

# Gene expression responses to interactive stressors of diet quality and viral infection in *Apis mellifera*

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## 1.1 Introduction

Commerically managed honeybees have undergone unusually large declines in the United States and parts of Europe over the past decade ([vanEngelsdorp et al. 2009](#), [Kulhanek et al. 2017](#), [Laurent et al. 2016](#)), with annual mortality rates exceeding what beekeepers consider sustainable ([Caron and Sagili 2011](#), [Bond et al. 2014](#)). More than 70 percent of major global food crops (including fruits, vegetables, and nuts) at least benefit from pollination, and yearly insect pollination services are valued worldwide at \$175 billion ([Gallai et al. 2009](#)). As honeybees are largely considered to be the leading pollinator of numerous crops, their marked loss has considerable implications regarding agricultural sustainability ([Klein et al. 2007](#)).

Honeybee declines have been associated with several factors, including pesticide use, parasites, pathogens, habitat loss, and poor nutrition ([Potts et al. 2010](#), [Spivak et al. 2011](#)). Researchers generally agree that these stressors do not act in isolation; instead, they appear to influence the large-scale loss of honeybees in interactive fashions as the environment changes ([Goulson et al. 2015](#)). Nutrition and viral infection are two broad factors that pose heightened dangers to honeybee health in response to recent environmental changes.

Pollen is the main source of nutrition (including proteins, amino acids, lipids, sterols, starch, vitamins, and minerals) in honeybees ([Roulston and Buchmann 2000](#), [Stanley and Linskens 1974](#)). At the individual level, pollen supplies most of the nutrients necessary for physiological development ([Brodschneider and Crailsheim 2010](#)) and is believed to have considerable impact on longevity ([Haydak 1970](#)). At the colony level, pollen enables

young workers to produce jelly, which then nourishes larvae, drones, older workers, and the queen (Crailsheim et al. 1992, Crailsheim 1992). Various environmental changes (including urbanization and monoculture crop production) have significantly altered the nutritional profile available to honeybees. In particular, honeybees face less diverse selections of pollen, which is of concern because mixed-pollen (polyfloral) diets are generally considered healthier than single-pollen (monofloral) diets (Schmidt 1984, Schmidt et al. 1987, Alaux et al. 2010). Indeed, reported colony mortality rates are higher in developed land areas compared to undeveloped land areas (Naug 2009), and beekeepers rank poor nutrition as one of the main reasons for colony losses (Engelsdorp et al. 2008). Understanding how undiversified diets affect honeybee health will be crucial to resolve problems that may arise as agriculture continues to intensify throughout the world (Neumann and Carreck 2010, Engelsdorp and Meixner 2010).

Viral infection was a comparatively minor problem in honeybees until the last century when *Varroa destructor* (an ectoparasitic mite) spread worldwide (Rosenkranz et al. 2010). This mite feeds on honeybee hemolymph (Weinberg and Madel 1985), transmits cocktails of viruses, and supports replication of certain viruses (Shen et al. 2005, Yang and Cox-Foster 2007, Yang and Cox-Foster 2005). One of these viruses that has been linked to honeybee decline is Israeli Acute Paralysis Virus (IAPV). A positive-sense RNA virus of the Dicistroviridae family (Miranda et al. 2010), IAPV causes infected honeybees to display shivering wings, decreased locomotion, muscle spasms, and paralysis, and 80% of caged infected adult honeybees die prematurely (Maori et al. 2009). IAPV has demonstrated higher infectious capacities than other honeybee viruses in certain conditions (Carrillo-Tripp et al. 2016) and is more prevalent in colonies that do not survive the winter (Chen et al. 2014). Its role in the rising phenomenon of “Colony Collapse Disorder” (in which the majority of worker bees disappear from a hive) remains unclear: It has been implicated in some studies (Cox-Foster et al. 2007, Hou et al. 2014) but not in other studies (vanEngelsdorp et al. 2009, Cornman et al. 2012, Miranda et al. 2010). Nonetheless, it seems likely that IAPV reduces colony strength and survival.

## 1.2 Methods

## 1.3 Results

## 1.4 Discussion

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# Bibliography

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- C. Alaux, F. Ducloz, and D. Crauser Y. Le Conte. Diet effects on honeybee immunocompetence. *Biol. Lett.*, 6:562–565, 2010.
- J. Bond, K. Plattner, and K. Hunt. *Fruit and Tree Nuts Outlook: Economic Insight U.S. Pollination- Services Market*. USDA. Economic Research Service Situation and Outlook FTS-357SA, 2014.
- R. Brodschneider and K. Crailsheim. Nutrition and health in honey bees. *Apidologie*, 41: 278–294, 2010.
- D. Caron and R. Sagili. Honey bee colony mortality in the Pacific Northwest: Winter 2009/2010. *Am Bee J*, 151:73–76, 2011.
- J. Carrillo-Tripp, A.G. Dolezal, M.J. Goblirsch, W.A. Miller, A.L. Toth, and B.C. Bonning. In vivo and in vitro infection dynamics of honey bee viruses. *Sci Rep*, 6:22265, 2016.
- Y.P. Chen, J.S. Pettis, M. Corona, W.P. Chen, C.J. Li, and M. Spivak. Israeli acute paralysis virus: Epidemiology, pathogenesis and implications for honey bee health. *Plos Pathog*, 10:e1004261, 2014.
- R.S. Cornman, D.R. Tarry, Y. Chen, L. Jeffreys, D. Lopez, and J.S. Pettis. Pathogen webs in collapsing honey bee colonies. *Plos One*, 7:e43562, 2012.
- D.L. Cox-Foster, S. Conlan, E.C. Holmes, G. Palacios, J.D. Evans, N.A. Moran, P-L. Quan, T. Briesse, M. Hornig, D.M. Geiser, V. Martinson, D. vanEngelsdorp, A.L. Kalkstein, A. Drysdale, J. Hui, J. Zhai, L. Cui, S.K. Hutchison, J.F. Simons, M. Egholm, J.S. Pettis, and W.I. Lipkin. A metagenomic survey of microbes in honey bee colony collapse disorder. *Science*, 318:283–287, 2007.
- K. Crailsheim. The flow of jelly within a honeybee colony. *J Comp Physiol B*, 162:681–689, 1992.

- K. Crailsheim, L.H.W. Schneider, N. Hrassnigg, G. Bühlmann, U. Brosch, R. Gmeinbauer, and B. Schöffmann. Pollen consumption and utilization in worker honeybees (*Apis mellifera carnica*): dependence on individual age and function. *J Insect Physiol*, 38: 409–419, 1992.
- D. Van Engelsdorp and M.D. Meixner. A historical review of managed honey bee populations in Europe and the United States and the factors that may affect them. *J Invertebr Pathol*, 103:S80–S95, 2010.
- D. Van Engelsdorp, J. Jr. Hayes, R.M. Underwood, and J. Pettis. A survey of honey bee colony losses in the U.S., fall 2007 to spring 2008. *Plos One*, 3:e4071, 2008.
- N. Gallai, J.-M. Salles, J. Settele, and B.B. Vaissière. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecol. Econ.*, 68:810–821, 2009.
- D. Goulson, E. Nicholls, C. Botías, and E.L. Rotheray. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science*, 347:1255957, 2015.
- M.H. Haydak. Honey bee nutrition. *Annu Rev Entomol*, 15:143–156, 1970.
- C. Hou, H. Rivkin, Y. Slabezki, and N. Chejanovsky. Dynamics of the presence of israeli acute paralysis virus in honey bee colonies with colony collapse disorder. *Viruses*, 6: 2012–2027, 2014.
- A.-M. Klein, B.E. Vaissière, J.H. Cane, I. Steffan-Dewenter, S.A. Cunningham, C. Kremen, and T. Tscharntke. Importance of pollinators in changing landscapes for world crops. *Proc Biol Sci*, 274:303–313, 2007.
- K. Kulhanek, N. Steinhauer, K. Rennich, D.M. Caron, R.R. Sagili, J.S. Pettis, J.D. Ellis, M.E. Wilson, J.T. Wilkes, D.R. Tarpy, R. Rose, K. Lee, J. Rangel, and D. vanEngelsdorp. A national survey of managed honey bee 2014–2015 annual colony losses in the USA. *Journal of Apicultural Research*, 56:328–340, 2017.
- M. Laurent, P. Hendrikx, M. Ribiere-Chabert, and M.-P. Chauzat. A pan-European epidemiological study on honeybee colony losses 2012–2014. *Epilobee*, 2013:44, 2016.
- E. Maori, N. Paldi, S. Shafir, H. Kalev, E. Tsur, E. Glick, and I. Sela. IAPV, a bee-affecting virus associated with Colony Collapse Disorder can be silenced by dsRNA ingestion. *Insect Mol Biol*, 18:55–60, 2009.
- J.R. De Miranda, G. Cordon, and G. Budge. The acute bee paralysis virus-Kashmir bee virus-Israeli acute paralysis virus complex. *J Invertebr Pathol*, 103:S30–47, 2010.
- D. Naug. Nutritional stress due to habitat loss may explain recent honeybee colony collapses. *Biol Conserv*, 142:2369–2372, 2009.

- P. Neumann and N.L. Carreck. Honey bee colony losses. *J Apicult Res*, 49:1–6, 2010.
- S.G. Potts, J.C. Biesmeijer, C. Kremen, P. Neumann, O. Schweiger, and W.E. Kunin. . *Global pollinator declines: trends, impacts and drivers*, 25:345–353, 2010.
- P. Rosenkranz, P. Aumeier, and B. Ziegelmann. Biology and control of Varroa destructor. *J Invertebr Pathol*, 103:S96–S119, 2010.
- T.H. Roulston and S.L. Buchmann. A phylogenetic reconsideration of the pollen starch-pollination correlation. *Evol Ecol Res*, 2:627–643, 2000.
- J.O. Schmidt. Feeding preference of *Apis mellifera* L. (Hymenoptera: Apidae): Individual versus mixed pollen species. *J. Kans. Entomol. Soc.*, 57:323–327, 1984.
- J.O. Schmidt, S.C. Thoenes, and M.D. Levin. Survival of honey bees, *Apis mellifera* (Hymenoptera: Apidae), fed various pollen sources. *J. Econ. Entomol.*, 80:176–183, 1987.
- M.Q. Shen, L.W. Cui, N. Ostiguy, and D. Cox-Foster. Intricate transmission routes and interactions between picorna-like viruses (Kashmir bee virus and sacbrood virus) with the honeybee host and the parasitic varroa mite. *J Gen Virol*, 86:2281–2289, 2005.
- M. Spivak, E. Mader, M. Vaughan, and N.H. Euliss. The Plight of the Bees. *Environ Sci Technol*, 45:34–38, 2011.
- R.G. Stanley and H.F. Linskens. *Pollen: Biology, biochemistry, management*. Springer Verlag, 1974.
- D. vanEngelsdorp, J.D. Evans, C. Saegerman, C. Mullin, E. Haubruge, B.K. Nguyen, M. Frazier, J. Frazier, D. Cox-Foster, Y. Chen, R. Underwood, D.R. Tarpy, and J.S. Pettis. Colony collapse disorder: A descriptive study. *PLos One*, 4:e6481, 2009.
- K.P. Weinberg and G. Madel. The influence of the mite *Varroa Jacobsoni* Oud. on the protein concentration and the haemolymph volume of the brood of worker bees and drones of the honey bee *Apis Mellifera* L. *Apidologie*, 16:421–436, 1985.
- X. Yang and D. Cox-Foster. Effects of parasitization by *Varroa destructor* on survivorship and physiological traits of *Apis mellifera* in correlation with viral incidence and microbial challenge. *Parasitology*, 134:405–412, 2007.
- X.L. Yang and D.L. Cox-Foster. Impact of an ectoparasite on the immunity and pathology of an invertebrate: Evidence for host immunosuppression and viral amplification. *P Natl Acad Sci USA*, 102:7470–7475, 2005.