Genotype, Location, and Harvest Date Effects on the Sensory Character of Fresh and Frozen Red Raspberries

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ABSTRACT. Fruit from three red raspberry (*Rubus idaeus* L.) cultivars—‘Glen Clova’, ‘Glen Lyon’, and ‘Glen Moy’—were harvested from four sites on two harvest dates and evaluated fresh or following storage at –20 °C to determine the relative importance of genotype, harvest date, location and freezing effects on 19 sensory attributes using a trained sensory panel. Freezing and cultivar × freezing interaction effects were relatively large while site, harvest date, and other interactions were of minor importance. The cultivar × freezing interaction was caused by differential responses among cultivars for the sensory attributes purple, juicy, sweet, and raspberry aroma with less discrimination among cultivars postfreezing. ‘Glen Clova’ fresh fruit received the highest values for juicy, fruity, sweet, and raspberry aroma; ‘Glen Moy’ fresh fruit received the highest values for purple; ‘Glen Lyon’ fresh fruit received the lowest values for juicy, postfreezing, ‘Glen Lyon’ received the highest values for purple and sweet and all three cultivars were similar for the other attributes. These data suggest that selection for improved postfreezing sensory characteristics should not rely solely on fresh fruit evaluations although further study of a more genetically diverse group of genotypes would be beneficial. The significant cultivar and minimal harvest date and location effects suggest that these fruit sensory analysis methods should be useful in selecting raspberry genotypes with superior fruit quality.

Fruit quality is an important criterion to most consumers, yet it is one of the most complex and ill-defined factors that producers, breeders and other fruit researchers must consider. In most breeding programs, evaluations of flavor, aromatic volatiles and physical qualities are subjective with only a small number of observers making assessments (Daubeney, 1996). Such measurements introduce a high level of error into the evaluations. Researchers have used various forms of sensory analysis to improve fruit quality measurements in raspberry (Bushway et al., 1992; Heiberg, 1988; Wrolstad et al., 1993). However, due to the complexity of the methodology or the lack of statistical precision, these methods have not been useful for the assessment of the large numbers of samples often encountered in breeding programs.

Recent developments in multivariate statistical methods make quantified sensory data useful in breeding, selection and identifying molecular-marker associations (Paterson et al., 1993). Such methods developed specifically for fruit and fruit products have successfully detected differences among juice drinks made from a

large, genetically diverse group of black currant (Brennan et al., 1997) and red raspberry (unpublished data) genotypes. The juice drinks in these studies were heavily processed though filtration, pasteurization and the addition of sucrose, sodium metabisulphite, sodium benzoate, citric acid and water; however, genotypic discrimination was still evident.

Careful design of sensory experiments can improve the precision of the evaluations made by sensory assessors and improve their repeatability (Hunter, 1996). Specially designed computer software makes these designs available in an easy-to-use form for sensory technicians. Use of a well-designed system that integrates the design and data collection with the analysis process, greatly reduces the problems associated with managing large data sets. A further benefit of using an integrated system is that experiments can be designed, run and first-level statistical analysis produced by sensory technicians with only modest input by the sensory scientist (Williams et al., 1996). These improvements in methodology, which incorporate recent statistical advances in designing and analyzing sensory profiling experiments, have increased the number of samples that can be included in each experiment thus enhancing a plant breeder’s ability to address the complex issues surrounding the genetic improvement of fruit quality.

Before comparisons can be made among segregating progenies assessed as single plant plots, a better understanding of the sources of variation associated with sensory characteristics is needed. Seasonal variation, cultivar, maturity at harvest and method of harvesting have been cited as important factors affecting the size, texture, color, soluble solids, sugar and acidity of berry fruit at harvest (Given, 1985). Cultivar differences have been observed for sugar, nonvolatile acids, ¹³C/¹²C ratio, and mineral analyses (Durst et al., 1995), anthocyanin concentration (Boyles and Wrolstad,

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1993), flavonol content, and ellagic acid content (Rommel and Wrolstad, 1993a, 1993b). However, effects due to maturity, harvest date, and geographic origin have been difficult to assess (Boyles and Wrolstad, 1993; Durst et al., 1995; Rommel and Wrolstad, 1993a, 1993b). Maturity and harvest date effects were clearly important in a study of 'Meeker' (Sjulin and Robbins, 1987). Additionally, many of these studies have relied on instrumental measurements of components of fruit quality, although the relationships between such measurements and human sensory perception are often lacking (Brennan et al., 1997).

Raspberries are used in a variety of processed products, such as juice, yoghurt, jam, flavorings, toppings, and for dessert and individually quick-frozen fruit (IQF) (Daubeny, 1996). Nearly all raspberries that are harvested for processing are frozen before use, which allows for flexibility in the timing of the preparation of products, and for long-distance shipping. Thawing of frozen fruits can cause deformation and juice loss, resulting in reduced quality with the degree of fruit damage being heavily dependent on cultivar (Crivelli and Rosati, 1975; Lee and Slate, 1954; Lenartowicz et al., 1980). Therefore, the effects of freezing are an important aspect of selecting raspberry cultivars for processing. This study determines the relative importance of genotype, harvest date, location of production, and the processing effect of freezing on the sensory character of red raspberry fruit.

Materials and Methods

FRUIT SAMPLES. Fruit was picked from three cultivars, 'Glen Clova', 'Glen Lyon', and 'Glen Moy', at each of four sites within 20 km of the Scottish Crop Research Institute (SCRI) near the villages of Cupar, Longforgan (two sites) and Invergowrie. Raspberries were hand harvested once a week over the 4-week period from 22 July 1996 to 12 Aug. 1996. 'Glen Clova' was harvested on 22 and 29 July, 'Glen Moy' was harvested on 29 July and 5 Aug., and 'Glen Lyon' was collected on 5 and 12 Aug. These dates represent early midseason and late midseason harvest dates for these cultivars. Fruit was harvested by different groups of pickers, at each site, therefore maturity of the harvested fruit could not be controlled among sites.

At each harvest a total of 2 kg of raspberries per site and per harvest date were collected. All the fruit was stored overnight at 4 °C and delivered to the Hannah Research Institute (HRI) for sensory evaluation the following morning. Upon arrival at HRI, each 2-kg sample of fruit was divided into 1-kg subsamples. One sample was used immediately as fresh fruit. The other samples were placed into plastic bags and frozen at -20 °C. Although the samples were not individually quick frozen, nearly all of the fruit remained intact and whole throughout the freezing and thawing process.

SENSORY ANALYSIS. An initial vocabulary was assembled by two sensory scientists who were familiar with fresh and frozen raspberries. Additional attributes were adopted from previous work on fruit cordials (unpublished data), blackcurrant juice (Brennan et al., 1997) and red raspberry juice (unpublished data). The vocabulary was then tested by a sensory panel using store-bought fresh and frozen fruit. After familiarization, 19 attributes were used for sensory analysis: red, brown, purple, uniformity of appearance, size, fruity, sweet, woody, sour-acid, raspberry aroma, grassy, bitter, floral, other, aftertaste intensity, aftertaste persistence, firmness, seedy, and juicy. The attribute "other" was included to allow assessors to indicate when the 19 vocabulary terms were not sufficient to describe the sensory qualities of the fruit under evaluation.

The taste panel consisted of 15 assessors, with previous experience in sensory analysis. Sensory profiling was carried out using the Design, Data collection and Analysis of Sensory Profiles Protocol (DDASPP), developed by Williams et al. (1996). In DDASPP, experimental design, tasting instructions, sample rating, data collection, and statistical analysis are performed by means of an integrated computer-assisted system. Presentation order was balanced to allow estimation of assessor, sample, and order of tasting effects (McFie et al., 1989; Muir and Hunter, 1991-92). These designs are based on a special form of cyclic Latin square (Williams, 1949) that balances order effects and residual effects of the previous treatment. Hunter (1996) has shown how these Latin squares can be used to generate efficient designs for sensory testing when there are too many samples to be tested in each session and where the numbers of assessors is not a multiple of the number of samples.

The sensory evaluation sessions were held once a week, for 8 weeks. On each of the four harvest weeks, the sensory panel evaluated half of the fruit from each sample as fresh fruit. Frozen samples were thawed overnight at 4 °C and then brought to room temperature (25 °C) before evaluation. Before profiling each sample, assessors could cleanse their palate with a plain soda cracker and cold, filtered tap water, available in the labs. The sensory evaluation was repeated three times, with three to five fruit per subsample.

The score of each assessor was recorded by marking a position on a 15-cm line displayed on a computer screen. The extreme values for each attribute were the ends of this line and representative of absent and extremely strong. The computer calculated the scores directly by measuring the length of the line from the left hand side to the mark of the assessor. Data for analysis were expressed as a percentage of the assessment line.

DATA ANALYSIS. A mixed model was fitted with assessor and assessor within replication designated as random effects and order of tasting and replicate $\times$ cultivar designated as fixed effects. Main factor effects and standard errors were calculated by Genstat (release 3.1; Copyright 1993, Lawes Agricultural Trust, Rothamsted Experimental Station, U.K.). The replicate $\times$ sample tables of means were used as input for ANOVA as implemented in Genstat. Data were analyzed as a split-plot design with cultivar, site, harvest date, and associated interactions as whole-plot effects and freezing and associated interactions as subplot effects.

Results and Discussion

The largest effect in the study was freezing followed by the cultivar $\times$ freezing interaction. Site and harvest date effects were rarely significant. Other interactions were only of minor importance and will not be considered in the results and discussion (Table 1).

The values for the brown and other attributes were low in comparison to the remaining attributes (data not presented). This suggests that brown was not an informative attribute for describing these samples. The low values for other indicate that the vocabulary was sufficient for describing these samples and that the assessors felt no additional characteristics remained unexplained. The attributes, brown and other will not be used in the discussion of these results.

Freezing caused a reduction in red, purple, uniformity of appearance, firmness, seedy, fruity, sweet, raspberry aroma, and floral attributes, and an increase in juicy, sour-acid, and bitter attributes (Table 2). There was little change in size, woody, or aftertaste attributes. These observations, that the fruit are light in

Table 1. Statistical significance of treatment effects from ANOVA of sensory attribute responses.

Fruit attribute	Significance of treatment effects									
	Cultivar	Site	Freezing	Harvest date	Cultivar × site	Cultivar × harvest date	Site × harvest date	Cultivar × freezing	Site × freezing	Harvest date × freezing
Red	NS	*	**	NS	NS	NS	NS	NS	NS	NS
Purple	NS	NS	***	NS	NS	NS	NS	***	NS	NS
Uniformity of appearance	NS	NS	***	NS	NS	NS	NS	NS	NS	NS
Size	NS	NS	NS	NS	NS	NS	NS	NS	**	NS
Firmness	NS	*	***	*	NS	NS	NS	NS	**	NS
Seedy	*	NS	***	NS	NS	NS	NS	NS	NS	*
Juicy	**	NS	***	NS	NS	**	NS	**	NS	NS
Fruity	*	NS	***	NS	NS	NS	NS	***	NS	NS
Sweet	NS	NS	***	NS	NS	NS	NS	***	NS	NS
Woody	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sour-acid	NS	NS	**	NS	NS	NS	NS	NS	NS	NS
Raspberry aroma	NS	NS	***	NS	NS	NS	NS	***	NS	NS
Grassy	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Bitter	NS	NS	***	NS	NS	NS	NS	NS	NS	NS
Floral	NS	NS	**	NS	NS	NS	NS	NS	NS	NS
Aftertaste intensity	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Aftertaste persistence	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS, *, **, *** Nonsignificant or significance from Fisher test at $p < 0.05$, 0.01, or 0.001, respectively.

color, acidic, bitter, or soft are common descriptions of frozen raspberries.

Only the seedy, juicy, and fruity attributes had significant cultivar main effects (Table 1); however, the interaction between cultivar and freezing was significant for the purple, juicy, fruity, sweet, and raspberry aroma attributes suggesting that cultivar responses for these attributes were different with respect to the fresh and frozen treatment (Table 1). The individual responses of the cultivars within the fresh and frozen treatments reveal that, of the three cultivars evaluated, 'Glen Lyon' was least affected by freezing (Table 3). The purple, fruity, sweet, and raspberry aroma attributes were all less affected by freezing in 'Glen Lyon' compared with 'Glen Clova' and 'Glen Moy' (Tables 3). Following freezing, 'Glen Lyon' was also significantly higher than the other cultivars for the sweet attribute. After freezing, both 'Glen Clova' and 'Glen Moy' had noticeable reductions in the raspberry aroma attribute compared with 'Glen Lyon'. The cultivar × freezing interaction for the juicy attribute was due to the lower juicy attribute values of the fresh 'Glen Lyon' fruit (Table 3).

These data suggest that all three cultivars were equally well suited for processing by freezing although the higher sweet attribute values of 'Glen Lyon' may be desirable. 'Glen Clova' and 'Glen Moy' are considered to have better fresh-fruit quality than 'Glen Lyon' although higher fresh-fruit responses for the fruity, raspberry aroma, and, to a lesser extent, sweet attributes were only observed with fresh fruit from 'Glen Clova'. Firmness is considered one of the distinctive characteristics of 'Glen Lyon' (Knight et al., 1989) and in most seasons, the fresh fruit of 'Glen Lyon' can be distinguished from 'Glen Clova' and 'Glen Moy' based on the improved firmness (R. McNicol, personal communication). In this study, the firmness of 'Glen Lyon' was not significantly different from 'Glen Moy' or 'Glen Clova', although the lower responses for the juicy attribute clearly distinguished 'Glen Lyon' from the other two cultivars (Table 3). Therefore, the juice characteristics of

'Glen Lyon' may be more important than the actual whole-fruit firmness when evaluated in the mouth.

These results have important implications for raspberry breeding by suggesting that fresh fruit characteristics are not indicative of the postfreezing quality and that suitable genotypes for freezing will only come through evaluations of frozen fruit. Since, this interaction is essentially defined by the response of 'Glen Lyon', additional experiments are in progress to determine if similar responses are observed using a more diverse sample of red raspberry genotypes.

Differences among the sites were small and in general not significant for most attributes (Table 1) although small differences were detected for the red and firmness attributes ($p \leq 0.05$). This may indicate maturity differences among the sites due to different picking criteria. The Invergowrie site was less red than the other

Table 2. Significant percentage means of sensory attribute responses to fresh and frozen treatments and the associated standard error and F test results for freezing effects from ANOVA.

Attributes	Fresh	Frozen	SE	F test
Red	68.44	66.08	0.85	$p \leq 0.01$
Purple	24.76	17.16	1.38	$p \leq 0.001$
Uniformity of appearance	60.15	55.07	1.30	$p \leq 0.001$
Firmness	48.38	24.75	0.76	$p \leq 0.001$
Seedy	49.57	44.61	0.78	$p \leq 0.001$
Juicy	43.18	54.40	1.73	$p \leq 0.001$
Fruity	60.01	54.76	0.61	$p \leq 0.001$
Sweet	28.64	17.01	1.05	$p \leq 0.001$
Sour-acid	35.90	42.25	1.76	$p \leq 0.01$
Raspberry aroma	53.08	44.91	0.76	$p \leq 0.001$
Bitter	18.17	23.79	0.83	$p \leq 0.001$
Floral	15.31	12.29	0.91	$p \leq 0.01$

Table 3. Significant percentage mean responses for sensory attributes of fresh and frozen fruit from three red raspberry cultivars and the associated standard error and F test results for cultivar by freezing effects from ANOVA.

Attributes	Freezing treatment	Glen Clova	Glen Moy	Glen Lyon	SE ^z	F test
Purple	Fresh	20.89	28.34	25.03	3.68	$p \leq 0.001$
	Frozen	14.90	12.06	24.52		
Juicy	Fresh	51.63	42.76	35.16	2.44	$p \leq 0.01$
	Frozen	56.62	51.06	55.50		
Fruity	Fresh	64.39	57.94	57.70	1.69	$p \leq 0.001$
	Frozen	55.73	51.75	56.80		
Sweet	Fresh	32.77	26.90	26.25	3.69	$p \leq 0.001$
	Frozen	13.85	15.49	21.70		
Raspberry aroma	Fresh	59.22	50.98	49.05	2.62	$p \leq 0.001$
	Frozen	46.96	41.40	46.38		

^zSE among each set of six cultivar by freezing means.

three sites, and the Cupar site had the highest firmness values.

Harvest date effects were not important in this study (Table 1). Harvests were made ≈ 1 week before and after the peak harvest date. It appears that there are no significant sensory differences among fruit within this harvest period.

Although the freezing treatment clearly had the largest effect on the sensory character of the fruit, cultivar or genotype effects were the next most important factor. The presence of the cultivar $\times$ freezing interaction complicates the assessment of the cultivar effect, however, within the fresh and frozen treatments, important cultivar differences were found.

'Glen Clova', 'Glen Lyon' and 'Glen Moy' are all quite closely related having similar coancestry (Dale et al., 1993). 'Glen Moy' and 'Glen Lyon' each have *R. occidentalis* L. in their pedigree while 'Glen Lyon' differs from the others through 'Creston', an old cultivar from British Columbia. Because the three cultivars in this study are so similar and have been selected for fruit quality, sensory variation of segregating progenies should be even greater than that observed in this experiment which would benefit effective phenotypic selection. Although the quality of red raspberry fruit is surely multigenic, the environmental effects of site and harvest date were relatively small in comparison to the genotypic effects. Therefore in this experiment the heritability of red raspberry fruit quality was relatively high and these methods should be useful for quantifying the sensory characteristics of raspberry genotypes, differentiating genotypes and for selection.

The necessity for multiple locations for these types of experiments is likely to depend on the size of the target breeding environment. The sites chosen for this study reflect the limited area of our target environment, the Tayside region of Scotland or within 30 km of Dundee. In this case, it should not be necessary to include multiple locations for such evaluations although two locations would always be preferable. As the target environment enlarges, the importance of multiple sites will increase.

Fruit collected anytime within the 2-week midharvest period should give an accurate assessment of sensory character. This would allow for the collection of a larger number of samples which could be critical if single-plant plots are assessed. If frozen fruit or processed products are evaluated, fruit could be collected over the entire 2-week period and stored at -20°C prior to sensory assessment. This would be a particularly flexible system and lessen any logistical problems associated with variable fruit set and ripening.

Although whole, thawed fruit was evaluated in this study, this represents only one way processors might market and retail purchasers might consume frozen raspberries. In fact, frozen raspberry fruit is often used for further processing through the addition

of sugar or other products that would mask the genotypic sensory character of the fruit. However, for breeding and selection purposes, the evaluation of whole frozen-thawed raspberry fruit should be the most discriminating test. This unprocessed product will also be the cheapest and simplest evaluation which is critical for an efficient selection program.

The influence of year effects has not been addressed in this study. Others have identified significant year effects associated with the sensory character among raspberry genotypes (Jiang, 1991); however, these effects were due in part to fruit diseases initiated by poor weather conditions. Year effects should not be as important when fruit from two good growing seasons are compared, but should be considered when designing future studies. If feasible, multiple year data should be included, but if the growing seasons are good, and fruit rots are minimal, the advantage of a second year of data is likely to be minor.

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