Queensland High Density Planting System Trials for New Scab-Resistant Apples

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Apple scab (also known in Australia as apple black spot) caused by the fungus *Venturia inaequalis*, is a major disease of apples in Australia and throughout the world.

Apple varieties resistant to apple scab have been bred and developed in the Agri-Science Queensland (previously DPI&F) apple breeding program, which commenced in 1985. From a population of over 100,000, several selections from this program show considerable promise.

One of these, 'RS103-130', is currently protected by provisional Plant Breeders Rights (PBR) in Australia, and by a US Plant Patent issued in May 2009.

'RS103-130' matures mid-season (6-8 weeks after 'Royal Gala') and has a broken red stripe to almost full block red overcolour on a yellow-green to yellow background. Fruit is round-conic in shape with a medium length stalk.

Flesh is off-white, medium textured, crisp and breaking. 'RS103-130' is juicy with a sweet, low-acid and mild flavour. Fruit colour up very late on the tree (within 2-3 weeks of harvest), which helps ensure the apples are harvested close to optimum maturity for both storage and fresh market consumption.

High density planting (hdp) system trials have been established at Applethorpe Research Station to evaluate the productivity of 'RS103-130' and a further five superior scab-resistant selections, and to provide sufficient volumes of fruit for consumer evaluations.

HDP System Trials

The site is approximately one hectare and consists of trees in their 5^{th} to 8^{th} leaf (2009/10). The first 'RS103-130' trees were planted in winter 2002.

The trees are on a range of rootstocks (M.9, MM.102, Ottawa 3, M.26, MM.106), and planted at densities from 1428 to 5925 trees/hectare. Trees are trained as either a vertical axis system to a 6-wire trellis, or as a double-row open V-trellis.

The rootstocks, planting densities and training systems are summarised in Table 1. A permanent hail netting structure covers the entire block of trees.

Tree training and pruning was based on maintaining a dominant upright leader, using a minimum of pruning cuts, and tying down limbs to control growth and encourage fruiting.

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Table 1: HIGH DENSITY SYSTEMS TRIALS - APPLETHORPE RESEARCH STATION

ROW		SELECTION	AGE (2009/10)	TRELLIS	ROOTSTOCK	SPACINGS (intra-row)	DENSITIES (trees/ha)
Expt 4							
6	North	RS103-130	6th leaf	Open V	MM106	1.25m, 0.75m	3555, 5925
	South	RS103-130	5th leaf	Open V	M9, M26	1.0m	4444
7	North	RS103-130	6th leaf	Open V	MM106, M26	1.0m	4444
	South	Selection 2	6th leaf	Open V	M26	1.0m	4444
	South	Selection 3	6th leaf	Open V	M26	1.0m	4444
8	North	RS103-130	6th leaf	Standard	MM106, M26	1.0m	2500
	South	Selection 2	6th leaf	Standard	M26	1.0m	2500
	South	Selection 3	6th leaf	Standard	M26	1.0m	2500
Expt 2							
9		Selection 3	6th leaf	Standard	MM106, M26	1.5m, 1.25m, 1.0m 0.75m, 0.5m	1666, 2000, 2500 3333, 5000
10		Selection 3	7th leaf	Standard	MM106, M26 O.3	1.5m, 1.25m, 1.0m 0.75m, 0.5m	1666, 2000, 2500 3333, 5000
Expt 1							
11		RS103-130	8th leaf	Standard	MM106, M26	1.75m, 1.5m, 1.25m 1.0m, 0.75m, 0.5m	1428, 1666, 2000 2500, 3333, 5000
12		RS103-130	8th leaf	Standard	MM106, M26	1.75m, 1.5m, 1.25m 1.0m, 0.75m, 0.5m	1428, 1666, 2000 2500, 3333, 5000

Table 1: HIGH DENSITY SYSTEMS TRIALS - APPLETHORPE RESEARCH STATION

ROW		SELECTION	AGE (2009/10)	TRELLIS	ROOTSTOCK	SPACINGS (intra-row)	DENSITIES (trees/ha)
Expt 3 Rootstock trial							
13		RS103-130	6th leaf	Standard	MM106, MM102 M26, O3, M9	1.0m	2500
14		RS103-130	6th leaf	Standard	MM106, MM102 M26, O3, M9	1.0m	2500
Expt 6	Rootstock trial						
15	3.6m alley	Selection 4	6th leaf (N) 5th leaf (S)	Standard	MM106, MM102 M26, O3, M9	**1.0m** 1.25m, 0.9m, 0.75m	**2777** 2222, 3086, 3703
16	3.6m alley	Selection 4	6th leaf (N) 5th leaf (S)	Standard	MM106, MM102 M26, O3, M9	**1.0m** 1.25m, 0.9m, 0.75m	**2777** 2222, 3086, 3703
Expt 5	Rootstock trial						
17	3.7m alley	Selection 2	5th leaf	Standard	MM106, MM102 M26, O3, M9	1.25m, **1.0m** 0.75m, 0.625m	2162, **2702** 3603, 4324
18	3.7m alley	Selection 2	5th leaf	Standard	MM106, MM102 M26, O3, M9	1.25m, **1.0m** 0.75m, 0.625m	2162, **2702** 3603, 4324
19	3.7m alley	Selection 2	5th leaf	Standard	MM106, MM102 M26, O3, M9	1.5m, 1.25m, **1.0m** 0.75m, 0.625m	1818, 2162, **2702** 3603, 4324
20	North	Selection 5	5th leaf	Open V	MM106, O3	1.25m, 1.0m, 0.75m	3555, 4444, 5925
	South	Selection 6	5th leaf	Open V	MM106, O3	1.25m, 1.0m, 0.75m	3555, 4444, 5925

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Measurements

The vigour of trees in each of the six experiments (Table 1) has been measured annually, using tree height, annual shoot growth, total leaf area per tree, and trunk cross-sectional area (TCA).

The leaf area index (LAI) of each orchard system was calculated from leaf counts and average individual leaf areas (cm^2) as m^2 leaf per tree / m^2 orchard floor surface area. Spur leaves and shoot leaves were counted separately, and individual leaf areas measured on the tree with a specially designed, calibrated perspex grid.

At harvest, all fruit on each tree was counted and weighed.

Apple fruit colour was assessed visually on a scale of 1 to 3, as illustrated in Plate 1 for 'RS103-130'. A colour rating of 1 was used for fruit of unacceptable, sub-standard colour; 2 for adequately coloured fruit; and 3 for apples with premium colour.

Sunburn was visually assessed using a scale of 0 (nil), 1 (slight) or 2 (severe). Due to protection of the trees with hail netting, there has been insignificant sunburn damage to apples in any of the experiments.

Plate 1. Rating classes (1-3) used to visually assess the colour of 'RS103-130' apples

Apple Scab Resistance in the Field

No sprays for apple scab control (with the exception of green tip copper) have been applied to any of the trees (Table 1) since planting.

‘RS103-130’ and the other selections continue to show no incidence of leaf or fruit symptoms of apple scab (black spot). In comparison, 75% of fruit on nearby unsprayed ‘Pink Lady’ trees were affected by apple scab in 2008/09.

‘RS103-130’ Orchard Productivity

An important objective of intensive planting systems is to be able to harvest apples from the second year onwards, and any fruit produced in the second year is important to generate early returns on investment.

The yields of ‘RS103-130’trees in their second leaf (Table 2) were moderate to high. The advantage of planting trees at high densities in a ‘V’ trellis system to rapidly attain a high canopy volume became evident with 2^{nd} leaf trees yielding 17-22 tonnes/ha with an LAI of 1.0 - 1.5 (Table 2).

It is critical, however, to avoid over-cropping trees in their second leaf as this can retard tree growth and thereby delay the achievement of full canopy volume and cropping potential.

Yields of ‘RS103-130’ have averaged over 60 tonnes per hectare across all experiments (trees 5^{th} to 7^{th} leaf) in 2008/09.

Shading effects (light interception well above the optimal 60%) reduced the packouts in 2008/09 to as low as 65% on MM.106 trees at the higher densities. From preharvest observations it is evident that the packouts from trees on M.26 in 2009/10 will continue to be higher than for trees on MM.106.

‘RS103-130’ trees in the open V-trellis system yielded 80 tonnes per hectare in their 5^{th} leaf. The return crop in 2009/10 of ‘RS103-130’ on M.26 rootstock is higher than on MM.106, however the yields are not yet available as we are currently harvesting the trees.

Overcropping an apple tree can, depending on rootstock and tree habit, set up a biennial bearing pattern in the tree. ‘RS103-130’ is a semi-spur variety and trees have carried a high number of fruiting buds from season to season.

In ongoing trials to determine the upper cropping limit of ‘RS103-130’, the crop loads of ‘RS103-130’ trees in their 7^{th} leaf in 2008/09 (Experiment 1) were pushed to over 100 tonnes/hectare through a combination of no dormant pruning and minimal fruitlet removal, which was done late in the season. Average fruit size was reduced (this is desirable as ‘RS103-130’ is a large apple), however the return crop on these trees in 2009/10 is down.

Further work is required to define the cropping level at which ‘RS103-130’ becomes biennial bearing, however the results to date suggest that well-managed ‘RS103-130’ trees can consistently yield 60-70 tonnes/hectare/annum.

Following the hottest August on record, blossoming in spring 2009 was approximately two weeks earlier than normal. Two severe dust storms on 23 and 26 September 2009 coincided with the later blossom and early fruit development period, providing testing environmental conditions for the trees.

Despite heavy infestations of Western Flower Thrip (*Frankliniella occidentalis*) in spring 2009, and no application of control sprays, there has been no damage or "pansy spot" symptoms noted on fruit of 'RS103-130' since the planting of the experiments.

Table 2. The yield, packout and vigour of 'RS103-130' trees in their second leaf (Experiment 4)

Rootstock	Density (trees/ha)	Yield (t/ha)	Av. Fruit wt (g)	Packout* (%)	Packout** (%)	TCA (cm^2)	LAI
M.26	**2500**	6.2	193	96	87	6.8	0.5
M.26 V trellis	**4444**	12.1	197	97	83	7.1	0.9
MM.106	**2500**	8.9	203	99	96	14.2	0.9
MM.106 'V'	**3555**	16.8	196	99	95	11.5	1.0
MM.106 'V'	**4444**	19.7	197	99	87	11.5	1.2
MM.106 'V'	**5925**	22.1	179	99	94	11.5	1.5
LSD ($p<0.05$)		***3.8***	***NS***	***NS***	***NS***	***2.4***	***0.4***

TCA: trunk cross-sectional area LAI: Leaf Area Index *NS*: not significant
* Packout percentage based on fruit weight > 120 g and colour rating = 2 on a 1-3 scale.
ie. includes fruit of 'acceptable' colour (rating 2)
**Packout percentage based on fruit weight > 120 g and colour rating 3 on a 1-3 scale.
ie. only includes fruit of premium colour (rating 3)

'Selection 2' Orchard Productivity

'Selection 2' is a red apple with a dark red over-stripe on yellow-green ground, and matures two to three weeks after 'Royal Gala'. Flesh is crisp and juicy with fine texture, and a sweet, low acid, clean, fresh and mild flavour. Fruit shape is flat round.

In 2008/09, early hand thinning of the 4th leaf 'Selection 2' trees in experiment 5 at 3, 4, 5, 6 or 7 weeks after full bloom helped to increase the average fruit weight of this small to medium sized apple.

The trees in 2008/09 yielded up to 35-40 tonnes/hectare. Fruit quality was excellent, with packouts of 95 - 100%. The early thinning also helped ensure heavy return crops in 2009/10.

The target yield of these 5th leaf trees in 2009/10 was 50 tonnes/hectare. Some trees will yield up to 70 tonnes/hectare. The trees were again thinned hard in spring 2009 to maximise fruit size, maintain high packouts and ensure good return bloom next season. The experiment has just been harvested and it is evident that the high packouts of 2008/09 have been duplicated in 2009/10.

To date there has been little difference in the yields, packouts and vigour (TRV, LAI) of trees on the five rootstocks in experiment 5. Trees on M.26, M.9 and MM.106 in their 4th and 5th leaf have yielded slightly more than trees on MM.102 and Ottawa 3.

The packouts of the more vigorous MM.106 trees may decline from their 6th leaf onwards if internal shading occurs.

The main issue for 'Selection 2' is to maximise fruit size.

'Selection 3' Orchard Productivity

'Selection 3' matures in April, but tends to retain high levels of starch. The apple colour is similar to 'Red Delicious', with a broken dark red stripe and small, prominent lenticels on yellow/green ground colour. The red over-colour darkens as fruit remain longer on the tree.

The apples are large to very large and flat-round to round in shape, with a thick skin. Flesh is white to off-white, has a medium-coarse texture and a sweet, low acid flavour.

High density planting systems for 'Selection 3' are very productive, due primarily to the consistency of cropping from year to year, and its large fruit size, which can average up to 300 g (Table 3).

Table 3. The yield, packout and vigour of 'Selection 3' trees in their third leaf (Experiment 2)

Rootstock	Density (trees/ha)	Yield (t/ha)	Av. wt (g)	Fruit	Packout* (%)	Packout** (%)	TCA (cm^2)
MM.106	**1666**	14.3	281		100	100	10.3
MM.106	**2500**	20.3	290		100	100	9.0
Ottawa 3	**2500**	38.6	308		100	100	7.8
M.26	**2000**	24.8	299		100	100	9.3
M.26	**2500**	31.1	312		100	100	8.5
M.26	**3333**	26.5	304		100	97	6.4
M.26	**5000**	45.0	290		100	100	6.5
LSD (p<0.05)		***12.1***	***NS***		***NS***	***1***	***1.2***

TCA: trunk cross-sectional area LAI: Leaf Area Index *NS*: not significant
* Packout percentage based on fruit weight > 120 g and colour rating = 2 on a 1-3 scale.
ie. includes fruit of 'acceptable' colour (rating 2)

**Packout percentage based on fruit weight > 120 g and colour rating 3 on a 1-3 scale.
ie. only includes fruit of premium colour (rating 3)

Tree management of 'Selection 3' will need to focus on producing apples closer to 200 g than 300 g. Strategies to reduce the fruit size of 'Selection 2' include retaining higher crop loads (modified thinning), reduced, targeted irrigation and modified nitrogen practices. 300 g apples are too large for wide consumer appeal.
In 2008/09, trees of this selection in their 5th and 6th leaf (Experiment 2) were deliberately cropped heavily (up to 100 tonnes/hectare) in an attempt to reduce fruit size.

The effect of very high crop loads in 2008/09 on subsequent biennial bearing, tree growth and productivity for a range of rootstock x planting density combinations will not be known until harvest in April 2010.

It is noteworthy that with only one exception, trees of 'Selection 3' in their third leaf had a 100% packout (Table 3). 'Selection 3' is a very highly coloured, large apple. Packouts have declined in subsequent years as the trees became older and larger, but have continued to remain above 90%.

General Principles

Differences in the early yields (2nd, 3rd, 4th leaf) of the hdp systems are largely due to the tree row volume (TRV), LAI and light interception. Young trees with higher canopy volumes, LAI (Table 2) and light interception are producing the higher yields.

Rootstock and planting density effects on yield and fruit quality as a consequence of increasing tree size and vigour occur as trees become older.

The true gauge of consistent longer-term hdp system performance of the scab-resistant selections will come in the next two to three years. Appropriate high density planting systems can then be identified that consistently produce at least 50-60 tonnes/ha/annum of apples, with packouts of 80 - 90% and above.

The key to success with all systems will be to manage tree vigour for maximum productivity, through the development of a "well-illuminated" canopy and tree structure that ensures adequate sunlight can penetrate to leaves and fruit in all parts of the tree.

The use of intensive planting systems with trees grown on semi-dwarfing and dwarfing rootstocks is an effective means to attain high yields early in the lifetime of the orchard. At higher tree densities it is particularly critical to confine individual trees to their small allotted space in the orchard.

The effect of higher planting densities on increasing early yields (2nd and 3rd leaf) is evident in Tables 2 and 3. The 'V' trellis system for 'RS103-130' in Experiment 4 (Table 2) is an efficient means of growing trees at a high density to minimise potential shading within and between trees. This maximises light interception, and permits light penetration to lower regions of the canopy. With such a system, yields of up to 22 tonnes/ha were obtained in the second year, albeit at a very high planting density.

Problems may arise and packouts decline if tree vigour is not kept under control as the trees age.

Reductions in TCA occur with increasing tree density (Tables 2 and 3), as individual trees occupy less orchard floor area at higher densities, and experience root competition from closely adjacent trees. This effect is greater as the trees age, and along with the influence of dwarfing rootstocks, helps to control vigour and encourage fruit bud development.

These effects were already evident on trees of 'RS103-130' in their 2nd leaf where trees on MM.106 rootstock at densities of 3555, 4444 and 5925 trees/ha already had significantly lower TCA than MM.106 trees at 2500 trees/ha (Table 2).

Similarly, the TCA of 'Selection 3' trees in their 3rd leaf declined at increasing tree densities (Table 3).

Although individual trees on a given rootstock tend to be smaller at higher densities, the orchard LAI tends to increase with planting density (Table 2), due to the greater number of trees per unit area.

Based on measurements of the light interception, LAI, yield and fruit quality of a wide range of apple orchard systems throughout Australia, an LAI of close to 2.0 is considered optimal for high productivity of mature, bearing trees in 'standard' single-row apple orchard systems (Middleton *et al*., 2002), and an LAI of 2.5 - 3.0 ideal for 'V' trellis systems.

Compared to single-row systems, the angle of trees positioned on the 'V' trellis system permits a broader spread of tree canopy, and hence leaf area, across a greater orchard floor surface area. This in turn means that the 'V' trellis can accommodate a higher LAI before declines in yield and fruit quality occur.

The objective in tree management should be to achieve these LAI levels as early as possible in the lifetime of the orchard.

Reference

Middleton, S., McWaters, A., James, P., Jotic, P., Sutton, J. and Campbell, J. (2002). "The productivity and performance of apple orchard systems in Australia". Compact Fruit Tree 35:43-47.

Measurement of Light Interception and Light Levels within Apple Tree Canopies

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A demonstration will be given in the orchard of how to measure sunlight levels and light interception with a ceptometer, and the type of information that can be obtained from these measurements.

Sunlight intercepted by leaves provides the energy to drive the process of photosynthesis. The light used by plants in photosynthesis is also known as PAR (photosynthetically active radiation) and is of wavelengths 400– 700nm.

Without the capture of this sunlight, trees cannot manufacture the carbohydrates and food required to produce high yields of good size, well-coloured, high quality apples.

The yields and packouts of scab-resistant apples produced in the high density planting system trials at Applethorpe Research Station can be directly attributed to light interception and light distribution within the canopies, as determined by tree vigour, TRV and LAI.

Trials consistently show that apple orchard yields increase as midseason light interception increases to 60%. A point is reached beyond this (eg. 70%) where the canopy is too dense or excessive tree spread and height lead to severe shading effects, with subsequent declines in tree productivity.

There are several techniques to measure light interception and the sunlight levels within tree canopies. One way is to have fixed sensors in the orchard that record light levels at regular intervals throughout the day. This can be very expensive and is generally impractical.

Another option is to take regular measurements with a device such as an AccuPAR linear ceptometer. The measuring probe of this instrument is 80cm long and consists of 80 independent sensors. The ceptometer measures PAR and is readily portable.

When using a ceptometer to measure light interception, readings should be made at regular intervals throughout the day to account for changes in light levels, shading patterns, cast shadow lengths and incident solar angles as the sun passes across the sky. Up to 80 readings may be taken at any one particular time in the day to adequately sample the variable light environment beneath trees and into the alleyway.

In the apple producing regions of Australia, midsummer incident PAR levels in the middle of the day can be regularly above 2100 – 2200 µmol/m^2/sec. This is much higher than the light levels in many other apple growing regions of the world. Eg. 1600 µmol/m^2/sec in parts of Europe and North America.

In Australian orchards protected by hail netting, even a 15-18% reduction in sunlight still sees incident PAR levels of 1800 μmol/m^2/sec in midsummer.

Consumer Evaluations and Post-harvest Quality of ‘RS103-130’

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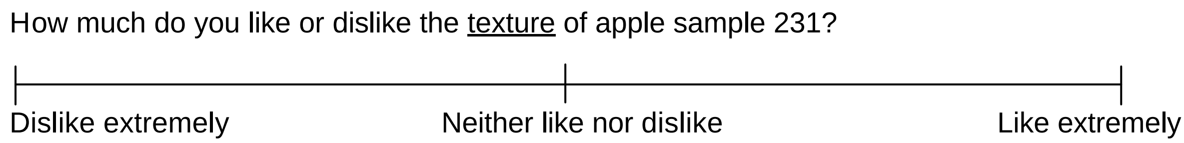
Consumer Evaluations

Consumer evaluations of the appearance and eating quality of ‘RS103-130’apples were undertaken in May 2009 (two months after harvest) and December 2009 (nine months after harvest) in Brisbane. Commercial varieties included as comparators were ‘Fuji’, ‘Pink Lady’ ^{TM} and ‘Jonagold’ in May 2009, and ‘Royal Gala’, ‘Hi Early Red Delicious’ and ‘Sundowner’ ^{TM} in December 2009.

Each consumer was presented with five apple samples in individual clear plastic cups. The individual plastic cups were labelled with 3-digit blinding codes to identify the samples and conceal the variety name.

The four consumer acceptability parameters assessed using hedonic scales were: appearance, flavour, texture and overall likability. These scales were anchored from ‘dislike extremely’ (0), through ‘neither like nor dislike’ (50), to ‘like extremely’ (100), as shown in Figure .

Figure 1 Example of the hedonic scale used for consumer tasting



Samples that score over 50, towards 100, are samples that are liked for that attribute. The closer to 100 the more a sample is liked. Conversely, samples rated below 50, toward 0, are samples that are not liked for that attribute. The lower the score, the less the sample is liked.

Consumers were also given the opportunity to make comments regarding what they liked or disliked about the samples.

‘RS103-130’ was rated highly by consumers on both occasions, and in May 2009 scored as most preferred apple overall, and most preferred or equally most preferred apple for appearance, flavour and texture. ‘RS103-130’ received the most positive comments from consumers about texture and also received many positive comments regarding flavour and appearance.

‘RS103-130’ was also selected as the preferred apple by consumers interviewed ‘on-the-spot’ in front of television cameras (ABC, Channel 10, Channel 9) in Brisbane in November 2009. The consumers were given four unidentified apple varieties to evaluate and taste (‘RS103-130’, ‘Gala’, ‘Pink Lady’, ‘Red Delicious’), and rated ‘RS103-130’ particularly highly for its texture, crunch, taste and juiciness, commenting on the excellent eating quality after eight months in storage.

Post-harvest Quality

Instrumental measurements of post-harvest quality to evaluate the rate of flesh browning after cutting, and the rate of softening when stored at room temperature (20°C) over four weeks, showed ‘RS103-130’ to be equal to or superior to the commercial apple varieties (the same varieties as used in the consumer evaluations) in retaining texture and firmness, and resisting flesh browning.

To compare the shelf life potential of each apple variety in terms of texture, 30 apples of each variety were stored in a temperature controlled cabinet at 20°C and were removed for pressure testing every 3-4 days over a period of 25 days (Table 1).

At each time point, three apples of each variety were randomly selected and two sites of each apple were pressure tested by penetrometer, giving a total of six measurements for each variety at each time point. The test involved measuring the force required to push an 11 mm fruit probe a depth of 8 mm into the fruit.

The four week shelf storage trial at 20°C demonstrated that all the apple varieties decreased in texture firmness at a similar rate. Most of the selections were equivalent in terms of initial flesh firmness and rate of softening, but ‘RS103-130’ was a much firmer fruit and retained this advantage over the other three varieties for up to 22 days at 20^0C (Table 4).

Table 4 Summary of texture measurements of varieties at each time point, May 2009

		Compressive load at 8mm (Newtons)							
Apple	**n**	**Day 0**	**Day 4**	**Day 8**	**Day 12**	**Day 15**	**Day 19**	**Day 22**	**Day 25**
RS103-130	6	77 a	68 a	69 a	63 a	66 a	56 a	60 a	52 ab
Fuji	6	59 b	62 ab	54 bcd	57 a	49 b	47 ab	47 bc	55 a
Jonagold	6	60 b	52 b	61 abc	52 ab	59 ab	44 bc	55 ab	55 a
Pink Lady	6	66 ab	66 a	63 ab	58 a	52 b	46 ab	43 c	41 bc

n: the number of assessments made: abc Different letters within a column indicate a statistically significant difference between samples by ANOVA and application of Tukey-Kramer HSD where $p<0.05$. *not assessed in consumer testing