ments in propagation and genetic adjustment indicate the way to go. A prerequisite for this approach is that sources of heritable variation are readily available. This implies well maintained, up-to-date variety collections. It is pleasing to note that despite stringent, parsimonious government economies, good collections are still held and utilized by the Division of Horticulture at Merbein.

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Walnut Cultivars: Evidence for Differential Susceptibility to Insect Pests

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Abstract

Early maturity walnut cultivars appear to be more susceptible to insect pest damage than later maturity cultivars. This is due to the phenological synchrony with pests, and tendency to suffer sunburn and walnut blight damage, which predisposes early walnuts to attack by several insect species. Cultivars with soft, thick hulls are more susceptible to damage by the walnut husk fly, *Rhagoletis completa* Cresson.

Introduction

Persian walnut *(Juglans regia)* is cultivated worldwide with U.S. production almost exclusively in California. Prior to about 1955, most U.S. walnut producers selected chance seedlings or bud sports, or imported cultivars. The University of California walnut breeding program began in 1948, and led to many new walnut cultivars (12). These walnut scion cultivars differ in susceptibility to walnut blight, *Xanthomonas campestris pv juglandis* (9, 15) and deep bark canker, *Erwinia rubrifaciens* (4). Walnut rootstock species and hybrids are differentially susceptible to *Phytophthora* spp. root and crown rot (6), *Armillaria mella* root and crown rot (15), crown gall, *Agrobacterium tumefaciens* (15), Blackline disease caused by cherry leafroll virus (15), and parasitic nematodes (5, 15). Thus it is not surprising that walnut cultivars show differential response to insect attack.

Genetic engineering technology is now being applied to produce transgenic walnut plants which resist caterpillar pests (3) by producing an insecticidal toxin of *Bacillus thuringiensis*, a bacterium whose toxin-coding genes will be transferred to walnut embryos. This approach might provide a de-

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pendable, inherited mechanism of insect resistance in walnuts, regardless of cultivar or leafing phenology.

Until recently varietal resistance to insect pests has been considered incidental to enhancement of yield and walnut quality factors. However, numerous reports of suspected varietal resistance to insects have been published, though few empirical studies have been conducted. The objectives of this report are to 1) present the evidence for differential susceptibility to insect pests in walnut cultivars, and 2) discuss the possible reasons for varietal resistance or susceptibility to insects.

Factors Affecting Insect Susceptibility in Walnut

Walnut Cultivar and Insect Phenology

Synchrony between walnut and insect phenology appears to be the key factor in determining which cultivars are most susceptible to insect attack. Persian walnut cultivar leaf and bloom phenology is compared to that of 'Payne' (13), which matures early but is very susceptible to several insect pests (Fig. 1). Boyce (2) and others reported that early-leafing walnut cultivars such as 'Payne' and 'Placentia' were more susceptible to codling moth, *Cydia pomonella* (L.), damage than later leafing cultivars such as 'Eureka' and 'Scharsch-Franquette.' In a three year study of 11 cultivars in northern California, Olson (10) showed that the early cultivars 'Ashley' and 'Chico' consistently had higher codling moth susceptibility than 'Hartley' (mid-season) or 'Scharsch-Franquette.' First generation codling moths begin to oviposit on walnuts when the average cross-sectional diameter of the developing nuts is ca. ⅜ to ½ inch (8). Nuts of early cultivars mature early enough to support the first generation larvae, while later cultivars escape damage.

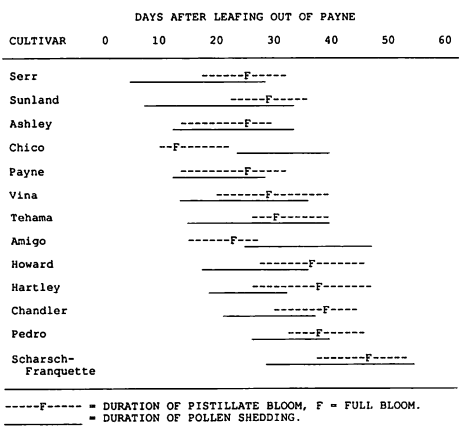

Figure 1. Sequential blooming periods of protandrous and protogynous Persian walnut cultivars grown in California (Adapted from Ryugo, K. 1988. Fruit Culture: Its Science and Art. John Willey & Sons).

Early nut maturity may confer some protection to walnuts against another major insect pest. The walnut husk fly, *Rhagoletis completa* Cresson, is a mid- to late-season pest whose larval development in husk tissue causes shell staining, improper husksplit, and internal kernel damage. Since the flies don't appear in orchards until July or August, and have a 1-2 week preovipositional period, some early maturing cultivars such as 'Ashley' usually escape serious damage from this pest (15). Mid- and late-season cultivars such as 'Eureka,' 'Hartley,' and 'Scharsch-Franquette' are the most susceptible to husk fly damage.

Walnut Blight

The incidence of walnut blight is related to leaf and bloom phenology in walnuts. Though all cultivars are attacked by this bacterium, only those blooming early are highly susceptible, since they leaf out and bloom in early spring when rainfall encourages blight (11). Blighted nuts are attractive to both codling moth and the navel orangeworm, *Amyelois transitella* (Walker) for larval development (15). Walnut varietal susceptibility to blight

and caterpillar pests is thus related to early maturity.

Sunburn in Walnuts

Walnut sunburn damage is also more common in early leafing cultivars because leaf senescence and hullsplit (dehiscence) begins in August, when air temperatures usually peak in the interior California valleys. Sunburned nuts are attractive to the second and subsequent generations of navel orangeworm as developmental sites (14). As a result, early-leafing cultivars such as 'Ashley' and 'Payne' are the most heavily infested by the navel orangeworm (1). Sunburn damage to exposed nuts can be increased as a result of aphidproduced honeydew. Walnut growers have repeatedly noted that cultivars such as 'Payne' are more heavily attacked by walnut aphids (7).

Nature of the Walnut Husk Tissue

Boyce (2) found that walnut cultivars exposed to similar levels of walnut husk fly infestation suffered varying degrees of damage. Though all Persian and black walnuts in California were suitable hosts for this pest, those cultivars with the softest and thickest husks were most susceptible to damage. The most susceptible cultivars included 'Payne,' 'Eureka' and 'Scharsch-Franquette.' More resistant cultivars included 'Placentia,' 'Ware' and 'Neff,' which have largely been replaced by newer cultivars.

Varietal Differences in Insect Damage

Insect Damage

An analysis of walnut quality data from Diamond Walnut Growers, a cooperative which processes ca. 50% of California walnuts, reveals significant differences in insect damage levels among four major cultivars (Table 1). These data represent mean insect damage classes for all 'Ashley,' 'Payne,' 'Serr' and 'Hartley' walnuts processed by Diamond Walnut between 1981 and 1986. There were significant differences in insect damage between years ($P < 0.01$) and cultivars ($P < 0.01$). 'Hartley' walnuts consistently received less damage than the early-leafing 'Ashley' and 'Payne' cultivars. The quality of the California walnut crop in 1986 was the poorest in many years, yet the quality of 'Hartley' nuts was still high, and this cultivar received much less insect damage than 'Ashley,' 'Payne' or 'Serr' walnuts. Though some undetermined factor(s) may contribute to insect resistance in 'Hartley' walnuts, simple varietal phenology is probably responsible.

Inshell Classification

The percentage of walnuts which qualify for inshell sales, and consequently a premium price, is a less direct indication of insect susceptibility. The Diamond Walnut inshell grade requires that a walnut delivery contain

Table 1. Mean (± SD) insect damage classes of walnuts, 1981-86.[1,2]

Cultivar	Year					
	1981	1982	1983	1984	1985	1986
Ashley	1.4 ± 0.9	1.1 ± 0.6	1.4 ± 0.9	1.4 ± 0.8	1.1 ± 0.4	1.9 ± 1.3
Payne	1.2 ± 0.6	1.1 ± 0.5	1.3 ± 0.9	1.3 ± 0.7	1.1 ± 0.6	1.6 ± 1.1
Serr	1.2 ± 0.6	1.0 ± 0.2	1.1 ± 0.6	1.1 ± 0.5	1.0 ± 0.2	1.7 ± 1.2
Hartley	1.2 ± 0.5	1.0 ± 0.1	1.0 ± 0.2	1.1 ± 0.3	1.0 ± 0.2	1.1 ± 0.4

[1]Data from Diamond Walnut Growers, Stockton, CA. Damage classes represent the following percentages of insect-damaged walnuts: class 1 = 0-4.99%; 2 = 5.0-7.99%; 3 = 8.0-10.99%; 4 = 11.0-21.0%; 5 = >21.0%.

[2]The percent nuts in each damage class for each variety were arcsine transformed to improve normality.

Table 2. Percent walnuts qualifying for inshell sales, 1981-86[1]

Variety	Year						Mean ± SD 1981-86
	1981	1982	1983	1984	1985	1986	
Ashley	20	51	30	26	55	16	33.0 ± 16.3
Payne	42	64	26	36	52	24	40.7 ± 15.4
Serr	43	78	45	55	74	30	54.2 ± 18.7
Hartley	48	81	54	60	76	76	65.8 ± 13.6

[1]Data from Diamond Walnut Growers, Stockton, CA.

large walnuts with less than 5% insect damage, less than 6% serious internal defects (mold, rancidity, etc.), and less than 10% serious external defects (stained shell, adhering hull, etc.). As shown in Table 2, the early cultivars had consistently fewer inshell grade deliveries than 'Hartley,' the mid-season cultivar, particularly in poor quality years (1983 and 1986). These data indicate why the walnut industry favors later leafing cultivars such as 'Hartley.'

Conclusions

Few morphological or physiological mechanisms have been related to differential susceptibility to insects in Persian walnut cultivars. Nonetheless, mid- to late-season cultivars are usually less susceptible to insect damage, except for thick-hulled cultivars in areas where the walnut husk fly is a problem.

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