HORTSCIENCE 35(4):604–607. 2000.

Blackheart in a Tender Apple Cultivar is Not Influenced by Using a Hardy Frame

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Additional index words. *Malus* ×*domestica*, tree hardiness, blackheart, hardy frame, cold injury

***Abstract*. To determine the effects of rootstock and frameworking on hardiness, 'Gravenstein' apple, which is not winter hardy, was grafted on trees frameworked with the hardy genotypes 'Budagovsky 9' (B. 9), 'Lobo', Kentville Stock Clone (KSC 28), or 'Dudley', all of which were propagated on either 'Beautiful Arcade' (BA) seedlings or on 'Alnarp 2' (A. 2) rootstocks. For comparison, 'Dudley' was grafted on 'Dudley' frames propagated on both rootstocks. Growth after 8 years was greatest at Kentville; 'Gravenstein' was larger than 'Dudley', although when grafted, it was 40% smaller on the dwarf B. 9 than on the 'Lobo' frame. On one night in Feb. 1993, all sites recorded temperatures below –30 °C. Blackheart was therefore measured in the rootstock trunk, framebuilder, and scion to document the resistance to this sublethal winter injury. Trees at the two colder sites, Truro and Centreville, had more blackheart than did those at the milder site. The percentage of blackheart in the trunk and frame was greatest for B. 9 and least for KSC 28. The tender scion, 'Gravenstein', exhibited extensive blackheart regardless of site, rootstock, or the hardiness of the frame. The hardy scion, 'Dudley', had some blackheart in the colder locations but none at Kentville. Blackheart levels in 'Gravenstein' were very high on the framebuilder B. 9, and while generally less with the other hardy framebuilders, they were still high. While the hardy frames may have helped improve the survival of this cultivar, they did not change its hardiness status relative to 'Dudley', even when 'Dudley' was one of the hardy framebuilders.**

In northeastern North America, significant tree losses have been attributed to cold temperatures in early or midwinter (Blackburn, 1984; Blair, 1935). The risk of economic loss is high in modern, high-density orchards because many of the current dwarf rootstocks are susceptible to low temperature injury (Cummins and Aldwinckle, 1974). Using popular new cultivars that have not been tested sufficiently for winter hardiness adds to this risk. Apple cultivars on the same rootstock vary in their capacity to withstand winter injury (Steinmetz, 1937). Laboratory and field research has not conclusively shown whether rootstocks can affect the hardiness of the scion (Embree, 1988; Lapins, 1963). Clearly, more field research on the hardiness of apple orchards is needed to develop strategies to minimize winter injury.

Frame building has been suggested as a way of improving tree hardiness and orchard survival, especially for tender cultivars (Blair, 1939; Lapins, 1963; Nelson et al., 1959). A known hardy cultivar, or, in this case, a rootstock cultivar, is used as the tree's basic frame for the desired cultivar. The first four or five limb crotches are usually included. Although this concept has not been used for dwarf, high-density orchards, the identification of new, hardy, dwarfing and semi-dwarfing rootstocks opened this possibility (Embree and Crowe, 1986; Zagaja, 1974.) These dwarf, hardy genotypes, when used as framebuilders, would likely be smaller than for a typical inter-stem tree with the same rootstock type; dwarfing intensity increases with the length of the dwarf stem (Van Oosten, 1978). Should this effect add considerable dwarfing, a more vigorous rootstock may have to be used, especially for cultivars low in vigor. Designing a high-density planting system with a well-anchored, semi-dwarf, hardy rootstock that does not require support may then be possible. The purpose of this study was to evaluate the use of winter-hardy dwarf and semi-dwarf rootstock genotypes as framebuilders to increase the hardiness of the winter-tender cultivar, 'Gravenstein', under three different Atlantic Canadian climates.

Received for publication 19 July 1999. Accepted for publication 15 Sept. 1999. We thank David Baldwin for grafting, both him and John Heukshorst for data collection, Kenneth McRae for statistical analysis and interpretation, and Rob Smith and Keith Fuller for their helpful reviews. The cost of publishing this paper was defrayed in part by page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.
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Materials and Methods

Trials were established in orchard sites in three distinct climatic regions of Nova Scotia and New Brunswick: Agriculture and Agri-Food Canada (AAFC), Kentville, N.S.; the Nova Scotia Agricultural College, Truro, N.S.; and the commercial orchard of Sterling and Janet Lamoreau, Centreville, N.B. The Kentville and Centreville sites were located in the two main apple-growing regions in Atlantic Canada, namely the Annapolis Valley of Nova Scotia and the Saint John River Valley of New Brunswick. The Kentville, N.S., site has the mildest climate and is rated 6a on the hardiness zone map (Ouellet, 1967). The Centreville, N.B., site has a colder climate with hardiness zone rating of 4b. The Truro, N.S., site has a moderate winter and a hardiness zone rating of 5a. These three sites provided a full range in risk of winter injury.

The framebuilders were composed of both the hardy cultivars Lobo (Blair, 1935) and Dudley (Hilborn and Stiles, 1937) and the hardy rootstocks Budagovsky 9 (B. 9) (Zagaja, 1974) and Kentville Stock Clone 28 (KSC 28) (Embree and Crowe, 1986). The framebuilders were bud-grafted onto 'Alnarp 2' (A. 2) and 'Beautiful Arcade' (BA) seedling rootstock liners in the AAFC nursery at Kentville in Aug. 1984. The budded trees were fall-dug in 1985 and stored at 2 °C until planting in Spring 1986. In Apr. 1987, the winter-tender scion 'Gravenstein' (Christopher, 1976) was budded at 1 to 2 m aboveground onto the main trunk of the framebuilders and onto five of its branches ≈10 to 30 cm from the main trunk. This ensured a hardy frame complete with limb crotches. The hardy cultivar, 'Dudley', was also budded as a framebuilder onto the two rootstocks and later frame-grafted to 'Dudley' to serve as a scion control treatment. The eight treatments (four framebuilders on two rootstocks), plus the 'Dudley' scion on a 'Dudley' framebuilder on the two rootstocks, were arranged in a randomized complete-block design with single-tree plots in seven complete-blocks at each site. All trees were planted at a spacing of 4.3 × 6.0 m, trained to a central leader, and given care as recommended by Estabrooks (1993).

Trunk diameter measurements were taken at 25 cm above the soil surface. Daily maximum and minimum temperatures from 1986 to 1993 were obtained from the Atmosphere Environment Service weather stations of Environment Canada (Environment Canada, 1994), located within 10 km of each of the test sites (Table 1). Fortunately for this trial, the test winter of 1992–93 had some of the coldest February nights on record (the coldest since 1911 at Kentville). To quantify the extent of

Table 1. Lowest monthly air temperatures (degrees below 0 °C) November to March at the three test sites: Kentville and Truro, N.S., and Centreville, N.B. (1986–93).

	Site														
	Kentville					Truro[z]					Centreville[y]				
Year	Nov.	Dec.	Jan.	Feb.	Mar.	Nov.	Dec.	Jan.	Feb.	Mar.	Nov.	Dec.	Jan.	Feb.	Mar.
1986–87	11	16	20.5	18	20	12.6	21.4	24.5	23.5	26	20	31	34.5	27	29.5
1987–88	10.5	15	22.5	23.5	14.5	10	20	24.5	25	19	21	22	32	29.5	26
1988–89	6	18	20	20	21	8	21.5	24.5	24.5	23.5	12	30	29	34	29.5
1989–90	11	21	16	23.5	19.5	16	32	18.5	27	23.5	19.5	37	25.5	30.5	25
1990–91	5	12.5	21	17	10	6.5	18.5	25.5	21	12	9	25	34.0	30	16.5
1991–92	6	15	19	22	19.5	4	18.5	23	27.5	21	11	26.0	30	35	26
1992–93	12	18	27.5	30	21	11.5	21	32	34	23	15.5	25	27	32	26

[z]Debert weather station, near Truro.
[y]Beachwood weather station, near Centreville.

Table 2. Main effects of site, rootstock, cultivar, and framebuilder on mean trunk cross-sectional area (cm²) of apple trees at three sites after eight growing seasons (1986–93).

Site (SEM = 3.2, n = 40, df = 9)			Rootstock (SEM = 1.3, n = 60, df = 72)	
Centreville, N.B.	Truro, N.S.	Kentville, N.S.	A. 2	BA
45	44	66	46	54
	Framebuilder (SEM = 2.1, n = 24; df = 72)			
Cultivar	Lobo	KSC 28	B. 9	Dudley
Gravenstein	64	57	39	50
Dudley				43

midwinter injury, we destructively measured blackheart in all parts of the tree. This was an attempt to describe the source and extent of any hardiness improvement on the scion. This technique has been previously described by Warmund et al. (1991) to measure damaged apple trees across locations in the NC-140 coordinated project. Blackheart injury, the first apparent damage from midwinter cold, occurs in the central xylem of the tree (Steinmetz, 1937). When xylem ray parenchyma cells are killed, and vessel elements are obstructed, the xylem turns brown but the phloem tissue remains apparently uninjured (Waring, 1936), at least to the extent that regrowth is not affected. Blackheart injury is rarely monitored in the field, as these tests are destructive. Because sustained injury was expected following the exceptionally cold winter of 1992–93, an opportunity was available to conduct this type of sampling.

In Nov. 1993, trees in four of the seven blocks were cut as close to the ground as possible. The outer limbs were removed and the frames were taken inside. Two cuts were made through the trunk with a radial arm saw, the first through the rootstock 2 cm below the graft union and the second through the framebuilder 25 cm above the first cut. Radial cuts were also made across the limbs 10 cm above and below the graft union, exposing the crosssection of the scion and the hardy framebuilder portions of the tree.

The percentage of blackheart was determined by first measuring the blackened diameter of the xylem at the widest point, and then taking a second diameter at right angles to the first, as described by Warmund et al. (1991). Similar measurements were recorded for the total xylem tissue. Diameters of the discolored xylem and total xylem were then averaged, and the area of the blackheart injury was calculated as a percentage of the total xylem area. These percentage data were then transformed to arcsin square root and statistically analyzed on the logarithmic scale by analysis of variance (ANOVA), using the statistical programming language Genstat 5 (Genstat Committee, 1993). The back-transformed mean values are expressed in percentages. The trunk cross-sectional areas were also transformed to logarithms prior to analysis, and the means back transformed for presentation.

The first comparison among framebuilders in the ANOVA (Table 4) is the contrast between the control ('Dudley' on 'Dudley') vs. the set of framebuilders with the scion 'Gravenstein'; this contrast is denoted as "cultivar" in the table. The term for "framebuilder", with 3 df, compares the differences among the framebuilders with the scion 'Gravenstein'. A direct comparison between scion cultivars on the framebuilder 'Dudley' is available through Student's *t* test, significant for all variables (data not presented).

Effects of site, rootstock, framebuilder, cultivar, and their interactions were taken to be multiplicative, rather than additive, effects, and are described in terms of multiples. The framebuilders are a sample from the range of possible cultivars, so that interactions involving them are described in general trends. The significance level for statistical tests was $P \leq 0.05$.

Results

The minimum winter air temperatures reported at the three sites ranged from –20 °C to –37 °C (Table 1). At Centreville, a temperature of –37.0 °C in Dec. 1989 resulted in visible winter injury to aboveground portions of the trial trees; branch die-back occurred and yields were low for several years. Despite this low temperature, the percentage of trees killed outright at Centreville was <8% (one out of seven trees for B. 9/BA, KSC 28 /BA, and B. 9/A. 2, and two out of seven for KSC 28/A. 2).

After 8 years of growth, the differences in tree size among sites were considerable. The Kentville site had the largest trees with a trunk cross-sectional area (TCA) of 66 cm² (Table 2); TCA at Centreville was 32% smaller. As this site was maintained by private funds, the trees were not cared for as well as at the other two sites. Trees on BA were larger than those on A. 2 over all sites, and 'Gravenstein' was larger than 'Dudley' at all sites. Interaction between rootstock and cultivar was not significant. As a framebuilder, 'Lobo' produced the largest trees (64 cm²) followed by KSC 28 and 'Dudley'. 'Dudley'/'Dudley' and 'Gravenstein'/B. 9 trees were the smallest. Mean tree growth for the largest framebuilder, 'Lobo', across both rootstocks was 63% greater than the mean for the smallest framebuilder, B. 9 (data not shown).

The amount of blackheart in the rootstock near ground level was relatively low at all sites (mean <5%, data not shown). Centreville had the highest incidence of, and the greatest differences in, blackheart injury. The area of blackheart on the control, hardy trees of 'Dudley'/'Dudley' showed that the rootstock BA sustained more damage than A. 2 at Centreville and Truro, respectively, but the total area damaged never exceeded 10%. At Kentville, each rootstock averaged < 1% blackheart (data not shown).

The percentage of blackheart in the trunk was also significantly influenced by site, rootstock, hardy framebuilders, and cultivars (Table 3), with an interaction among site × framebuilder × rootstock for the 'Gravenstein' scion. Trees at Centreville had two to eight times more blackheart, on average, than those at Truro and Kentville. Trees with the hardy dwarf framebuilder B. 9 suffered the greatest damage; those on A. 2 rootstocks were damaged more than those on BA. By contrast, KSC 28 was consistently most effective as a hardy framebuilder, but trunks had twice the blackheart when grafted on A. 2 than on BA. 'Gravenstein'/'Dudley' frame trees had more blackheart in the trunk than did 'Dudley'/'Dudley' trees. This indicates that the scion influenced trunk injury, particularly at Centreville and Truro.

The percentage of blackheart in the frame differed among sites, framebuilders, rootstocks, and cultivars (Fig. 1), and interactions were significant (Table 3). Injury ranged from 7% to 27% at Centreville and from 8% to 69% at

Truro, but was <10% at Kentville. With the exception of the hardy framebuilder KSC 28 on BA, there was generally more blackheart in the frame with 'Gravenstein' than in those with 'Dudley' scions. KSC 28 was the hardiest framebuilder on BA, similar to 'Dudley', while B. 9 was the least hardy on A. 2. In general, B. 9 and KSC 28 had twice the blackheart in the frame when grafted on A. 2 than on BA.

The percentage of blackheart in the scion part of the tree structure did not differ significantly between the Centreville and Truro sites, but was less at Kentville. Regardless of the framebuilder, 'Gravenstein' was less hardy than 'Dudley'. 'Dudley' scions on 'Dudley' frame at the Kentville site were not injured, while injury to 'Gravenstein' ranged from 35% to 56%, explaining much of the site × cultivar interaction.

Discussion

The commercial production of apples in New Brunswick (Estabrooks, 1986) and other parts of Canada (Blair, 1935) is limited because of low-temperature injury. In the commercial production area of the Annapolis Valley, N.S., the climate is not as severe, but some trunk injury did occur on 'Gravenstein' at Kentville following Winter 1981 (Embree, 1984). In this study, tree growth at Kentville was 60% greater than that at Centreville or Truro. Whether this improved growth was a result of milder winter temperatures and less winter injury at Kentville, a longer growing season, or differences in management, was not resolved by this study.

Since 'Dudley' was not present over all framebuilders, the effect of the framebuilders on cultivar hardiness cannot be determined. However, 'Dudley' trees exhibited a low incidence of blackheart, implying that their field performance would be superior to 'Gravenstein'. This is consistent with industry reports indicating that 'Gravenstein' does not perform well outside the Annapolis Valley. Although the Budagovsky rootstocks were bred for hardiness (Zagaja, 1974), and, according to controlled-environment studies (Embree, 1988), have hardy roots, the B. 9 framebuilder did not increase hardiness in the frame and scion in this study. Using B. 9 as a rootstock (Warmund et al., 1996) did not increase the hardiness of the scion ('Red Delicious'). The amount of blackheart in the B. 9 framebuilder was higher than in all others and more than double that of KSC 28, which also has hardy roots (Privé and Embree, 1996).

The rating of blackheart as used by Warmund et al. (1991) proved to be an effective method of assessing sublethal winter injury, even though the trial had to be sacrificed to make this assessment. This technique could be used to assess other promising new rootstocks, framebuilders, and cultivars without having to wait for a "test" winter to cause visible injury. That tree parts differ in their cold hardiness is well known, but this trial shows that these differences are affected by the genetic makeup of other parts. Using a hardy, dwarf frame to reduce tree size and

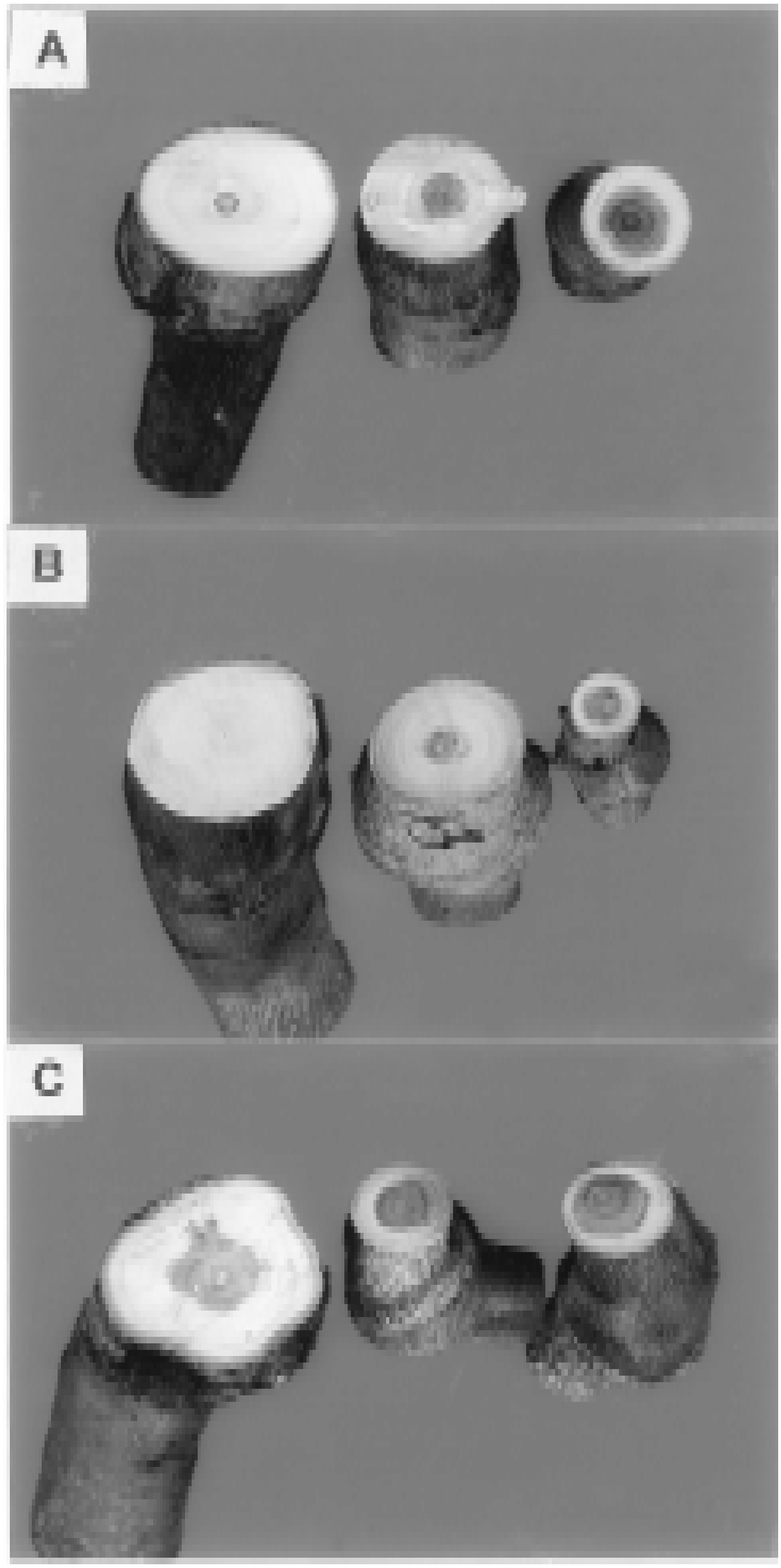

Fig. 1. Cross sections of three trees after eight growing seasons, each illustrating the extent of blackheart injury in the Alnarp 2 rootstock (**left**), framebuilders (**middle**), and 'Gravenstein' scion (**right**). Samples from: Centreville N.B. (**A**), with slight early blackheart in the rootstock, somewhat lighter discoloration in the hardy frame KSC 28 and extensive blackheart in 'Gravenstein'; Kentville, N.S. (**B**), with no damage in the rootstock, some blackheart in the hardy frame B. 9 and in 'Gravenstein'; and Centreville, N.B. (**C**), with lighter early damage in the rootstock and extensive blackheart in the hardy frame B. 9 and in 'Gravenstein'.

Table 3. Effects of site, rootstock, cultivar, and framebuilder on blackheart injury (% cross-sectional area[z]) in trunk, frame, and scion of apple trees measured after an extreme winter (1992–93).

			Trunk				Frame				Scion			
			Site				Site				Site			
Rootstock	Cultivar	Framebuilder	C	T	K	Mean	C	T	K	Mean	C	T	K	Mean
A. 2	Gravenstein	Lobo	21[z]	5	3	7	17	13	6	11	30	34	43	35
		B. 9	51	34	9	26	27	69	10	28	48	76	35	52
		KSC 28	13	7	4	7	13	26	7	14	39	49	43	43
		Dudley	20	29	1	7	24	22	3	12	35	50	56	46
	Dudley	Dudley	8	6	1	4	17	8	1	6	17	8	1	5
	Mean (A. 2)		19	12	2	8	19	22	4	12	32	36	22	30
BA	Gravenstein	Lobo	21	10	0	4	14	33	2	11	33	51	40	41
		B. 9	25	47	9	22	21	43	2	12	53	68	43	54
		KSC 28	5	3	2	3	7	12	1	4	41	46	40	42
		Dudley	25	4	1	5	26	19	2	10	42	46	52	47
	Dudley	Dudley	9	3	0	2	20	8	1	6	23	5	1	5
	Mean (BA)		15	8	1	5	16	19	2	8	37	34	21	30
	Mean (Site)		17	10	2		17	21	3		35	35	21	
Significant contrasts/effects[y] ($P \leq 0.05$)			S, R, C, F, S × F, S × R × F				S, R, C, F, S × R, S × C, R × F				S, C, F, S × C			

[z]The percentage data were transformed first to angles [i.e., $x = \sin^{-1}(\sqrt{p})$] and then to $y = \log_{10}(x + 1)$ prior to analysis of variance. The mean y values were back transformed to percentages for presentation in this table. Main effect means differ from the arithmetic means because of the transformation.
[y]Contrasts and effects: S = among Sites; R = Rootstock (A. 2 vs. BA); C = Cultivar ('Gravenstein' vs. 'Dudley'); F = among Framebuilders within 'Gravenstein'.

Table 4. Significance of main effects of site, rootstock, framebuilder, and scion cultivar and their interactions (using a multiplicative model) on percentage of blackheart in the trunk, frame, and scion of apple.

Source of variation	df	Trunk	Frame	Scion
Among blocks				
Site	2	***	***	*
Blocks within sites	9			
Within blocks				
Rootstock	1	**	**	NS
Cultivar	1	***	***	***
Framebuilder (within 'Gravenstein')	3	***	***	*
Site × Rootstock	2	NS	*	NS
Site × Cultivar	2	NS	**	***
Rootstock × Cultivar	1	NS	NS	NS
Site × Framebuilder	6	**	NS	NS
Rootstock × Framebuilder	3	NS	*	NS
Site × Rootstock × Cultivar	2	NS	NS	NS
Site × Rootstock × Framebuilder	6	*	NS	NS
Residual	74			

[NS, *, **, ***]Nonsignificant or significant at $P \leq 0.05$, 0.10, or 0.001.

improve hardiness might increase the overall hardiness of the orchard. Our study, however, provides little evidence that the hardiness of a tender cultivar can be improved by a hardy framebuilder. It also indicates that 1) the hardiness of a rootstock is not transmitted to a tender scion, and 2) the scion cultivar can influence the hardiness of the trunk, particularly at colder sites.

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