Supporting Information

Rader et al. 10.1073/pnas.1517092112

SI Materials and Methods

This section provides additional information concerning unpublished studies. Methods for all of the studies not described below are published elsewhere (see references in Table S1).

Research on the watermelon B system (Table S1) was carried out during 2009 in the Judean Foothills, a Mediterranean agronatural ecosystem in central Israel (31.6–31.9°N, 34.7–35.0°E, 60–280 m above sea level). All data were collected under standardized weather conditions (sunny days, wind velocity <6 m/s, temperature >18 °C). The Malali cultivar watermelon for seed production is commonly grown in the region under a crop rotation regime, either with drip irrigation or under dryland conditions. Fields are sown in March at a density of three plants/m^2, and plants bloom in mid-May; seeds are harvested from August to September. The majority of our research fields lacked honeybee hives; nevertheless honey bees from nearby hives usually were abundant. A survey of flower visitors to watermelon was conducted in 19 fields, all at a minimum distance of 1 km from each other. In each field, a 25 × 25 m plot was marked at the field edge; in eight fields that were sufficiently large to test for edge effects, an additional 25 × 25 m plot was marked at the interior of the field, 80−110 m from the edge. Edge plots were surrounded by 10−70% (median 25%) seminatural habitat at a 1,000-m radius. Each plot was surveyed on one or two different dates, two times per day, between 7:00–9:00 AM and 9:00–11:00 AM, with intervals of ≥60 min between successive rounds. Each sampling round included 10 min of slow walking along the rows of the plot and recording the number of honey bees, wild bees, and other insect visitors to watermelon flowers.

In the soursop and custard apple A studies insect visitation was assessed for 20 min at four times during the day. For soursop these time intervals were 8:00–8:20 AM, 12:00–12:20 PM, 4:00–4:20 PM, and 8:00–8:20 PM; for custard apple the time intervals were 8:30–8:50 AM, 12:30–12:50 PM, 4:30–4:50 PM, and 8:30–20:50 PM. Insects were surveyed by walking along the tree rows and checking the interior of the flowers for visitors. The number of flowers sampled at each transect varied according to the blooming stage of the different plants. Each flower observed was marked individually, and the number and identity of insects within that flower were recorded. Fruit set was recorded 15 d later as the proportion of marked flowers that had turned into fruitlets.

For avocado, observations were conducted around the circumference of each tree. A 1.5-m pole marked with colored tape at both ends was held vertically 30–50 cm from the tree racemes so that the number of racemes observed was restricted within a marked area of the tree. Flower visitors were counted around the entire circumference of the tree at 9:00–10.30:00 AM, 12:00–1:30 PM, and 3:00–4.30 PM. Twenty-five flowering racemes of each raceme type (outside versus within) were counted to compare tallies of flower-visiting insects.

In the oilseed rape J study in Sweden, data on insect visitation and seed set were collected in 11 landscapes during 2010. In each landscape, four phytometers were placed at the edge of a wheat field. On sunny days during the flowering period in June and July insect visitation was observed four or five times for 45–60 min. The observations sessions were distributed evenly during the day, and all flower-visiting insects were noted. In August, five branches on each phytometer were harvested, and all the pods, both developed and underdeveloped, were counted. When the pods were dry, the seeds from 10 pods from each plant were counted, and the weight was measured.

In the strawberry study in Yorkshire, United Kingdom, eight fields were selected and 2 × 150 m transects were walked between rows in each field in 2011. For recording purposes, the transects were subdivided into 3 × 50 m transects, each of which was walked in 10 min. Any pollinators observed carrying out floral visits were recorded. If the pollinator could not be identified on the wing, it was caught in a hand net and identified back at the laboratory. Three rounds of strawberry surveys were carried out in each field between the May 18 and June 14. All surveys were conducted at temperatures in excess of 15 °C with only light wind.

In the oilseed rape C study, flower-visiting insects were surveyed in 14 oilseed rape fields in the eastern part of The Netherlands. Eight oilseed rape fields were surveyed in 2011; six other fields were surveyed in 2012. In each year, the distance between fields was at least 2 km. With the exception of one field, which was sampled only once on April 30, 2011, all fields were surveyed twice between April 17 and May 30, once in the morning and once in the afternoon. In each field, flower-visiting insects were surveyed in two 1 × 150 m transects located at the edge and in the interior of the field (>25 m from the field edge). Transects were subdivided into three 1 × 50 m plots. In each plot, insects visiting crop flowers were collected during a period of 5 min. Easily recognizable species generally were identified in the field; all other species were collected and identified in the laboratory. Surveys were carried out under dry weather conditions, with low to moderate wind speeds and temperatures above 15 °C. Landscape composition in a 1-km radius around the focal fields was determined using national topographical maps and field inspections, and the nearest distance to seminatural habitat (e.g., forest edges, seminatural grasslands, hedges, heathlands, orchard meadows) was determined using ArcMap 10 (ESRI).

In the oilseed rape A study, 10 autumn-sown oilseed rape fields located in the western part of Sweden (Västergötland; 58°21′41′′N 13°9′59′′E; World Geodetic System 1984) were surveyed in 2009. Fields were separated by minimum of 1.7 and a maximum of 38.3 km. Fields were surveyed for flower-visiting insects four times during the flowering period of May16 to June 1, 2009. Insect surveys were conducted in three 200 × 2 m transects per field. Transects were located 100, 200, and 300 m from the field edge. Observed flower-visiting insects were identified as honey bees, bumble bees, other wild bees, and non-bee pollinators. Surveys were conducted in dry weather, with no to moderate winds and temperatures above 15 °C. Surrounding land use was extracted from a national database on agricultural land use [the Integrated Administration and Control System (IACS)], combined with a land-use classifications based on satellite images and a variety of national maps (provided by the Swedish mapping, cadastral, and land registration authority). Harvest and threshing to estimate seed yield of 10 plants per transect was done by hand and with an experimental threshing machine harvesting an area of ∼1.5 × 10 m near each transect.

In the oilseed rape E study, 32 autumn-sown oilseed rape fields located in the southernmost part of Sweden (Scania; 55°48′15.31′′N, 13°28′4.12′′E) were surveyed 2011–2012, with 16 fields surveyed each year. Fields within a year were separated by at least 2 km, to avoid regular exchange of insects. Fields were surveyed for flower-visiting insects twice in during the year from May 9 to June 5, 2011 and from May 7 to June 7, 2012. Insect surveys were conducted in two 150 × 1 m transects per field, one transect located 8 m and the other 100 m from the edge of the field. Each transect was surveyed for insects visiting the crop flowers during a 15-min period. Insects that could not be identified as to species in the field were collected, frozen, and brought to the laboratory for species determination. Surveys were conducted during dry weather, with no to moderate winds and temperatures above 14 °C (except in one case where the temperature was 12 °C). Surrounding land use was extracted from the IACS national database on agricultural land use combined with land use classifications based on satellite images and a variety of national maps (provided by the Swedish mapping, cadastral and land registration authority) and landscape mapping of the land use during the study years. Relative covers of different land uses were calculated using an automated procedure in MATLAB [MathWorks version R2012b (8.0.0.783)] combined with a SAS script, version 9.3 (SAS Institute Inc.).

Surveys on flower-visiting insects in the apple A and pear studies were conducted in six apple and six pear orchards. Surveys were performed in 2010 and 2011, using the same apple and pear orchards in both years. Each orchard was surveyed twice each year, once in the morning and once in the afternoon with at least 3 and at most 7 d separating surveys. Surveying was conducted between April 23 and May 6 in 2010 and between April 8 and April 20 in 2011 under sunny conditions or scattered clouds. Temperatures ranged from 15–20 °C with calm wind to moderate breeze. Flower visitors were surveyed using a single transect between two rows of trees along the length of each orchard; the transect was subdivided into 25 m long plots (mean number of plots per orchard ± SE: 8.5 ± 1.0 for apple and 9.7 ± 0.5 for pear). In each plot all flower visitors observed on apple or pear flowers during a 10-min period were identified as to species. Easily recognizable species generally were identified in the field; all other species were collected and identified in the laboratory. All orchards were adjacent to seminatural habitat (river levee).

In the *Coffea canephora* study, Google Earth Quickbird images of 0.6-m resolution from the year 2009, topographic maps developed by the Survey of India (1:50,000 scale), the Forest Survey of India, and LANDSAT satellite images were used to develop localized maps around the study sites. The landscape components were classified as forests, coffee plantations, rice paddies, water-bodies, and human settlements. Forests and coffee plantations could be differentiated by the difference in canopy pattern using Google Earth. The shade trees in the coffee plantations are pruned extensively and hence have a much narrower crown than the forested areas. The sites were ground-truthed, and local farmers were consulted to confirm the presence of any forested regions around the study areas, thus reducing the possibility of errors. The area of each landscape component was calculated for three spatial scales (a 500-, 1,000-, and 1,500-m radius from the center of the forest sampled), and water bodies within these areas were counted. Three sites were excluded from the spatial analysis because cloud cover obscured the determination of land-cover types. All the geographic information system (GIS) data were processed using ArcGIS version 9.3 software.

Fig. S1. Examples of non-bee pollinators on selected crops. (*Upper Row*, *Left*) Black hoverfly on Avocado flower in New Zealand (photograph by Brian Cutting); (*Center*) Blue hoverfly on avocado flower in New Zealand (photograph by Brian Cutting); (*Right*) wasp (Synoeca sp., Vespidae) visiting a passion fruit flower in Columbia (photograph by Catalina Gutiérrez-Chacón, University of Freiburg, Germany); (*Lower Row*, *Left*) Syrphid fly visiting a chilli flower in a private garden in Germany (photograph by Felix Fornoff, University of Freiburg, Germany); (*Center*) Syrphid on watermelon in North America; (*Right*) Syrphid on Sunflower.

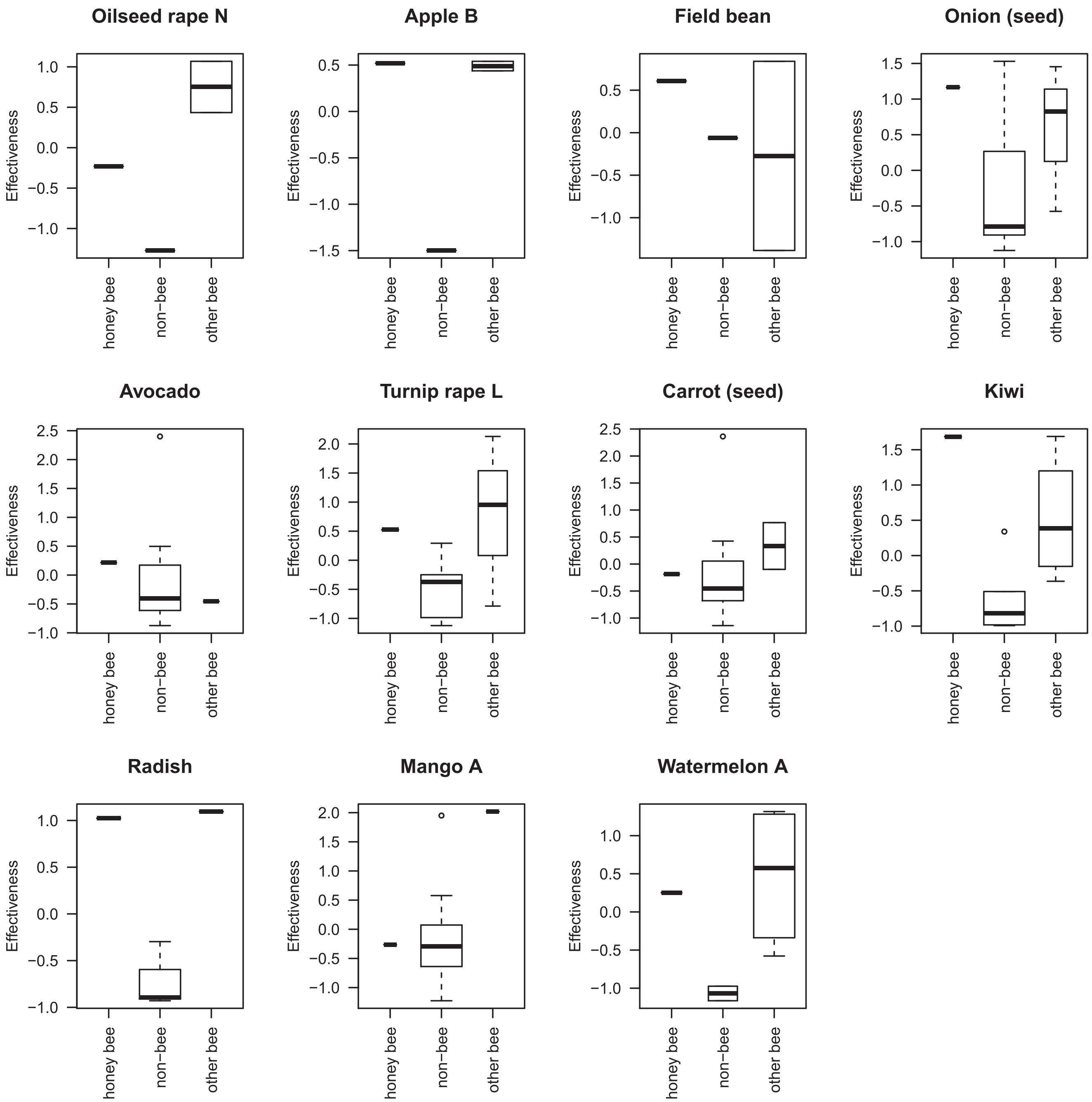

Fig. S2. The relative differences in the effectiveness of honey bees, other bees, and non-bees across 11 crops as measured by pollen deposition or fruit set per visit.

Table S1. Datasets used in this study

Study name	Crop common name	Data holder contact	Source of study methodology	Study location
Actinidia deliciosa	Kiwi	m.mayfield@uq.edu.au	(1)	New Zealand
Actinidia deliciosa A	Kiwi	brad.howlett@plantandfood.co.nz	*	New Zealand
Allium cepa	Onion	brad.howlett@plantandfood.co.nz	(2)	New Zealand
Annona muricata	Soursop	freitas@ufc.br	*	Brazil
Annona squamosa A	Custard apple	freitas@ufc.br	*	Brazil
Annona squamosa B	Custard apple	saul.cunningham@csiro.au	(3)	Australia
Brassica napus A	Oilseed rape	Riccardo.Bommarco@slu.se	*	Sweden
Brassica napus B	Oilseed rape	Frank.Jauker@allzool.bio.uni-giessen.de	(4)	Germany
Brassica napus C	Oilseed rape	jeroen.scheper@wur.nl	*	Netherlands
Brassica napus D	Oilseed rape	darastanley@gmail.com	(5, 6)	Ireland
Brassica napus E	Oilseed rape	Maj.Rundlof@biol.lu.se	*	Sweden
Brassica napus F	Oilseed rape	darastanley@gmail.com	(5, 7)	Ireland
Brassica napus G	Oilseed rape	Sandra.Lindstrom@hushallningssallskapet.se	*	Sweden
Brassica napus K	Oilseed rape	saul.cunningham@csiro.au	(8)	Australia
Brassica napus M	Oilseed rape	nacho.bartomeus@gmail.com	(9)	Sweden
Brassica napus N	Oilseed rape	m.p.garratt@reading.ac.uk	(10)	United Kingdom
Brassica rapa J	Turnip rape	Georg.Andersson@biol.lu.se	*	Sweden
Brassica rapa L	Turnip rape	brad.howlett@plantandfood.co.nz	(11)	New Zealand
Citrullus lanatus A	Watermelon	rwinfree@rutgers.edu	(12)	USA
Citrullus lanatus B	Watermelon	Yael.Mandelik@mail.huji.ac.il	*	Israel
Citrus paradisi	Grapefruit	nchacoff@gmail.com	(13)	Argentina
Coffea arabica	Highland coffee	carlosh.vergara@udlap.mx	(14)	Mexico
Coffea canephora	Lowland coffee	Smitha.krishnan@env.ethz.ch	(15) *	India
Daucus carota	Carrot	brad.howlett@plantandfood.co.nz	(16)	New Zealand
Fagopyrum esculentum A	Buckwheat	hajnalka.szentgyorgyi@gmail.com	(17)	Poland
Fagopyrum esculentum B	Buckwheat	htaki@affrc.go.jp	(18)	Japan
Fragaria vesca	Strawberry	m.p.garratt@reading.ac.uk	*	England
Helianthus annuus A	Sunflower	Yael.Mandelik@mail.huji.ac.il	(19)	Israel
Helianthus annuus B	Sunflower	lgcarvalheiro@gmail.com	(20)	South Africa
Malus domestica A	Apple	David.Kleijn@wur.nl	*	Netherlands
Malus domestica B	Apple	m.p.garratt@reading.ac.uk	(21)	United Kingdom
Mangifera indica A	Mango	rrader@une.edu.au	*	Australia
Mangifera indica B	Mango	lgcarvalheiro@gmail.com	(22)	South Africa
Mangifera indica C	Mango	jhdsousa@yahoo.com	(23)	Brazil
Persea americana	Avocado	brad.howlett@plantandfood.co.nz	*	New Zealand
Prunus avium	Cherry	entling@uni-landau.de	(24)	Switzerland
Prunus dulcis	Almond	alexandra.klein@nature.uni-freiburg.de	(25)	United States
Pyrus communis	Pear	David.Kleijn@wur.nl	*	Netherlands
Raphanus sativus	Radish	brad.howlett@plantandfood.co.nz	*	New Zealand
Vicia faba	Field bean	m.p.garratt@reading.ac.uk	(10)	United Kingdom

*Details of methodology for unpublished studies provided in *SI Materials and Methods*.

1. Ricketts TH, Williams NM, Mayfield MM (2006) *Connectivity for Conservation* (Cambridge Univ Press, Cambridge, UK).
2. Howlett BG, Walker MK, Newstrom-Lloyd LE, Donovan BJ, Teulon DAJ (2009) Window traps and direct observations record similar arthropod flower visitor assemblages in two mass flowering crops. *J Appl Entomol* 133(7):553–564.
3. Blanche R, Cunningham SA (2005) Rain forest provides pollinating beetles for atemoya crops. *J Econ Entomol* 98(4):1193–1201.
4. Jauker F, Diekötter T, Schwarzbach F, Wolters V (2009) Pollinator dispersal in an agricultural matrix: Opposing responses of wild bees and hoverflies to landscape structure and distance from main habitat. *Landscape Ecol* 24(4):547–555.
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10. Garratt MPD, et al. (2014) The identity of crop pollinators helps target conservation for improved ecosystem services. *Biol Conserv* 169(100):128–135.
11. Rader R, et al. (2009) Alternative pollinator taxa are equally efficient but not as effective as the honeybee in a mass flowering crop. *J Appl Ecol* 46:1080–1087.
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14. Vergara CH, Badano EI (2009) Pollinator diversity increases fruit production in Mexican coffee plantations: The importance of rustic management systems. *Agric Ecosyst Environ* 129(1–3):117–123.
15. Krishnan S, Kushalappa CG, Shaanker RU, Ghazoul J (2012) Status of pollinators and their efficiency in coffee fruit set in a fragmented landscape mosaic in South India. *Basic Appl Ecol* 13(3):277–285.
16. Howlett BG (2012) Hybrid carrot seed crop pollination by the fly *Calliphora vicina* (Diptera: Calliphoridae). *J Appl Entomol* 136(6):421–430.
17. Carré G, et al. (2009) Landscape context and habitat type as drivers of bee diversity in European annual crops. Agriculture, Ecosystems *and Environment* 133(1–2):40–47.
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24. Schüepp C, Herzog F, Entling MH (2014) Disentangling multiple drivers of pollination in a landscape-scale experiment. *Proc Biol Sci* 281(1774):20132667.
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Table S2. Crops used to address the four research questions

Study name	Crop common name	Visitation	Pollen deposition	Seed/fruit set	Response to natural/ seminatural vegetation
Actinidia deliciosa	Kiwi	x		x	x
Actinidia deliciosa A	Kiwi		x		
Allium cepa	Onion	x	x		
Annona muricata	Soursop	x		x	
Annona squamosa A	Custard apple	x			
Annona squamosa B	Custard apple	x			x
Brassica napus A	Oilseed rape	x		x	
Brassica napus B	Oilseed rape	x			
Brassica napus C	Oilseed rape	x			x
Brassica napus D	Oilseed rape	x			
Brassica napus E	Oilseed rape	x		x	x
Brassica napus F	Oilseed rape	x		x	x
Brassica napus G	Oilseed rape	x			x
Brassica napus K	Oilseed rape	x			
Brassica napus M	Oilseed rape	x		x	x
Brassica napus N	Oilseed rape	x	x		x
Brassica rapa J	Turnip rape	x		x	x
Brassica rapa L	Turnip rape	x	x		x
Citrullus lanatus A	Watermelon	x	x		x
Citrullus lanatus B	Watermelon	x			x
Citrus paradisi	Grapefruit	x			
Coffea arabica	Highland coffee	x		x	x
Coffea canephora	Lowland coffee	x		x	x
Daucus carota	Carrot	x	x		
Fagopyrum esculentum A	Buckwheat	x		x	
Fagopyrum esculentum B	Buckwheat	x		x	x
Fragaria vesca	Strawberry	x		x	x
Helianthus annuus A	Sunflower	x			
Helianthus annuus B	Sunflower	x		x	x
Malus domestica A	Apple	x			
Malus domestica B	Apple	x	x	x	x
Mangifera indica A	Mango	x	x	x	x
Mangifera indica B	Mango	x		x	x
Persea americana	Avocado		x		
Prunus avium	Cherry	x		x	x
Prunus dulcis	Almond	x		x	x
Pyrus communis	Pear	x			
Raphanus sativus	Radish		x		
Vicia faba	Field bean	x	x	x	x

Thirty-seven datasets were used to investigate differences in visitation rate; 11 datasets were used to investigate differences in pollen deposition; 19 datasets were used to investigate differences in fruit set; and 23 datasets were used to investigate isolation from natural/seminatural vegetation.

Table S3. Percentage of crops in the United Nations Food and Agriculture Organization (FAO) pollinator-dependent crop database pollinated by bee and non-bee pollinators

	Non-bee only, %	Bees plus non-bees, %	Bee only, %	Unknown, %
Composition of pollinators across all crop types worldwide*	5	23	36	36
Expected composition of pollinators across crop types selected in this study†	6	56	28	11
Actual pollinator composition based on all studies in this synthesis‡	17	78	6	0

*Composition of pollinator community based on Klein et al. (1). The Klein study demonstrated that of the top 208 global crops that are known to benefit from animal pollinators, 36% were visited mostly by bee pollinators, 23% were visited both by bee and non-bee pollinators (including birds and mammals), 11% were visited mostly by non-bees, and for the remaining 36% the pollinator composition was unknown. Here we tallied the dominant pollinator taxa into four groups (i.e., non-bees only, bees and non-bees, bee only, and unknown pollinator composition) based on the FAO database data and present these values as a percentage of the total number of crops.

†Composition of pollinator community expected for the crops selected in this synthesis based on ref. 1. Here we performed the same tally for our crop species based on the FAO database and present these values as a percentage of the total number of crop species in our study.

‡Actual pollinator composition based on empirical data collected for this synthesis. Here we compiled the actual tallies from the results of the empirical studies synthesized in this paper. We tallied data from individual studies (not crop species; hence the same crop type may have a different pollinator composition in a different region).

1. Klein et al. (2007) Importance of pollinators in changing landscapes for world crops. *Proc Biol Sci* 274(1608):303–313.

Table S4. AIC for mixed-effects models of the potential influences on fruit set, including visitation rate by other bees (ob), visitation rate by honey bees (hb), and visitation rate by non-bees (nb)

Model	AIC	Δ	ob	hb	nb	ob*nb*hb	nb*ob	ob*hb	nb*hb	Random slope ob	Random slope hb	Random slope nb
Null	591.28											
A:best	555.64		0.19 (0.07)	−0.02 (0.07)	0.12 (0.07)							
B	574.33	19	0.21 (0.08)	−0.04 (0.08)	0.12 (0.07)	0.17 (0.15)	0.02 (0.06)	0.05 (0.09)	−0.02 (0.09)			
C	561.47	6	0.19 (0.08)	−0.02 (0.07)	0.13 (0.07)		−0.007 (0.06)					
D	561.09	5	0.19 (0.07)	−0.02 (0.08)	0.12 (0.07)			−0.02 (0.07)				
E	560.52	5	0.19 (0.07)	−0.03 (0.08)	0.12 (0.07)				−0.03 (0.09)			
F	572.32	17	0.17 (0.08)	−0.014 (0.08)	0.14 (0.08)					X	X	X
G	559.37	4	0.17 (0.08)	−0.01 (0.08)	0.13 (0.07)					X		
H	559.27	4	0.20 (0.07)	−0.02 (0.09)	0.12 (0.07)						X	
I	559.63	4	0.19 (0.07)	−0.02 (0.07)	0.12 (0.07)							X

The Δ column depicts the difference between a model's AIC and that of the best-fitting model. Different intercepts (αi) were estimated for each crop system in all models by including study system as a random factor. All variables were standardized using z-scores within each crop system before analyses. Model estimates are presented in each variable with SE in parentheses.

Other Supporting Information Files

Dataset S1 (RTF)
Dataset S2 (RTF)
Dataset S3 (RTF)
Dataset S4 (RTF)