

# ‘WSU 2166’ Red Raspberry

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‘WSU 2166’ is a new florican fruiting raspberry cultivar (*Rubus idaeus* L.) released by Washington State University (WSU). ‘WSU 2166’ produces large, firm fruit that are well suited to machine harvesting and for processing. Because of its flavor, large fruit, attractive appearance, and easy fruit release at an early stage of maturity, ‘WSU 2166’ also should be suitable for fresh market use. It has good levels of tolerance to *Phytophthora rubi* (Man in ‘t Veld, 2007) in field trials.

## Origin

‘WSU 2166’ was selected from a cross of WSU 1447 and WSU 0697 (Fig. 1) made in 2007 at Washington State University Puyallup Research and Extension Center (WSU Puyallup). WSU 1447 was selected from a cross made in 1996 and produces large, firm fruit. WSU 0679 was selected from a cross made in 1974 and produces fruit with many small drupelets and small seeds (Moore, 1993). Seedlings from the cross of WSU 1447 and WSU 0697 were planted with a cooperating commercial grower in Skagit County, WA, in 2008. In 2010, these seedlings were subjectively evaluated as they were machine harvested. One promising seedling was selected that was identified as ‘WSU 2166’. Fruit of ‘WSU 2166’ machine

harvested very easily, with good quality fruit that were firm, with good color and flavor.

## Performance and Description

After ‘WSU 2166’ was selected, it was propagated from primocane shoot tips at WSU Puyallup. It was planted in a nonreplicated

plot consisting of 10 plants with a cooperating grower in Lynden, WA, in 2011. A nonreplicated plot of eight plants was planted in 2014 by another grower. These plantings were maintained by the growers using standard commercial production practices and picked every 2 to 3 d during the harvest season. Fruit was subjectively evaluated weekly over two harvest seasons, beginning 2 years after planting. The plots were evaluated for suitability to machine harvesting and overall fruit quality. In the 2014 planting, in addition to subjective evaluations, fruit were weighed for each harvest to determine yield and midpoint of harvest (date of 50% yield). The performance of ‘WSU 2166’ was good compared with ‘Cascade Harvest’ (Moore et al., 2015), ‘Meeker’ (Moore and Daubeney, 1993), and ‘Willamette’ (Daubeney et al., 1989) in the same planting, indicating favorable yield potential. In each of these plantings, the fruit ‘WSU 2166’ harvested easily and had large fruit size and good flavor.

Fruit of ‘WSU 2166’ were hand-harvested in a replicated planting at WSU Puyallup established in 2014. The planting was arranged in a randomized complete-block design with three replications of three plants in each plot, with 0.9 m between plants and 2.4 m between rows. The plantings were not sprayed for disease, but the plantings were treated for

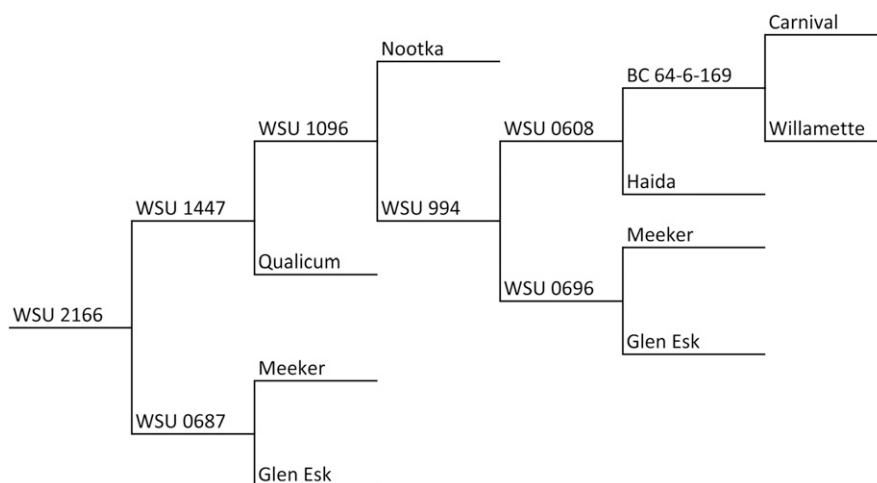


Fig. 1. Pedigree of ‘WSU 2166’ red raspberry.

Table 1. Yield, fruit weight, firmness, rot, and midpoint of harvest measured in 2016–17 for four florican fruiting red raspberry cultivars planted at Puyallup, WA, in a replicated trial with three replications containing three plants.

		Cultivar			
		WSU 2166	Cascade Harvest	Meeker	Willamette
Yield (kg/hill)	2016	1.83 c <sup>z</sup>	5.49 a	3.40 b	3.92 b
	2017	2.53 a	3.49 a	3.27 a	3.16 a
Fruit weight (g)	2016	4.30 a	4.16 a	3.10 b	3.01 b
	2017	3.84 a	3.54 ab	3.19 b	3.37 b
Fruit firmness (N)	2016	0.99 a	0.88 ab	0.74 b	0.74 b
	2017	1.34 a	1.04 a	1.05 a	1.20 a
Fruit rot (%)	2016	4.4 c	9.8 ab	11.4 a	7.2 bc
	2017	5.4 c	14.5 a	10.6 b	6.6 c
Midpoint of harvest	2016	19 June c	23 June b	28 June a	19 June c
	2017	8 July bc	12 July a	9 July ab	6 July c

<sup>z</sup>Mean separation within rows by Fisher’s protected least significant difference,  $P \leq 0.05$

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spotted wing drosophila (*Drosophila suzukii* Matsumura). Fruit were harvested by hand in 2016 and 2017, once or twice a week depending on environmental conditions and rate of ripening, and weighed to determine total yield. The weight of fruit with visible symptoms of fruit rot (mainly *Botrytis*) was measured separately at each harvest and divided by total yield to determine the percent of harvested yield affected by rot. In 2016, the yield of 'WSU 2166' was lower than that of 'Cascade Harvest', 'Meeker', and 'Willamette' (Table 1), which might be explained by slower establishment, as the 'WSU 2166' plots were observed to have fewer canes per hill than other cultivars. In 2017, the yield of 'WSU 2166' was similar to all three cultivars.

At each harvest, a subsample of 25 randomly selected fruit was weighed to determine average fruit weight. The seasonal fruit weight was calculated as a weighted arithmetic mean of fruit weight using the following formula:

$$\text{Weighted Mean} = \Sigma xw / \Sigma w,$$

where  $x$  = average berry weight in g from individual harvest and  $w$  = the weight (importance) of each harvest relative to total season yield. According to Fisher's protected least significant difference (LSD) method, the fruit weight of 'WSU 2166' was greater than 'Meeker' and 'Willamette' in both 2016 and in 2017. The midpoint of harvest date of 'WSU 2166' was similar to that of 'Willamette' and

earlier than 'Cascade Harvest' and 'Willamette' in 2016. In 2017, 'WSU 2166' was earlier than 'Cascade Harvest' (Table 1).

Average fruit firmness was measured as the force a Hunter Spring Mechanical Force Gauge (Series L; Ametek, Hatfield, PA) required to close the opening (compression strength) of 5 randomly selected from each plot from each harvest (Barritt et al., 1980). The seasonal average for fruit firmness was calculated by a similar weighted mean as for average fruit weight. Morphological measurements of 'WSU 2166' fruit were compared with 'Cascade Harvest' and 'Meeker'. Each data set was analyzed as a randomized block design using analysis of variance and Fisher's protected LSD method for mean separation (SAS 9.4; SAS Institute Inc., Cary, NC). 'WSU 2166' was firmer than 'Meeker' and 'Willamette' in 2016, but no significant differences in fruit firmness were observed among the cultivars in 2017.

'WSU 2166' was evaluated in the U.S. Department of Agriculture–Agricultural Research Service (USDA-ARS)/Oregon State University (OSU) cooperative breeding trials at the OSU-North Willamette Research and Extension Center (NWREC) in the Willamette Valley (Aurora, OR). Fruit production was measured in a planting established in 2014 with four replicates of plots that had three plants each. Each plot was harvested by hand in 2016 and using a machine harvester in 2017. Compared with 'Lewis' and 'Meeker', 'WSU 2166' had significantly larger fruit overall over 2 years and similar yields (Table 2). The harvest season in Oregon passed 50% harvest for 'WSU 2166' on 23 June, which was about 5 d earlier than 'Meeker' and 11 d before 'Lewis' and the time from first to last harvest was 24 d for 'WSU 2166' and for 'Meeker' (data not shown).

In British Columbia, plots of 'WSU 2166' with four replications and consisting of five plants were included in breeding trial plots at Agriculture and Agri-Food Canada's substation in Abbotsford, planted in 2014 and again in 2016. The 2014 planting was harvested every 3 to 4 d with a machine harvester in 2016 and 2017. In this planting, 'WSU 2166'

had greater yield and larger fruit than 'Saanich', 'Rudi', 'Lewis', and 'Meeker' (Table 3). In 2016, 'WSU 2166' had an earlier midpoint of harvest than 'Lewis', whereas in 2017, 'WSU 2166' was earlier than 'Meeker', 'Saanich', and 'Lewis'. The 2016 planting was harvested every 3 to 4 d with a machine harvester in 2018. In this planting, 'WSU 2166' had comparable yield to 'Chemainus', and greater yields than 'Meeker' (Table 4). There were no significant differences in fruit weight.

On the basis of these evaluations in Oregon, WA, and British Columbia, 'WSU 2166' has shown adaptability throughout the Pacific Northwest growing area.

## Fruit Description

Fruit of 'WSU 2166' are attractive and large with a long, conic shape with many drupelets per fruit (Fig. 2). Fruit of 'WSU 2166' are sweet, balanced by tartness, and have excellent flavor. From the replicated planting at WSU Puyallup established in 2014, fruit of 'WSU 2166' was harvested 17 July 2017 and compared with 'Cascade Harvest' and 'Meeker' (Table 5). The fruit of 'WSU 2166' was intermediate in fruit and drupelet weight between 'Cascade Harvest' and 'Meeker'. The fruit of 'WSU 2166' and 'Cascade Harvest' had similar length and width whereas 'Meeker' had shorter fruit length.

Storage characteristics of 'WSU 2166' were compared with 'Cascade Harvest' (Table 6). Fruit were hand harvested 3 July 2017 to determine color (McGuire, 1992), firmness, and weight of 24 fruit of each cultivar. Firmness was destructively measured on 12 of the harvested fruit for each cultivar then discarded. The remaining 12 fruit were stored at 4 °C for 7 d, then stored at room temperature (≈20 °C) for 4 h, then evaluated for poststorage color, weight, and firmness. The effect of cultivar and storage on firmness, berry weight, and color (hue, value, and chroma) were determined by an analysis of variance using a mixed procedure (Proc Mixed) in SAS 9.4. There was a highly significant effect of cultivar and storage for firmness, berry weight, and value (data not shown). There were no significant interaction effects of clone × storage for any variable. Because there were no interaction effects,

Table 2. Mean yield and fruit weight in 2016 and 2017 for floricane-fruiting raspberry genotypes at OSU-NWREC planted in 2014. Hand harvested in 2016 and harvested with a machine harvester in 2017.

Genotype	Fruit wt (g)	Yield (kg/plant)	
	2016–17 <sup>z</sup>	2016	2017
WSU 2166	5.1 a <sup>y</sup>	2.86 a	2.6 a
Lewis	4.4 b	3.46 a	1.9 a
Meeker	3.5 c	2.58 a	2.42 a

<sup>z</sup>Weighted means for fruit weight over two evaluation seasons.

<sup>y</sup>Mean separation within columns by Fisher's protected least significant difference,  $P \leq 0.05$ .

Table 3. Mean yield and fruit weight in 2016–17 for floricane-fruiting raspberry cultivars in Abbotsford, BC, planted in 2014 and harvested with a machine harvester.<sup>z</sup>

Cultivar	Fruit wt (g)	Yield (kg/plant)		Harvest midpoint	
	2016–17	2016	2017	2016	2017
WSU 2166	4.3 a	3.01 a	3.63 a	22 June a	13 July a
Saanich	3.6 b	2.45 b	2.81 b	26 June ab	21 July b
Rudi	3.7 b	2.05 bc	2.24 bc	22 June a	12 July a
Lewis	3.7 b	1.95 bc	2.33 bc	28 June b	22 July b
Meeker	3.1 c	1.67 c	1.82 c	24 June a	19 July b

<sup>z</sup>Mean separation within columns by Fisher's protected least significant difference,  $P \leq 0.05$ .

Table 4. Mean yield and fruit size in 2018 for floricane-fruiting raspberry cultivars in Abbotsford, BC, planted in 2016 and machine harvested.

Cultivar	Fruit wt (g) <sup>z</sup>	Yield (kg/plant)	Midpoint of harvest
Chemainus	3.3 a	3.21 a	9 July a
WSU 2166	3.6 a	2.95 a	6 July a
Meeker	2.5 a	1.92 b	10 July a

<sup>z</sup>Mean separation within columns by Fisher's protected least significant difference,  $P \leq 0.05$ .



Fig. 2. Fruit of 'WSU 2166' red raspberry.

Table 5. Morphological measurements of fruit hand harvested from there red raspberry cultivars on 17 July 2017 grown at Puyallup, WA.

	Cultivars		
	WSU 2166	Cascade Harvest	Meeker
<b>Fruit</b>			
Weight (g) <sup>2</sup>	4.23 b	5.74 a	3.76 c
Length (mm)	26.4 b	28.4 a	21.7 c
Width (mm)	21.0 ab	22.3 a	20.0 a
<b>Drupelet</b>			
Weight (mg)	42.0 b	51.3 a	33.2 c
Length (mm)	5.0 a	5.2 a	5.1 a
Width (mm)	4.3 ab	4.5 a	3.7 b
Drupelet number	110.2 a	111.8 a	113.8 a
Individual seed weight (mg)	1.75 b	1.95 a	1.75 b
<b>Receptacle</b>			
Length (mm)	21.7 a	22.0 a	14.8 b
Width (mm)	8.8 a	8.9 a	9.0 a
Length/width	2.47 a	2.47 a	1.86 b

<sup>2</sup>Five fruit of each clone were measured. Mean separation within rows by Fisher's protected least significant differences,  $P \leq 0.05$ .

Table 6. Fruit weight, firmness, and color before and after storage for hand-harvested fruit of two cultivars in plots Puyallup, WA.<sup>2</sup>

	Cultivar	
	WSU 2166	Cascade Harvest
<b>Fruit weight (g)</b>		
Into storage	5.9 a <sup>y</sup>	5.2 b
After storage	5.2 a	4.5 b
<b>Firmness (N)</b>		
Into storage	1.29 a	0.86 b
After storage	0.65 a	0.41 b
<b>Color into storage<sup>x</sup></b>		
Hue	4.9 a	5.0 a
Value	2.9 b	3.3 a
Chroma	5.6 a	6.0 a
<b>Color after storage</b>		
Hue	5.0 a	4.8 a
Value	2.6 b	2.9 a
Chroma	4.4 a	4.3 a

<sup>2</sup>Values represent means of 12 fruit per cultivar. Fruit were harvested 3 July 2017, with data collected on individual fruit. Firmness was destructively measured on 12 fruit of each cultivar that were subsequently discarded. Fruits were stored at 4 °C for 7 d, then brought to room temperature ( $\approx 20$  °C) for 4 h for after storage measurements.

<sup>y</sup>Means within a row followed by the same letter are not significantly different at  $P \leq 0.05$ , by Fisher's protected least significant differences test.

<sup>x</sup>Color measured with a Minolta CR-400 colorimeter using HVC color coordinates.

Table 7. Soluble solids, pH, titratable acidity, anthocyanin content, and total phenolics in machine harvested fruit collected from two trials in Lynden, WA. Plants established in 2011 had fruit samples collected in 2013 and 2014. Plants established in 2013 had fruit samples collected in 2017.

	Cultivar		
	WSU 2166	Meeker	Willamette
Soluble solids (%) <sup>2</sup>	8.3	10.5	8.3
pH	3.25	3.50	3.34
Titratable acidity (as % citric acid)	1.83	1.54	1.63
Anthocyanin content (mg/100 g juice)	49.7	61.7	93.3
Total phenolics (mg GAE/100 g FW)	241	282	285

<sup>2</sup>Single samples of each clone were collected in 2013, 2014, and 2017 from nonreplicated plots. Samples were analyzed in duplicate and averages presented without statistical analysis.

GAE = gallic acid equivalent; FW = fresh weight.

data for each trait were analyzed separately for each storage condition of before and after (Table 6). The fruit of 'WSU 2166' had a greater weight and greater firmness than 'Cascade Harvest', both going into storage and after storage. There were no significant differences for 'WSU 2166' and 'Cascade Harvest' for hue and chroma. 'WSU 2166' was slightly, but significantly, lighter in value than 'Cascade Harvest' both pre- and post-storage. There were no significant effects of

cultivar or storage on hue, and no significant effect of cultivar on chroma, though storage had a significant effect, with post-storage chroma values being lower than before storage for both cultivars (data not shown).

Machine-harvested fruit samples of 300 g were collected from the two nonreplicated plantings (established 2011, 2014) in Lynden, WA, and analyzed for pH, titratable acidity, soluble solids, total anthocyanins, and total phenolics. Single samples of each clone

were collected in 2013, 2014, and 2017 from nonreplicated plots. Samples were analyzed in duplicate and averages presented without statistical analysis. The pH of the juice was measured with a Thermo Scientific Orion Star A211 pH meter (Beverly, MA); titratable acidity by titration to pH 8.1 with 0.1 N NaOH; and soluble solids with an Atago PAL-1 refractometer (Atago U.S.A., Inc., Bellevue, WA). Total anthocyanins were determined by a pH differential method described by Lee et al. (2005) using a Shimadzu ultraviolet-1201 spectrophotometer (Shimadzu Corp., Kyoto, Japan), and expressed as cyanidine-3-glucoside (molar extinction coefficient =  $26,900 \text{ L}\cdot\text{cm}^{-1}\cdot\text{mol}^{-1}$ , molecular weight =  $449.2 \text{ g}\cdot\text{mol}^{-1}$ ). Total phenolics were determined with the Folin-Ciocalteu method described by Waterhouse (2001) and expressed as gallic acid equivalents. Each sample was measured in duplicate and the results averaged. 'WSU 2166' had similar soluble solids as 'Willamette', lower pH than 'Meeker', and less total anthocyanin content than 'Willamette' (Table 7).

Because of the ease of fruit release, firmness, large size, and attractive appearance with darker fruit color than 'Cascade Harvest', 'WSU 2166' is suitable for either processed or fresh market uses.

## Plant Description

'WSU 2166' is a florican fruiting raspberry that has not been observed with primocane fruit at WSU Puyallup. Dark purple prickles are numerous at the base of primocanes, but few to no prickles were present at 1.2 m. The prickles are straight and pointed toward the base of the canes. The pigmented spots at the base of the prickles were the same color as the prickles and oval in shape. Primocanes of 'WSU 2166' are a light green in midsummer. There is no visible pubescence on the canes of 'WSU 2166'. The primocane leaflets are pinnately compound and generally with five leaflets. During the evaluation years of 2016 and 2017, fruit of 'WSU 2166' had early season fruit production with a midpoint of harvest similar to 'Willamette' (Tables 1 and 8).

## Disease and Pest Reaction

'WSU 2166' was evaluated for susceptibility to *Phytophthora* root rot in naturally infested plots at WSU Puyallup Goss Farm in plantings established in 2014. The presence of *P. rubi* in these plots has been verified previously using ITS primers DC1 and MP5 (Bonants et al., 1997, 2004). The root rot trial consisted of 14 total clones, including one cultivar, 'Lewis'. Four plants of each clone were planted in a randomized complete block design. Plants were evaluated in the fall of each year after planting using a subjective rating for vigor from 0 to 5, with 0 being dead and 5 a healthy and vigorous plant free of root rot symptoms. In all 3 years, there was a significant effect of clone at the  $P < 0.001$  level (Table 9). In 2015, 1 year after establishment, 'WSU 2166' had significantly lower

Table 8. Yield and midpoint of harvest of four florican-fruiting red raspberry cultivars planted in a grower field in Lynden, WA, in 2014 and machine harvested in 2016–17.

		Cultivar			
		WSU 2166	Cascade Harvest	Meeker	Willamette
Yield (kg/hill) <sup>2</sup>	2016	4.2	4.9	3.2	3.3
	2017	3.0	3.9	3.8	3.0
Midpoint of harvest	2016	24 June	1 July	1 July	24 June
	2017	11 July	11 July	19 July	12 July

<sup>2</sup>Values represent means for eight plants/plot in a nonreplicated planting.

Table 9. Root rot ratings for 14 red raspberry clones established in 2014 in a site infested with *P. rubi* and evaluated for three subsequent years in Puyallup, WA.

Clone	N	2015 rating	2016 rating	2017 rating
WSU 0836 <sup>2</sup>	4	4.8 ab <sup>3</sup>	5.0 a	4.8 a
ORUS 4499-1	4	4.8 ab	5.0 a	4.3 ab
WSU 2130	4	5.0 a	4.8 a	4.3 ab
WSU 2166	4	2.5 cd	4.5 ab	3.5 abc
ORUS 4462-2	4	1.8 d	4.8 a	3.3 abc
ORUS 4373-1	4	5.0 a	4.8 a	3.0 abc
WSU 2087	4	3.5 abc	4.8 a	3.0 abc
WSU 2133	4	3.3 bcd	5.0 a	2.8 bcd
WSU 1985	4	4.0 abc	4.8 a	2.3 cde
WSU 2001	4	4.0 abc	4.5 ab	2.3 cde
WSU 2122	4	1.8 d	2.3 c	1.0 de
Lewis	4	4.3 ab	2.5 c	0.8 e
ORUS 4619-1	4	4.8 ab	2.8 c	0.8 e
WSU 1980	4	3.3 bcd	3.3 bc	0.8 e

<sup>2</sup>Ratings are on a scale of 0 to 5, where 0 represents a dead plant, and 5 represents a healthy, vigorous plant free of root rot symptoms.

<sup>3</sup>Means within a column followed by the same letter are not significantly different at  $P \leq 0.05$  by Fisher's protected least significant differences test.

ratings than the best performing clones. However, in the second and third evaluation years, 'WSU 2166' showed moderate levels of root rot tolerance, with ratings similar to the most tolerant clones and significantly greater than the least tolerant clones. On the basis of this evaluation, 'WSU 2166' is not immune to root rot but has a moderate level of root rot tolerance.

## Uses

'WSU 2166' produces large, firm fruit with excellent flavor. Fruit of 'WSU 2166' machine harvest easily and are suitable for processing. However, the flavor, large fruit size, attractive appearance, and easy fruit release also makes 'WSU 2166' suitable for the fresh market. 'WSU 2166' may allow for longer planting rotations because of tolerance to *Phytophthora* root rot. It is expected that 'WSU 2166' will be an early

season cultivar, overlapping with 'Willamette' in most of the region.

## Availability

'WSU 2166' nuclear stock tested negative for *Apple mosaic virus*, *Arabidopsis mosaic virus*, *Cherry leaf roll virus*, *Cherry rasp leaf virus*, *Prunus necrotic ringspot virus*, *Raspberry bushy dwarf virus*, *Raspberry ringspot virus*, *Strawberry necrotic shock virus*, *Tobacco ringspot virus*, *Tobacco streak virus*, *Tomato black ring virus*, *Tomato ringspot virus*, and *Xylella* by enzyme-linked immunosorbent assay. In grafts to *R. occidentalis* 'Munger', it also indexed as negative for virus. 'WSU 2166' tested negative for *Blackberry chlorotic ringspot virus*, *Beet pseudo yellows virus*, *Blackberry virus Y*, *Blackberry yellow vein-associated virus*, *Black raspberry necrosis virus*, *Raspberry latent virus*, *Raspberry leaf mottle virus*, *Rubus yellow net*

*virus*, and *Strawberry latent ringspot virus* in reverse transcription polymerase chain reaction assays for phytoplasmas and *Xylella*. It was also negative in bioassays when it was grafted onto *Rubus occidentalis* 'Munger'. Nuclear stocks of 'WSU 2166' are maintained at the USDA-ARS Horticultural Crops Research Unit in Corvallis, OR. Neither the Washington Agricultural Research Center nor the USDA-ARS have plants for sale. Names of propagators with certified 'WSU 2166' plants will be supplied on request. An application for a U.S. Plant Patent has been submitted for 'WSU 2166'.

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