# Effects of Quercetin on Herbivores

Subjects: Agriculture, Dairy & Animal Science
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Quercetin is one of the most abundant flavonoids in terrestrial plants and pollen. In living plants, quercetin can function as a secondary metabolite to discourage insect herbivory. Literature on insect-quercetin interactions was searched and data synthesized to test the hypothesis that quercetin can become an effective biocide to reduce herbivory. The USDA, National Agricultural Library, DigiTop Navigator platform was used to search the literature for harmful versus nonharmful effects of quercetin on insect behavior, physiology, and life history parameters. Quercetin effects were evaluated on herbivores in five insect orders. Quercetin was significantly more harmful to Hemiptera, Diptera, and Lepidoptera but significantly more nonharmful to Coleoptera. Harmful and nonharmful effects to Orthoptera were indistinguishable. Quercetin had significantly more harmful (than nonharmful) effects on herbivores when data from the five insect orders were combined. Quercetin concentration (mg/mL) did not significantly affect these results. This study suggests that quercetin could prevent herbivory but field experiments are necessary to substantiate these results.

Keywords: chemical ecology ; flavonoids ; insect-plant interactions

## 1. Hemiptera (True Bugs)

Four herbivorous hemipterans (three aphid species and one mirid species) were subjects in bioassays with quercetin based on the review of the literature (Table 1). Quercetin had harmful (negative) effects on survival rate of the aphid species *Macrosiphum rosae* (L.) and *Acyrthosiphon pisum* Harris, both nymphs and adults. Quercetin also had harmful (negative) effects on development, preoviposition time, and fecundity of *A. pisum* and fecundity of the aphid *Sitobion miscanthi* (Takahashi) via innate resistance in wheat ears in a field bioassay. In contrast, quercetin had nonharmful (positive) effects on the mirid *Tupiocoris notatus* (Distant); nymphs were attracted to quercetin treated leaves in the laboratory.

**Table 1.** Exemplary research that tested the effects of quercetin on behavior and life history parameters of agriculturally important insect herbivores.

In a summary of this section, quercetin caused 0.857 and 0.143 proportional harmful and nonharmful effects on hemipteran species; the two effects were significantly different ($z$ = 2.672, $p$ = 0.008; $n$ = 7). A concentration of 1 mg/mL or less was sufficient to cause harmful effects on *M. rosae*, *A. pisum*, and *S. miscanthi*, whereas an extremely low quercetin concentration ($0.9 \times 10^{-4}$ mg) caused nonharmful (positive) effects on *T. notatus* (Table 1). Quercetin concentrations were variable amongst these studies. Concentration data were not subjected to statistical analysis for this order, only for combined data for all five orders.

**Table 1.** Exemplary research that tested the effects of quercetin on behavior and life history parameters of agriculturally important insect herbivores.

| Category | Bioassay Method | [1] Effects on Behavior and Life History | [2] Effective Concn. | Reference |
|---|---|---|---|---|
| **Herbivore: Hemiptera; true bugs** | | | | |
| ***Macrosiphum rosae*, nymphs and adults (Aphididae)** | **Treated red rose (*Rosa*) foliage** | **Survival (−−)** | **1 mg/mL** | [1] |
| ***Acyrthosiphon pisum*, nymphs and adults (Aphididae)** | **In artificial diet** | **Development (−−), Pre-oviposition time (−−), Fecundity (−−), Survival (−−)** | **1–10 mg/mL, 0.1–10 mg/mL, 1–10 mg/mL, 0.01–10 mg/mL** | [2] |

| Category | Bioassay Method | [1] Effects on Behavior and Life History | [2] Effective Concn. | Reference |
|---|---|---|---|---|
| *Sitobion miscanthi*, adults (Aphididae) | Innate resistance in wheat ears in field | Fecundity (−−) | 0.199 mg/mL | [3] |
| *Tupiocoris notatus,* nymphs (Miridae) | Treated tobacco (*Nicotiana*) leaves | Attractancy (++) | 0.09 μg | [4] |
| Herbivore: Coleoptera; beetles | | | | |
| *Callosobruchus chinensis*, eggs and adults (Bruchidae) | On filter paper and in plastic jar | Survival (−−), Oviposition (−−) | 5.0 mg/mL, 5.0 mg/mL | [5] |
| *C. chinensis*, adults | On glass beads | Oviposition (oo) | 0.001–1.0 mg/mL | [6] |
| *Tribolium castaneum*, adults (Tenebrionidae) | On wheat wafer discs | Feeding (−−) | 2.0 mg/mL | [7] |
| *Melolontha melolontha*, larvae (Scarabaeidae) | In potted soil, in field | Survival (oo) | 20.0 mg/mL | [8] |
| *Popillia japonica*, adults (Scarabaeidae) | In artificial diet | Feeding (++) | 30.2 mg/mL | [9] |
| *P. japonica*, adults | In artificial diet | Feeding (++) | 0.302–3.02 mg/mL | [10] |
| *Carpophilus hemipterus*, larvae and adults (Nitidulidae) | In artificial diet | Feeding (++) | 0.025 mg/mL | [11] |
| *Leptinotarsa decemlineata*, larvae (Chrysomelidae) | In artificial diet plus insecticide | Survival (−−) | 0.1 mg/mL | [12] |
| *Phaedon brassicae*, adults (Chrysomelidae) | Treated filter paper | Feeding (−−) | 3.02 mg/mL | [13] |
| *Oulema oryzae*, adults (Chrysomelidae) | Treated filter paper | Feeding (−−) | 3.02 mg/mL | [13] |
| *Plagiodera versicolora*, adults (Chrysomelidae) | Treated filter paper | Feeding (++) | 3.02 mg/mL | [13] |
| *Altica oleracea*, adults (Chrysomelidae) | Treated filter paper | Feeding (+ +) | 3.02 mg/mL | [13] |
| *Altica nipponica*, adults | Treated filter paper | Feeding (++) | 3.02 mg/mL | [13] |
| *Anthonomus grandis*, larvae and adults (Curculionidae) | In artificial diet | Feeding (oo), Oviposition (oo), Body weight (++) | 1–10 mg/mL, 1–10 mg/mL, 6 mg/mL | [14] |
| *A. grandis*, adults | Treated filter paper | Feeding (++) | 0.5 mg/mL | [15] |
| *Epilachna paenulata*, larvae (Coccinellidae) | Treated squash (*Curcubita*) leaves | Feeding (++), Survival (−−) | 0.01 μg/cm$^2$, 10–100 μg/cm$^2$ | [16] |
| *E. paenulata*, larvae | Treated squash (*Cucurbita*) leaves | Feeding (oo), Body Weight (oo), Survival (oo) | 0.1–50.0 μg/cm$^2$, 0.1–50.0 μg/cm$^2$, 0.1–50.0 μg/cm$^2$ | [16] |
| Herbivore: Lepidoptera; moths/butterflies | | | | |
| *Helicoverpa armigera*, larvae (Noctuidae) | In artificial diet; leaf-dip toxicity test | Development (−−), Pesticide sensitivity (oo) | 0.1% (*w/w*), 0.1% (*w/w*) | [17] |
| *Spodoptera litura*, larvae (Noctuidae) | Toxicity test | Development (−−), Survival (−−) | 0.005 mg/mL, 0.005 mg/mL | [18] |

| Category | Bioassay Method | [1] Effects on Behavior and Life History | [2] Effective Concn. | Reference |
| --- | --- | --- | --- | --- |
| *Helicoverpa armigera*, larvae (Noctuidae) | In artificial diet | Development (−−), Survival (−−), Pesticide sensitivity (oo) | 16 mg/g, 16 mg/g, 16 mg/g | [19] |
| *Helicoverpa armigera*, larvae (Noctuidae) | Ingested with liquid solution | Development (−−), Survival (−−) | 3 mg/g, 3 mg/g | [20] |
| *Spodoptera frugiperda*, larvae (Noctuidae) | Treated foliage (Lettuce) | Feeding (++), Feeding (−−) | 0.01 μg/cm$^2$, 100 μg/cm$^2$ | [21] |
| *Chilesia rudis*, larvae (Arctiidae) | Treated foliage (cultivated *Murtilla*) | Feeding (++) | 0.005 mg/mL | [22] |
| *Lymantria dispar*, larvae (Lymantriidae) (from *Quercus* forest) | In artificial diet | Survival (−−), Body weight (−−) | 2% (*w/w*), 2% (*w/w*) | [23] |
| *Bombyx mori*, larvae (Bombycidae) | In artificial diet | Body weight/Weight gain (−−) | 0.1% (*w/w*) | [24] |
| *Ostrinia nubilalis*, larvae (Pyralidae) | In artificial diet | Development (−−) Survival (−−) | 1 mg/g | [25] |
| *Heliothis virescens*, larvae (Noctuidae) | In artificial diet | Development (−−) | 0.25% (*w/w*) | [26] |
| *Heliothis virescens*, larvae *Helicoverpa zea*, larvae (Noctuidae) | In artificial diet | Body Weight (−−) Feeding (oo) | 0.10% (*w/w*) | [27] |
| *Pectinophora gossypiella,* larvae *Heliothis virescens*, larvae *Helicoverpa zea*, larvae (Noctuidae) | In artificial diet | Body Weight (−−) Development (−−) | 0.10% (*w/w*), *P. gossypiella*; 0.10% (*w/w*), *H. virescens*; 0.20% (*w/w*), *H. zea* | [28] |
| *Heliothis virescens*, larvae *Helicoverpa zea*, larvae (Noctuidae) | In artificial diet | Development (−−) Survival (−−) | 0.20% (*w/w*), *H. virescens*; 0.80% (*w/w*), *H. zea* | [29] |
| Herbivore: Diptera; true flies | | | | |
| *Bactrocera cucurbitae*, adults (Tephritidae) | On substrate (pumpkin) | Oviposition (−−) | 0.125 mg/mL | [30] |
| *B. cucurbitae*, eggs, larvae, and pupae | Dipped in test solution | Development (−−), Development (−−), Development (−−) | 3.125 mg/mL, 0.125 mg/mL, 0.005 mg/mL | [31] |
| *Rhagoletis pomonella*, larvae (Tephritidae) | In artificial diet | Development (−−) | 1.0 mg/mL | [32] |
| *Drosophila melanogaster*, larvae (Drosophilidae) | In artificial diet | Development (++) | 1.75% (*w/w*) | [33] |
| *D. melanogaster*, adults | In artificial diet | Fecundity (++) | 5% (*w/w*) | [34] |
| *Lycoriella pleuroti*, larvae (Sciaridae) | In artificial culture media | Survival (−−) | 0.1–0.3% (*w/w*) | [35] |
| Herbivore: Orthoptera; grasshoppers | | | | |
| *Calliptamus abbreviatus,* nymphs (Acrididae) | Sprayed on alfalfa foliage, field cages | Development (−−) Survival (−−) | 0.10 mg/mL | [36] |

| Category | Bioassay Method | [1] Effects on Behavior and Life History | [2] Effective Concn. | Reference |
|---|---|---|---|---|
| ***Oedaleus asiaticus*, nymphs (Acrididae)** | **Sprayed on natural host plant foliage, field cages** | **Development (−−) Survival (−−)** | **0.10–10 mg/mL** | [37] |
| ***Melanoplus sanguinipes*, nymphs (Acrididae)** | **In artificial diet** | **Body weight (oo) Survival (oo)** | **0.125–4.0% (*w*/*w*)** | [38] |

[1] Quercetin had harmful effects (negative (−−)) or non-harmful effects (positive (++) or neutral (oo)) on insects in comparison to control. [2] Effective concentration (concn) was the minimum concentration that caused a significant effect on insect behavior, physiology, or a life history parameter.

## 2. Coleoptera (Beetles)

Fourteen herbivorous coleopteran species were exposed to quercetin in bioassays (Table 1). The species included one bruchid *Callosobruchus chinensis* L., one tenebrionid *Tribolium castaneum* Herbst, two scarabaeids *Melolontha melolontha* (L.) and *Popillia japonica* Newman, one nitidulid *Carpophilus hemipterus* (L.), six chrysomelids *Leptinotarsa decemlineata* Say, *Phaedon brassicae* Baly, *Oulema oryzae* Kuwayama, *Plagiodera versicolora* Laicharting, *Altica oleracea* (L.), *Altica nipponica* (Ohno), one curculionid *Anthonomus grandis* Boheman, and one herbivorous coccinellid *Epilachna paenulata* (Germar). Quercetin had harmful (negative) effects and nonharmful (neutral and positive) effects on these species. For example, quercetin decreased the survival of *C*. *chinensis* eggs, *L*. *decemlineata* larvae, and *E*. *paenulata* larvae, and reduced feeding by *T*. *castaneum* adults, *P*. *brassicae* adults, and *O*. *oryzae* adults. In contrast, quercetin did not affect the survival of *M*. *melolontha* and *E*. *paenulata* larvae or feeding behavior by *A*. *grandis* and *E*. *paenulata* larvae. In other coleopteran species, quercetin increased feeding behavior (Table 1).

In summary, quercetin caused 0.304 and 0.696 proportional harmful and nonharmful effects, respectively, on herbivorous coleopterans ($z$ = 2.652, $p$ = 0.008, $n$ = 23); nonharmful effects were predominant. There was variability in quercetin concentration and positive feeding responses between and within coleopteran species. For example, a concentration of 0.30 mg/mL stimulated feeding by *P*. *japonica* adults in one study; but a higher concentration of 30.22 mg/mL stimulated feeding of the same species in another study (Table 1). Quercetin had harmful effects on oviposition by *C*. *chinensis* in one study but not in another; quercetin concentration was at least five times greater in the bioassay indicating reduced oviposition than in the one indicating neutral effects. At 1–10 mg/mL, quercetin had nonharmful (neutral) effects on oviposition and feeding behavior by *A*. *grandis* in one study, but nonharmful (positive) effects on feeding behavior at a lower concentration, 0.5 mg/mL, in another study.

## 3. Lepidoptera (Moths/Butterflies)

Ten lepidopteran species, representing five families, were challenged with quercetin in bioassays (Table 1). The noctuids included *Helicoverpa armigera* (Hübner), *Helicoverpa zea* (Boddie), *Heliothis virescens* (F.), *Spodoptera litura* (F.), *Spodoptera frugiperda* (J. E. Smith), and *Pectinophora gossypiella* (Saunders). One arctiid *Chilesia rudis* (Butler), one lymantriid *Lymantria dispar* (L.), one bombycid *Bombyx mori* (L.), and one pyralid *Ostrinia nubilalis* (Hübner) were also challenged with quercetin.

Quercetin had harmful effects on development or body weight, i.e., growth, of noctuid larvae in most studies (Table 1). Effects on feeding behavior were variable, with nonharmful (positive) effects on *S*. *frugiperda* at low concentration (0.01 μg/cm$^2$) on treated foliage as well as nonharmful (neutral) effects on *H*. *virescens* and *H*. *zea* at low concentration (0.10%, *w*/*w*) in an artificial diet. Quercetin also had nonharmful (positive) effects on feeding behavior of the arctiid *C*. *rudis* at 0.005 mg/mL on treated foliage. Quercetin had harmful effects on development, body weight, or survival of *L*. *dispar*, *B*. *mori*, and *O*. *nubilalis* at a concentration ranging from 0.1–2% (*w*/*w*) in an artificial diet (Table 1).

In summary, quercetin caused 0.792 and 0.208 proportional harmful and nonharmful effects on lepidopterans, respectively. A statistical analysis indicated a significant difference between the two effects ($z$ = 4.046, $p$ < 0.001, $n$ = 24); harmful effects were predominant.

## 4. Diptera (True Flies)

Dipteran species subjected to quercetin in bioassays included two tephritids *Rhagoletis pomonella* (Walsh) and *Bactrocera cucurbitae* (Coquillett), one drosophilid *Drosophila melanogaster* Meigen and one sciarid *Lycoriella pleuroti* Yang & Zhang. Records indicated harmful (negative) effects of quercetin on *B*. *cucurbitae*, *R*. *pomonella*, and *L*. *pleuroti* after direct physical bodily contact with the compound in test arenas, in an artificial diet or artificial culture media at variable quercetin concentrations. For example, quercetin at 0.05–3.1 mg/mL, in bioassays involving *B*. *cucurbitae*, reduced egg hatch rate, pupation, adult emergence, oviposition, and survival rate (Table 1). In two studies, quercetin had nonharmful (positive) effects on development time and fecundity of *D*. *melanogaster* larvae and adult females, respectively. Quercetin concentration ranged from 1.7% to 5.0% across these two studies. In summary of this section, quercetin caused 0.75 and 0.25 proportional harmful and nonharmful effects on dipterans, respectively. The statistical analysis indicated a significant difference between the two effects ($z$ = 2.00, $p$ = 0.046, $n$ = 8); harmful effects were more prevalent.

## 5. Orthoptera (Grasshoppers)

Three acridid species were tested against quercetin in field cage and laboratory bioassays. These species included *Calliptamus abbreviatus* Ikonn, *Oedaleus asiaticus* Bey-Bienko, and *Melanoplus sanguinipes* (F.) (Table 1). Quercetin had harmful (negative) effects on development and survival of *C*. *abbreviatus* nymphs at a concentration of 0.10 mg/mL. Quercetin concentrations ranging from 0.10–10 mg/mL significantly reduced growth/development and survival of *O*. *asiaticus* nymphs. In contrast, body weight and survival rate of *M*. *sanguinipes* nymphs were unaffected by quercetin at a concentration of ranging from 0.125–4.0% (*w/w*). In summary, quercetin caused 0.67 and 0.33 proportional harmful and nonharmful effects on orthopterans, respectively. A statistical analysis did not indicate a significant difference between the two effects ($z$ = 1.155, $p$ = 0.248, $n$ = 6).

## 6. Summary of Herbivores

The sections above indicated that quercetin caused more harmful effects to Hemiptera, Lepidoptera, and Diptera but more nonharmful effects to Coleoptera. In concluding the herbivore section, quercetin caused 0.618 and 0.382 proportional harmful and nonharmful effects on herbivores, respectively, across the five insect orders combined. The two effects were significantly different ($z$ = 2.744, $p$ = 0.006, $n$ = 68); harmful effects were predominant. Quercetin concentration (mg/mL) did not significantly influence the observed harmful and nonharmful effects on herbivores, based on pooling of data, when available, across the five insect orders ($U$ = 105.50; $p$ = 0.583; $n$ = 20 for harmful effects; n = 12 for nonharmful effects). Median values with 25% and 75% confidence intervals were 0.56 mg/mL (0.10, 2.76) for harmful effects and 1.00 mg/mL (0.09, 3.02) for nonharmful effects. Specific harmful effects of quercetin on herbivores, of five orders combined, are illustrated in Figure 1. Quercetin frequently affected survival rate and development/growth.

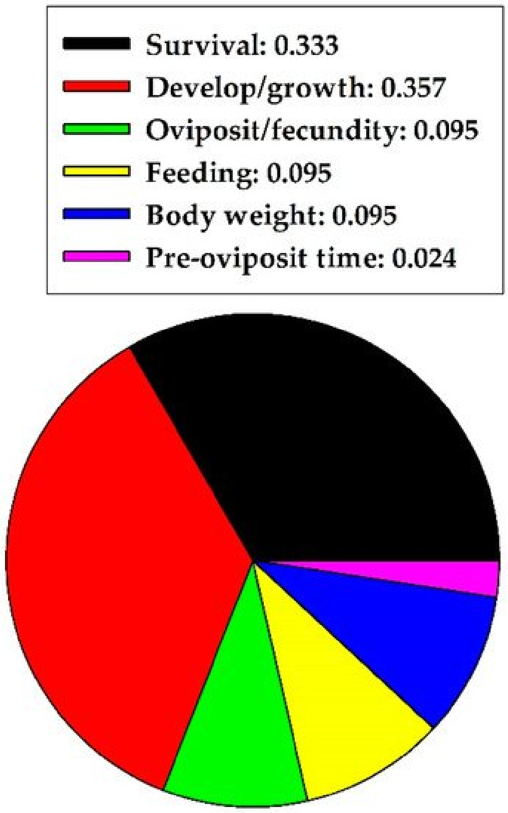


**Figure 1.** Proportion of specific harmful effects of quercetin on herbivores in five insect orders combined.

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