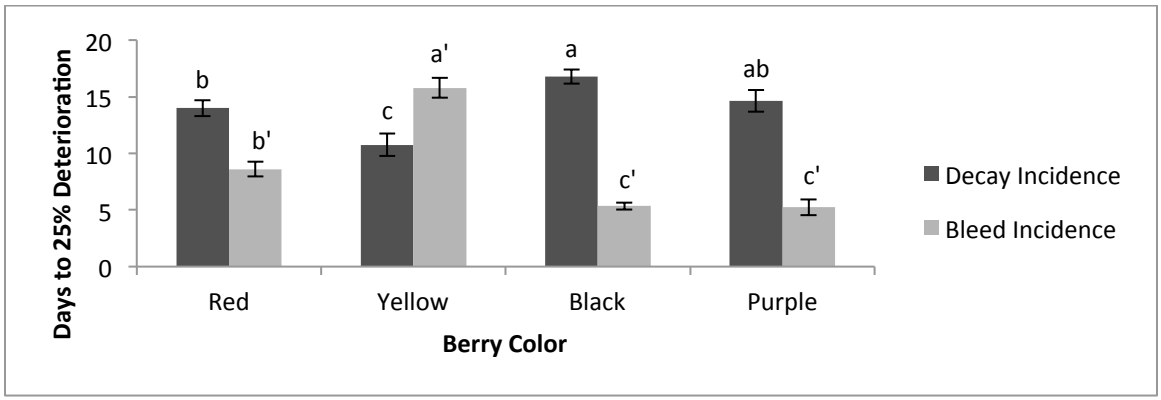

Figure 1. Mean decay and bleed incidence values for four different colored raspberries stored at 5°C for 2010 and 2011. Means followed by the same letter are not significantly different using the Tukey mean separation method (p=0.05). Note that the shorter bars indicate a shorter shelf life.

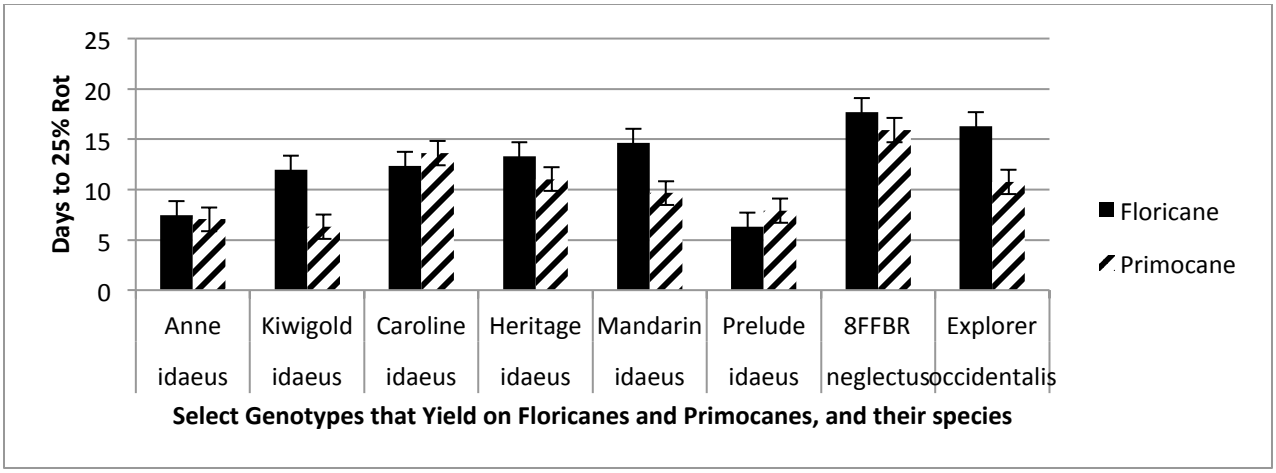

Figure 2. Mean decay incidence of eight field-grown raspberry genotypes harvested in both the floricane and primocane fruit season and stored at 5°C. Note that shorter bars indicate a shorter shelf life.

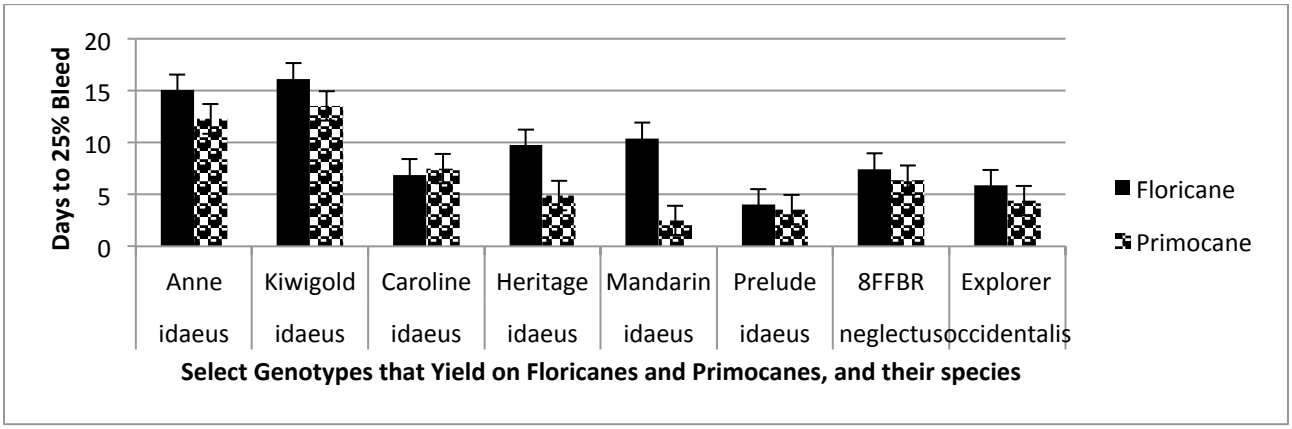

Figure 3. Mean incidence of bleed for eight field-grown raspberry genotypes harvested in both floricane and primocane fruit season and stored at 5°C. Note that shorter bars indicate a shorter shelf life.

Several conclusions can be drawn from this study on the four commonly grown colors of floricane- harvested raspberries.

1. The mechanism controlling decay and bleed are distinct and mediated by both biotic and abiotic factors.
2. The colors of fruit that performed well for well in our assessments of storage rot frequently did well in our storage bleed studies.
3. Firmness, while important on its own, had been expected to correlate with bleed and decay resistance. This was not observed in our studies.

For more information about our recent raspberry research see:

Harshman, J.M. Lewers, K.S., Jurick II, W. M. and C.S. Walsh, 2013. Resistance to *Botrytis cinerea* and Quality Characteristics during Storage of Raspberry Genotypes. HortScience. (*In press*).