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‘Thunderhead’ Erect Primocane Fruiting Blackberry

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‘Thunderhead’ is an erect primocane fruiting blackberry (*Rubus* subg. *Rubus*) that produces high yields of berries with excellent firmness and fruit quality for the fresh market. ‘Thunderhead’ is the first erect primocane fruiting blackberry released by the US Department of Agriculture (USDA)–Agricultural Research Service (ARS) Horticultural Crops Production and Genetic Improvement Research Unit (HCPGIRU) breeding program in Oregon, USA. The cultivar contains a genetic background derived primarily from eastern US primocane fruiting blackberry germplasm (developed previously by John Clark at the University of Arkansas System Division of Agriculture, AR, USA) that is predominantly tetraploid (2n = 4x = 28), erect in cane architecture, and has a hybrid mixture of *Rubus* backgrounds, including strong contributions from species native to eastern and southeastern North America (*Rubus argutus*, *Rubus trivialis*).

Commercially viable primocane fruiting blackberries are relatively recent (since 2004) and highly valuable to the industry because of their reduced cane management requirements and fruiting season flexibility. However, the earliest primocane fruiting cultivars were not competitive in terms of primocane fruit yields with elite floricane fruiting cultivars in Oregon, USA. The justification for releasing ‘Thunderhead’ is that it was the first primocane fruiting blackberry tested by the USDA-ARS HCPGIRU breeding program that consistently competed with productive floricane fruiting cultivar yields solely with its late-season primocane crop, in addition to having comparable fruit quality for the fresh market, lower prickle density, and improved resistance to red drupelet–related defects compared with our current reference cultivar Prime-Ark® 45.

‘Thunderhead’ can be distinguished by its exceptionally high plant vigor and yields of 7- to 8-g berries with excellent firmness, fruit quality, and flavor, and relatively small seed size for an erect primocane type. As an erect blackberry, ‘Thunderhead’ canes grow vertically, are relatively self-supporting, and can be tucked between T-trellis wires to support fruiting laterals, unlike semierect types that require training canes directly to a trellis wire to prevent drooping at more than 1.5 m, or Oregon trailing types that are not self-supporting. The cultivar has low prickle density compared with ‘Prime-Ark® 45’, which is desirable for ease of harvest and cane management, and it compensates for residual prickles with outstanding plant vigor and fruiting performance. ‘Thunderhead’ berries are well suited for fresh consumption, with good sweetness and gloss when picked firm, and low bitter notes. Although erect primocane fruiting blackberries tend to have larger, more noticeable seeds than trailing blackberry cultivars grown in Oregon, USA, ‘Thunderhead’ improves on this trait with less perceptible “seediness.” ‘Thunderhead’ begins ripening in Oregon during the late summer at a time similar to ‘Prime-Ark® 45’, but produces greater yields with comparable firmness and skin toughness, and lower red drupelet–related defects. ‘Thunderhead’ is a promising alternative to existing primocane fruiting blackberries grown in Oregon such as ‘Prime-Ark® 45’, and is expected to be adapted to areas where other erect and semierect floricane and erect primocane blackberries can be grown successfully. A US Plant Patent was granted in 2023 (US PP34,914 P2) (Hardigan and Finn 2023).

Origin

‘Thunderhead’, tested as ORUS 4999-2, was selected by Chad E. Finn at the Oregon State University Lewis Brown Farm (OSU-LBF; Corvallis, OR, USA) in 2016 as a seedling from a 2014 cross designed by Chad E. Finn and performed by Mary E. Peterson. The maternal parent was ORUS 4355-2 (unpatented), a prickly primocane fruiting selection derived from a cross of the prickly primocane fruiting blackberry NC 538 (unpatented) and prickly primocane fruiting blackberry ‘APF-45’ (US PP22,449), known by the trade name ‘Prime-Ark® 45’ (Clark 2012; Clark and Perkins-Veazie, 2011). The paternal parent was ‘APF-153T’ (US PP26,990), known by the trade name ‘Prime-Ark® Freedom’, which is

a nonprickly primocane fruiting selection derived from a cross of the blackberry plant A-2301 (unpatented) and the nonprickly primocane fruiting blackberry plant APF-49T (unpatented) (Fig. 1) (Clark 2014, 2016).

The original seedling of ORUS 4999-2 was clonally propagated in Benton County, OR, USA, and established in vitro in 2018 to perform virus testing and generate disease-free nuclear stock for trial and nursery distribution. Root cuttings were collected in February to ensure sufficient chilling hour accumulation and were then washed, cut into 8- to 12-cm segments, and placed under a mist bench in perlite media. The in vitro samples were initiated using shoot cuttings from the emerging canes. Virus testing was performed on in vitro plants by the National Clean Plant Network (NCPN) located in Corvallis, OR, USA. Nuclear stock was tested for *Apple mosaic virus*, *Blackberry vein banding associated virus*, *Cherry leaf roll virus*, *Impatiens necrotic spot virus*, *Prunus necrotic ringspot virus*, *Raspberry ringspot virus*, and *Tomato black ring virus* by enzyme-linked immunosorbent assay; and *Arabis mosaic virus*, *Beet pseudo yellows virus*, *Black raspberry necrosis virus*, *Blackberry calico virus*, *Blackberry chlorotic ringspot virus*, *Blackberry leaf mottle associated virus*, *Blackberry line pattern virus*, *Blackberry virus A*, *Blackberry virus E*, *Blackberry virus F*, *Blackberry virus S*, *Blackberry virus X*, *Blackberry virus Y*, *Blackberry yellow vein virus*, *Cherry rasp leaf virus*, *Raspberry luteo virus*, *Raspberry bushy dwarf virus*, *Raspberry latent virus*, *Raspberry leaf blotch virus*, *Raspberry leaf mottle virus*, *Raspberry vein chlorosis virus*, *Rubus yellow net virus*, *Strawberry latent ringspot virus*, *Strawberry necrotic shock virus*, *Tobacco ringspot virus*, *Tomato ringspot virus*, *Tomato spotted wilt virus*, raspberry stunt phytoplasma (‘*candidatus*’ *Phytoplasma rubi*), and *Xylella fastidiosa* (bacteria) by reverse transcription–polymerase chain reaction (PCR) or PCR test.

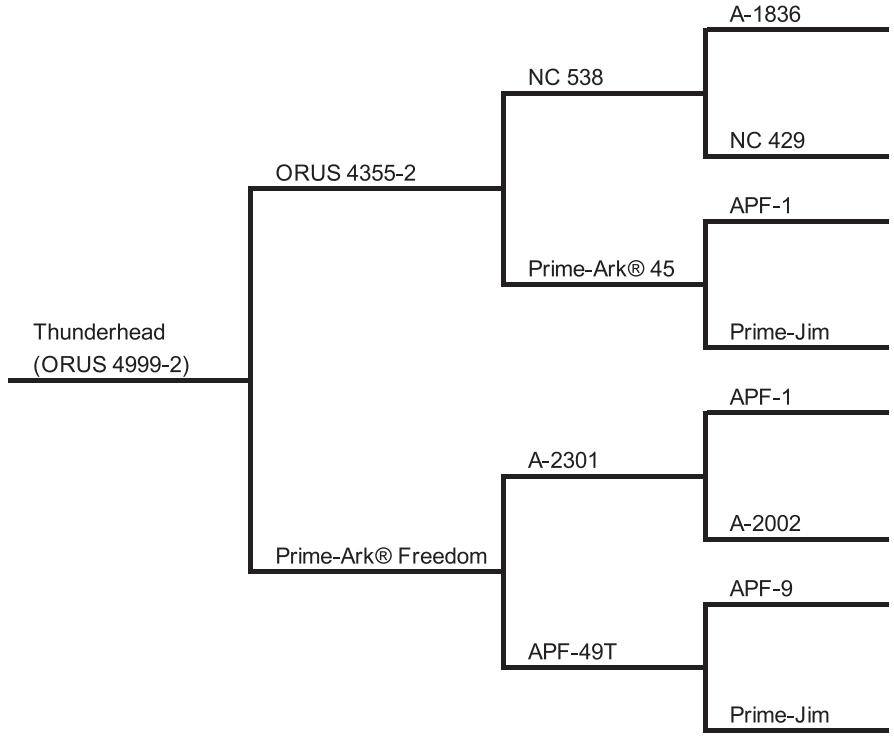

Fig. 1. Pedigree of ‘Thunderhead’ blackberry.

The samples were also bioassayed by grafting onto *Rubus occidentalis* cv. Munger. Rooted microcuttings of the virus-tested in vitro sample maintained by NCPN were planted in a true-to-type evaluation plot at the OSU Vegetable Research Farm (Corvallis, OR, USA) alongside plants dug from the original clone to confirm the cultivar’s stability after successive rounds of asexual propagation (observed 2020–23). An in vitro sample was also provided to North American Plants, Inc. (McMinnville, OR, USA) to generate clean material in the form of greenhouse-acclimated microcuttings, which were used for replicated trials at the OSU–North Willamette Research and Extension Center (NWREC; Aurora, OR, USA) and independent cooperator trials.

‘Thunderhead’ was evaluated in replicated trials at OSU-NWREC for statistical comparison of yield and fruit quality with reference cultivars, with additional nonreplicated trials at OSU-NWREC and OSU-LBF used for further observation. Trials were planted in early May; standard cultural practices for erect primocane fruiting blackberry production were used, including annual pre- and postemergent herbicide applications, spring nitrogen fertilization (78 kg N·ha^{-1}), training and tucking of canes within a two-wire T-trellis, tipping of primocanes at ∼0.9 m to encourage fruiting lateral branch development, and application of 2.5 to 5.0 cm of irrigation per week during the growing season, depending on rainfall. Delayed dormant applications of liquid lime sulfur and copper hydroxide were made to control leaf and cane spot caused by *Septoria rubi* Westend, purple blotch caused by *Sphaerulina westendorpii* (Westendorp) Verkley, Quaedvlieg & Crous (formerly *S. rubi* Westend), rust caused by *Kuehneola uredinis* (Link) Arth., and anthracnose caused by *Elsinoe veneta* (Burkholder) Jenk., as a standard practice without any knowledge of the susceptibility of the selections in trial to these diseases.

The trials were managed exclusively for primocane cropping, with dormant residual floricanes cut to the ground in February, beginning 1 year after planting. At OSU-NWREC, ‘Thunderhead’ was first planted in a nonreplicated trial in 2017 and later in replicated trial in 2019, along with other experimental selections and ‘Prime-Ark® 45’. ‘Prime-Ark® 45’was used as a reference cultivar for yield and fruit comparisons because it is a popular primocane fruiting blackberry in Oregon, USA, and is the nearest equivalent to ‘Thunderhead’ in fruiting season and productivity (Finn and Strik 2021).

Replicated trials were planted in a randomized complete block design with three replications, as used for trialing previous blackberry cultivars (Moore and Clark 1989). Each experimental unit consisted of a three-plant plot (1.37-m spacing) hand-harvested once a week to determine harvest season, weekly and cumulative yields, and average fruit weight (based on a randomly selected subsample of 25 berries from each harvest) (Finn et al. 2018). Yield and fruit measurements were collected for three consecutive growing seasons, beginning 2 years after planting, with data collected from 2019 to 2021 in the 2017-planted nonreplicated trial,

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Mention of trade names or commercial products in this manuscript is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture (USDA). The USDA is an equal opportunity provider and employer.
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and data collected from 2021 to 2023 in the 2019-planted replicated trial. These data were based exclusively on harvested primocane fruit without "double cropping" for floricane harvest the following season. A weighted mean fruit mass was calculated that adjusts the average mean fruit mass based on the proportion of the total yield harvested each week (Finn et al. 2018). Yield and fruit mass data collected from replicated trial plantings were analyzed as a split-plot in time with a fixed-effect model, with cultivar as the main plot and year as the subplot, with mean separation by least significant difference (LSD) test (PROC GLM; SAS Inc., Cary, NC, USA) when significant differences for the traits were detected. Of the multiple genotypes harvested from this replicated trial, only 'Thunderhead' and 'Prime-Ark® 45' were included in the statistical analysis of three harvest seasons from the 2019 replicated trial. 'Thunderhead' was evaluated independently for plant health and adaptation at grower sites in Clarksville, AR, USA; Kingsburg, CA, USA; and in Egypt.

Subjective fruit evaluations were made during the 2019–24 harvest seasons using a 1- to 9-point scale, where 1 point represented the least desirable expression of a trait, 9 points represented the best expression of a trait for commercial use, and scores of 6 or 7 points represented the minimum range for acceptability in a commercial cultivar (Finn et al. 2014, 2018, 2020).

Subjective fruit ratings were made using fresh berries in the field at OSU-NWREC and were evaluated at the plot level once during each week of harvest. The subjective fruit ratings included drupelet fertility (1 point = weak drupelet set, high sterility; 9 points = complete drupelet set); firmness, as evaluated by gently squeezing six to eight ripe fruit (1 point = collapses when squeezed; 9 points = strongly resists pressure when squeezed); color (1 point = majority red or purple drupelets, or drupelet mottling present; 9 points = solid, dark black); shape (1 point = nonuniform shape, lumpy, variable drupelet size creates uneven surface; 9 points = uniform shape, conical); texture, as rated when chewed while tasting six to eight ripe fruit in the field (1 point = watery, seedy, internally tough or chewy; 9 points = lacking qualities of being watery, seedy, internally tough or chewy); separation (1 point = fruit clasps to plant; 9 points = fruit releases easily when receptacle is bent at an angle); flavor (1 point = weak, overly tart, bitter, or lacking sweetness; 9 points = sweet, lacking bitterness, good sugar–acid balance and/or aroma); fruit glossiness (1 point = dull or fuzzy; 9 points = high gloss, shiny); skin toughness, as evaluated by rubbing a thumb across the fruit surface to check for skin breakage and bleeding (1 point = fruit skin tears easily or bleeds; 9 points = fruit exhibits no skin tearing or bleeding); and tolerance of heat/ultraviolet light damage (1 point = many bleached or scorched drupelets; 9 points = no bleached or scorched drupelets). Accumulated subjective ratings for each trait were compared between 'Thunderhead' and 'Prime-Ark® 45' using Fisher's LSD test to check for significant differences, and mean values were reported. Fruit were also evaluated for their potential to harbor spotted winged drosophila (SWD; *Drosophila suzukii*) by checking for berries with collapsed drupelets or receptacles coinciding with visible SWD larvae, and by visually estimating the percent of fruit with SWD damage.

Soluble solids concentration (SSC), titratable acidity (TA), and pH were determined from thawed and homogenized samples of individual quick-frozen (IQF) fruit harvested from OSU-NWREC. Fruit samples were cooled overnight and IQF-processed using a custom-built liquid nitrogen blast freezer (MBI Cryogenics, Inc., Irwindale, CA, USA). SSC was measured with an RFM 81 refractometer (Bellingham & Stanley, Weilheim, Germany). TA was measured with an Orion Star T910 pH Titrator (ThermoFisher Scientific, Waltham, MA, USA). pH was measured with an Orion Star A111 pH Meter (ThermoFisher Scientific) standardized to pH 4.0 and 7.0 buffers. TA was determined using 2 g of puree diluted with 60 mL deionized, degassed water by titration with 0.1 N sodium hydroxide to an endpoint of pH 8.1; results were expressed as percent citric acid. Fruit were evaluated informally as a thawed IQF product by 25 growers, processors, and researchers at the 2024 Oregon Raspberry and Blackberry Commission annual meeting. The evaluation involved a blind survey of IQF fruit samples from 24 blackberry genotypes, each with three samples representing their respective first three harvest weeks. Reference cultivars included 'Black Diamond', 'Celestial', 'Chester Thornless', 'Columbia Star', 'Prime-Ark® 45', 'Triple Crown', 'Twilight', and 'Zodiac'. Respondents were asked to score samples from 1 to 5 points (1 point = weakest; 5 points = strongest) for appearance, leakage/defects, sweetness, flavor, texture, and overall acceptability. Genotypes were ranked by average respondent score for each trait.

The fruit ripening season in Oregon, USA, was characterized by the dates at which 5%, 50%, and 95% of the total primocane fruit were harvested. Plant ratings were conducted once each year for primocane vigor (1 point = reached 0.9 m at 4 months postemergence or not at all; 5 points = reached 0.9 m within 2 months postemergence), fruiting lateral length (in centimeters), and fruiting lateral strength (1 point = weak, droopy; 5 points = sturdy, upright). The number of fruit per lateral was determined by counting fruit on eight representative fruiting laterals in each plot once during the season. 'Thunderhead' plants in the 2017-planted trial plot were left untipped in 2022 and allowed to overwinter for evaluation of cane height and floricane flowering season. Cane height (in meters) was measured using a metric ruler. Floricane flowering season was evaluated as the date when 5% of flower buds were observed to be fully open. Prickle density was evaluated in 2023 based on the average number of prickles per centimeter on three representative primocanes from three plot replicates when canes reached tipping height (~0.9 m).

The parentage of 'Thunderhead' (ORUS 4355-2 × 'Prime-Ark® Freedom') was confirmed using a DNA fingerprinting panel of eight simple sequence repeat (SSR) markers developed at the USDA-ARS National Clonal Germplasm Repository to genotype *Rubus* collections, with DNA extraction and marker analysis performed as described by Zurn et al. (2018).

Description

'Thunderhead' shows exceptionally high yield potential for a primocane fruiting type of blackberry (Table 1), which are often less productive than elite floricane fruiters (Strik et al. 2020). It produced the highest yields among tested primocane fruiting blackberries in every trial each year it was evaluated at OSU-NWREC and is the only primocane fruiting blackberry tested to date by the USDA-ARS breeding program that is able to compete with productive floricane fruiting cultivars. In nonreplicated trial plantings observed for three full harvest seasons (2017 and 2020 plantings), 'Thunderhead' yields within a given season ranged from 7.4 to 28.5 t·ha^{-1} and averaged 17.9 t·ha^{-1}. In 2022, 'Thunderhead' yields from the replicated 2019 trial exceeded productive semierect floricane fruiters such as 'Chester Thornless' and 'Triple Crown', and 'Thunderhead' was significantly higher yielding than 'Prime-Ark® 45' in 2022 and 2023 in the replicated trial (Galletta et al. 1998a, 1998b) (Table 1). 'Thunderhead' yielded more than 'Prime-Ark® 45' within the same trial plantings in every year, ranging from 1.44- to 3.74-fold greater than 'Prime-Ark® 45' from 2021 to 2023. 'Thunderhead' was fast to establish compared with other primocane fruiters, allowing it to produce a substantial "baby crop" in year 1 as assessed visually in 2023 (Fig. 2). The cultivar × year interaction was significant for yield but not for fruit

Table 1. Berry weight and yield from 2021 to 2023 for 'Thunderhead' and 'Prime-Ark® 45' blackberries planted in a replicated trial at Oregon State University North Willamette Research and Extension Center in 2019.

		Yield (t·ha^{-1})			
Year and cultivar	Berry wt (g), 2021–23	2021	2022	2023	2021–23
2021	7.27 b[1]	—	—	—	13.74 b
2022	8.48 a	—	—	—	20.83 a
2023	6.55 b	—	—	—	13.03 b
Prime-Ark® 45	7.34 a	11.28 a	13.18 b	5.49 b	10.00 b
Thunderhead	7.52 a	16.21 a	28.45 a	20.56 a	21.75 a

[1] Means within a column followed by the same lowercase letter are not significantly different, as determined by Fisher's least significant difference test ($P > 0.05$).

Fig. 2. Establishment vigor of 'Thunderhead' in trials at Oregon State University North Willamette Research and Extension Center, with 'Prime-Ark® 45' (**foreground**), 'Thunderhead' (**center**), and unnamed selections (**background**).

weight (Table 1). In most seasons, 'Thunderhead' showed no significant difference in fruit mass from 'Prime-Ark® 45' (Table 1), and berries were most commonly in the 7- to 8-g range, suitable for clamshell packaging. 'Thunderhead' fruit were more uniform in shape and size than 'Prime-Ark® 45', with smaller drupelets and a semiconical shape, whereas 'Prime-Ark® 45' fruit tended to be rounder, with a more variable shape and size (Fig. 3). The fruit of 'Prime-Ark® 45' were slightly darker and glossier than 'Thunderhead' when fresh, although 'Thunderhead' showed suitably dark coloration.

Red drupelet–related defects are commonly observed on primocane fruiting blackberries before and during harvest in August and September at OSU-NWREC. 'Thunderhead' appeared less susceptible to red drupelet–related defects at time of harvest than 'Prime-Ark® 45' (Edgley et al. 2020). Subjective firmness ratings for 'Thunderhead' fruit indicated they are similarly firm or slighter firmer than 'Prime-Ark® 45' (Table 2). 'Thunderhead' exhibited excellent skin toughness, greater than 'Prime-Ark® 45', and fewer ultraviolet and heat-related defects (dry cells, bleached drupelets) than 'Prime-Ark® 45' (Table 2), which was more likely to show sporadic ultraviolet bleaching and red drupelet–related defects under high temperatures in the late summer in Oregon, USA.

In multiple years of postharvest evaluation (2020–23), 'Thunderhead' fruit contained SSCs ranging from 13.1% to 15.1% and averaging

Fig. 3. Trays with fresh berries of 'Prime-Ark® 45' (**left**) and 'Thunderhead' (**right**) harvested from trials at Oregon State University North Willamette Research and Extension Center.

Table 2. Subjectively evaluated fruiting traits from 2018 to 2023 for 'Prime-Ark® 45' and 'Thunderhead' blackberries at Oregon State University North Willamette Research and Extension Center.

Cultivar	Drupelet fertility[i]	Firmness	Skin toughness	Shape	Color	Glossiness	Heat/ ultraviolet damage	Texture	Flavor
Prime-Ark® 45	6.9 b[ii]	7.4 b	7.4 b	6.4 b	8.2 a	7.6 a	7.7 a	6.9 a	6.5 b
Thunderhead	7.6 a	7.9 a	8.0 a	7.5 a	8.0 a	7.7 a	7.9 a	7.3 a	7.6 a

[i] A 1- to 9-point scale was used, where 9 points = the best expression of each trait and 1 point = the worst for all traits.

[ii] Means within a column followed by the same lowercase letter are not significantly different, as determined by Fisher's least significant difference test ($P > 0.05$).

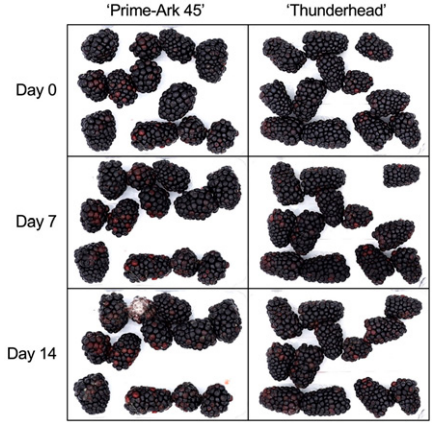

Fig. 4. Comparison of 'Prime-Ark® 45' (**left**) and 'Thunderhead' (**right**) berries at harvest at 0 d, and after postharvest cold storage at 7 d and 14 d.

14.1%, which was greater than 'Chester Thornless' but usually lower than 'Triple Crown' and 'Prime-Ark® 45'. 'Prime-Ark® 45' showed SSCs ranging from 15.8% to 17.1% in the same period. However, 'Thunderhead' also showed low TAs, typically 0.6 to 0.7 g citric acid·100 g^{-1} fruit; and higher pH, typically 3.9 to 4.0, compared with most reference cultivars, resulting in a ratio of SSC to TA that was greater than 'Triple Crown' and similar to 'Prime-Ark® 45'. A higher ratio of SSC to TA puts 'Thunderhead' in a favorable range for fresh consumption, as the fruit are still perceived as being sweet despite a lower concentration of sugars than 'Triple Crown' and 'Prime-Ark® 45' (Mikulic-Petkovsek et al. 2012). When chewed, 'Thunderhead' fruit were perceived to be less "crunchy" or "seedy" than those of 'Prime-Ark® 45'. The reduced seediness of 'Thunderhead' also lowers the perception of bitterness reported in primocane fruiting blackberries by growers accustomed to Oregon, USA, trailing blackberries. Its relatively small seed size combined with its good balance of soluble solids and acidity result in good flavor for fresh consumption.

Although 'Thunderhead' has not been the subject of formal postharvest studies, in our informal trials it was comparable to 'Prime-Ark® 45' for quality after 7 and 14 d storage at 4 °C (Fig. 4). It was uncommon to observe mold or leakage in 'Thunderhead' fruit before 14 d. 'Thunderhead' showed good firmness and less susceptibility to red drupelet reversion in cold than 'Prime-Ark® 45', indicating it is suitable for the fresh market. In a 2024 blind evaluation of fruit samples involving 25 participating growers, 'Thunderhead' ranked third out of 24 blackberry cultivars and selections in score for overall acceptability, ahead of 'Columbia Star' (10th), 'Triple Crown' (13th), and 'Prime-Ark® 45' (17th).

'Thunderhead' produces fruit in the midseason for a primocane fruiting blackberry cultivar in Oregon, USA. When managed as a primocane fruiter with cane tipping in early summer, the first ripe primocane fruit are typically harvested in mid-August, with peak harvest occurring in early September and the last harvest occurring the second or third week of September at OSU-NWREC (Table 3). Its early and midseason overlap late-ripening erect and semierect floricane fruiting cultivars such as 'Chester Thornless'. We have not evaluated the floricane fruiting potential of 'Thunderhead'; however, developing flower buds can be observed on floricanes in early to mid-March in Oregon, and floricane flowering has been observed in late March, indicating it has potential for producing an early-season floricane crop.

Cultivars with moderately vigorous or vigorous canes and upright fruiting laterals are desirable for hand harvest in tipped primocane blackberry plantings. 'Thunderhead' shows increased plant vigor compared with

Table 3. Ripening season estimated as the average date from 2018 to 2023 at which fruit yields reached 5%, 50%, and 95% of the cumulative yield in a given season at Oregon State University North Willamette Research and Extension Center for floricane and primocane fruiting reference cultivars.

		Harvest season (% total yield)		
Cultivar	Type	5%	50%	95%
Columbia Star	Trailing	27 Jun	5 Jul	12 Jul
Marion	Trailing	30 Jun	7 Jul	14 Jul
Galaxy	Semierect	20 Jul	27 Jul	7 Aug
Triple Crown	Semierect	23 Jul	2 Aug	13 Aug
Thunderhead	Primocane	19 Aug	5 Sep	20 Sep
Prime-Ark® 45	Primocane	16 Aug	6 Sep	16 Sep

Table 4. Subjective evaluation of cane vigor and fruiting lateral strength, and quantitative evaluation of fruiting lateral length and fruit per lateral from 2018 to 2023 for 'Chester Thornless', 'Prime-Ark® 45', 'Thunderhead', and 'Triple Crown' blackberries at Oregon State University North Willamette Research and Extension Center.

Cultivar	Type	Cane vigor[i]	Lateral strength[ii]	Lateral length (cm)	Fruit per lateral (n)
Triple Crown	Semierect	4.5 b[iii]	3.5 b	68.1 a	11 c
Chester Thornless	Semierect	4.5 b	1.5 c	63.8 a	57 a
Thunderhead	Primocane	5.0 a	4.5 a	40.4 b	44 ab
Prime-Ark® 45	Primocane	3.5 c	4.5 a	44.5 b	38 b

[i] A 1- to 5-point score was used for cane vigor, where 5 points = most vigorous and 1 point = weakest.
[ii] A 1- to 5-point scale was used for lateral strength, where 1 point = droopy and weak, and 5 points = nondrooping and strong.
[iii] Means within a column followed by the same lowercase letter are not significantly different, as determined by Fisher's least significant difference test $P > 0.05$.

'Prime-Ark® 45', and is on par with vigorous, semierect floricane fruiters such as 'Chester Thornless' and 'Triple Crown' (Table 4). The canes are fully erect and, when untipped, reached 3.0 to 3.7 m in height, similar to 'Triple Crown' (2.8–3.4 m) and taller than 'Prime-Ark® 45' (2.0–2.8 m). Canes should be tipped at ~0.9 m to encourage fruiting lateral growth in a primocane fruit-focused production system, with the option of further tipping developing laterals (Strik et al. 2020). New, emerging canes rapidly fill gaps between the original plant crowns such that the flush of laterals after tipping produces a continuous open canopy of fruit accessible at 0.9 to 1.5 m (Fig. 5). New primocanes emerging from 'Thunderhead' crowns grow rapidly and reached tipping height earlier than 'Prime-Ark® 45' in most years at OSU-NWREC. 'Thunderhead' fruiting laterals are slightly shorter than 'Prime-Ark® 45' at ~40 cm, similar in strength to 'Prime-Ark® 45', and stronger than 'Chester Thornless' and 'Triple Crown', which droop significantly by comparison (Fig. 6). The average number of fruit per lateral on 'Thunderhead' was 44, slightly greater than 'Prime-Ark® 45' at 38. When tipped and supported properly between T-trellis wires, 'Thunderhead' provides a relatively open canopy offering easy access for hand harvest (Figs. 5 and 6). Although not fully free of prickles, 'Thunderhead' prickle density was much less than that of 'Prime-Ark® 45', with the cultivars averaging 0.2 prickle/cm and 1.5 prickles/cm, respectively (Fig. 7). As 'Thunderhead' canes elongate in spring and early summer, the frequency of prickles becomes less, and they are sparse above 0.9 m and on fruiting laterals, where they are most commonly found on the underside of leaf petioles (Figs. 6 and 7). Residual prickles, although undesirable, are sparse and did not impede hand harvest of 'Thunderhead' at OSU-NWREC.

'Thunderhead' has not been evaluated extensively for cold hardiness. The lack of requirement to overwinter canes for floricane production may reduce the risk of winter injury to dormant buds. No winter injury in terms of weak or delayed primocane emergence has been observed in Oregon, USA, and it showed healthy growth and good fruit quality in Clarksville, AR, USA, as well (Thompson E, personal communication). 'Thunderhead' has so far shown to be well adapted to warmer climates, as it has performed well in the San Joaquin Valley, south of Fresno, CA, USA (Willems J, personal communication), and in Egypt under protected culture (Nottelman R, personal communication). Although 'Thunderhead' is expected to grow well in regions where other erect primocane blackberries (e.g., 'Prime-Ark® 45', 'Prime-Ark® Freedom') can be grown successfully, further testing is needed to determine the northern range in which 'Thunderhead' is suitable.

'Thunderhead' has exhibited no major signs of disease susceptibility under the minimal spray program implemented during the OSU-NWREC trials in the US Pacific Northwest. Other caneberries have demonstrated susceptibility to *Phytophthora* root rot at this location without any damage observed in 'Thunderhead'. It is unclear whether 'Thunderhead' has any resistance or tolerance for common diseases in California or the southeastern United States, such as anthracnose (*Elsinoë necator*) and fusarium wilt (*Fusarium oxysporum* f. sp. *mori*) (Gordon et al. 2016; Pastrana et al. 2017). 'Thunderhead' fruit can become a target of SWD, although its open canopy and exposed fruit resulted in much lower pressure at OSU-NWREC than floricane fruiting blackberry cultivars Chester Thornless and Triple Crown, which suffered significant SWD damage in August most years (10%–20% damaged fruit), along with similar damage to 'Prime-Ark® 45' (Lee et al. 2011). 'Thunderhead' and 'Prime-Ark® 45' showed only sporadic SWD damage in their harvested fruit samples, generally less than 5% of fruit in each harvest week.

A comparison of alleles amplified by an SSR marker panel for 'Thunderhead' and the parents, ORUS 4355-2 and 'Prime-Ark® Freedom', confirmed that all alleles observed in 'Thunderhead' were present in one parent or both parents (Table 5). Six of eight SSRs amplified successfully in 'Thunderhead' and both parents, with 21 total alleles identified. Two alleles

Fig. 5. Entire fruiting plot (single three-plant plot) of 'Thunderhead' growing during the trial at Oregon State University North Willamette Research and Extension Center.

Fig. 6. Fruiting lateral architecture of 'Thunderhead'.

Fig. 7. Comparison of prickle size and density on 'Thunderhead' and 'Prime-Ark® 45' canes. (**A**) Representative cane segments collected from 'Thunderhead'. (**B**) Representative cane segments collected from 'Prime-Ark® 45'.

Table 5. Genetic marker profiles of 'Thunderhead', maternal parent ORUS 4355-2, and paternal parent 'Prime-Ark® Freedom' at six of eight simple sequence repeat markers that amplified successfully in each genotype.[i]

	Genotype																				
Cultivar	RH_MEa0007aG06						RH_MEa0008cF01				Ro942		RH_MEa0013dA06		RH_MEa0015cE06			RH_MEa0011dG03a			
Thunderhead	124	—	129	—	142	152	—	—	145	148	116	—	219	—	236	246	248	—	341	—	—
ORUS 4355-2	124	—	129	131	—	152	—	142	145	148	116	138	219	—	236	246	248	—	341	344	—
Prime-Ark® Freedom	—	126	129	131	142	—	133	—	145	148	116	—	219	227	236	246	248	254	341	344	350

Allelic compositions for the three genotypes are indicated by the presence or absence of numeric values that indicate observed amplicon lengths for a given marker.

at one SSR locus (e_07aG06) were shared uniquely with ORUS 4355-2, and one allele at one SSR locus (e_07aG06) was shared uniquely with 'Prime-Ark® Freedom'. Nine alleles across all six amplifying SSR loci were shared with both parents. Nine alleles from the parents were not inherited. The observation of markers with three and four alleles amplifying in 'Thunderhead' and its parents is consistent with it being tetraploid (2n = 4x = 28), like most cultivars of semierect and erect blackberry (Meng and Finn 2002; Thompson 1995) (Table 5).

'Thunderhead' has been released as a new cultivar because it is a distinct plant with several advantages over reference cultivar Prime-Ark® 45 that support commercial production. These include the consistent generation of higher yields on par with productive floricane fruiters, reduced prickle density, reduced red drupelet–related defects, and excellent fruit quality for fresh consumption. 'Thunderhead' has been found to be stable and to reproduce true to type through successive rounds of asexual propagation.

Availability

'Thunderhead' nuclear stock has tested negative for 34 known plant viruses affecting *Rubus* species in addition to phytoplasma and *Xylella* bacteria. 'Thunderhead' plants can be requested for propagation in the form of in vitro microcuttings from the National Clean Plant Network laboratory (3420 NW Orchard Avenue, Corvallis, OR 97330, USA; https://www.ars.usda.gov/pacific-west-area/corvallis-or/horticultural-crops-disease-and-pest-management-research-unit/) and the Oregon State University Plant Clinic (2701 SW Campus Way, Corvallis, OR 97331, USA; https://bpp.oregonstate.edu/plant-clinic). A license must be obtained from the OSU Office of Technology Transfer (OSU Advantage) for propagation and sale of 'Thunderhead' within the United States. Requests for international propagation and sale should be directed to Ekland Marketing Company of California (EMCO-Cal, Chico, CA, USA). The USDA-ARS and OSU do not sell plants. Information including points of contact for licensing, plant acquisition, and a list of nurseries propagating 'Thunderhead' is available on written request to the breeder and corresponding author, Michael Hardigan. When this germplasm contributes to the development of a new cultivar, hybrid, or germplasm, it is requested that appropriate recognition be given to the USDA-ARS HCPGIRU breeding program. The US Plant Patent for 'Thunderhead' is US PP34,914 P2.

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