



The impact of honey bee colony quality on crop yield and farmers' profit in apples and pears



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ABSTRACT

Despite global interest in the role of pollinators for food production, their impact on farmers' profit, which determines farmers' livelihood and land-use decisions, is unclear. Although average values of pollinator benefits are generally assumed, there is potential for large spatial variation among crop species and varieties or among pollinator management strategies, even within the same region and year.

We studied how quality of honey bee colonies used for pollination services, which included artificial feeding during winter and pathogen control, affect flower visitation, fruit production, and farmers' profit in the main apple and pear producing region of Argentina (Patagonia).

For apple, high-quality colonies exhibited flower-visitation rates 130% greater than conventional colonies. Indeed, high-quality colonies increased fruit set by 15% (increasing production quantity), seed set and fruit sugar content, and subsequently farmers' profits by 70%. For pear, colony quality only affected fruit weight of the Abate Fetel variety, but not that of the Packham's Triumph variety. Fruits were ~20% heavier in farms deploying high quality colonies but did not contribute to increase farmers' profits to the extent that it did for apple.

In contrast to studies conducted elsewhere, we did not observe any wild pollinators visiting apple or pear flowers, highlighting the fragility of this conventionally intensified crop production system. We found that such orchard systems can suffer large pollinator deficits affecting farmers' profit. Given that *A. mellifera* was the only flower visitor, we could estimate the impact of improving colony management on farmer's profit without the influence of other pollinators. Our study also shows that variations within pome crops, *i.e.* apples and varieties of pears, in pollinator benefits can be very large, and that the assumption of global average values to guide local recommendations can be misleading.

1. Introduction

The ecosystem service of pollination might be threatened by ongoing pollinator decline (Goulson et al., 2015). Wild bee species, central to crop pollination (Garibaldi et al., 2011, 2013), have been declining in many parts of the world (e.g. Potts et al., 2010; Goulson et al., 2015). Although the global stock of domesticated honey bee colonies (*Apis mellifera*) has increased worldwide during recent decades (Aizen and Harder, 2009), demand for animal pollination has increased at a much

higher pace (Aizen et al., 2008; Lautenbach et al., 2012). As a result, these disparate trends could lead to mismatches between demand and supply of pollination services (Breeze et al., 2014; Schulp et al., 2014). The benefits of agricultural intensification on entomophilous crop production might thus cease, or even turn into costs in the long run, because of a trade-off between agricultural intensification and adequate pollination service (Deguines et al., 2014; Garibaldi et al., 2016). Hence, there is an urgent need to develop a more sustainable agriculture by optimizing pollination and agricultural production while

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conserving biodiversity (Garibaldi et al., 2014). As a first step, the effectiveness of current pollination practices needs to be assessed.

Improving pollination through effective management can influence farmers' income through increased yield and yield stability of many food crops (Klein et al., 2007; Garibaldi et al., 2011). In addition to affecting overall yield, adequate pollination can also determine fruit and seed quality, including nutrient content (Eilers et al., 2011; Brittain et al., 2014). However, despite its widespread use as the prime managed pollinator for temperate fruit crops, the contribution of honey bees to fruit production, fruit quality and farmers' profits remain poorly known (e.g. Viana et al., 2014; Garratt et al., 2014; Marini et al., 2015). Understanding the dependence on honey bee pollination for yield and fruit quality is critical to develop managing strategies that enhance pollination and reduce temporal variability in production and farmers' profits (Garratt et al., 2014). However, there is a need to link pollination practices to a farmer's profit in order to assess the far-reaching consequences of pollination services (Garratt et al., 2014; Melathopoulos et al., 2015). So far, most studies have focused on the effect of different pollinator management schemes on yield quantity and quality, whereas only a few have addressed the economic consequences (e.g., Kasina et al., 2009; Zhang et al., 2015). This lack of an economic dimension limits the usefulness of many of these studies to improve practices in different applied contexts (see Garibaldi et al., 2014 for a review).

Pears (*Pyrus communis*) and apples (*Malus domestica*) are economically major crops in Argentina, representing the first and third most exported fruit in 2012, respectively (García-Sartor and Ulgade 2013). Both crops are insect pollinated and self-incompatible (Maccagnani et al., 2003; Ramírez and Davenport, 2013), and cross-pollination between different cultivars is needed to ensure high fruit set (Jackson, 2003). Several wild flower visitors are recognized as efficient pollinators of pears and apples, including bumble bees (*Bombus* spp.) and solitary bees (Maccagnani et al., 2003; Zisovich et al., 2012; Sheffield 2014; Földesi et al., 2016). In addition, several managed pollinator species, mostly *Apis mellifera*, are also routinely used to pollinate apple and pear orchards (Ramírez and Davenport, 2013).

We studied the effect of honey bee colony management, particularly colony preparation and health, on the pollination of apples and pears in Northern Patagonia. We developed an integrative approach to assess the consequences of honey bee colony management for both fruit quantity and quality, and address how the enhancement of these two yield components contribute to farmers' profits. We demonstrate that honey bee colony management is particularly critical in agroecosystems, particularly when alternative pollinators such as wild bees are absent.

2. Methods

2.1. Study sites

We conducted this study in the Alto Valle of Rio Negro and Neuquén, NW Patagonia, Argentina, from October 2014 to February 2015. The region of the Valle accounts for 75 and 85% of Argentinás pear and apple production, respectively. Within this region, we selected an area of 30 km long and 5 km wide (centered at approx. 38°37' S, 68°18' O) of 25-to-43 ha orchards with mixed apple and pear production lying within a river valley surrounded by typical shrubby vegetation of the Patagonian steppe. Orchards were conventionally managed making intensive use of herbicides (glyphosate), fungicides, and insecticides (neonicotinoids and organophosphates). A chemical thinning was applied to apple trees at the end of the fruiting season to cause the abortion of misshapen fruits. This treatment was not applied to pear trees as thinning hormones are naturally produced by pear trees. Orchard management practices (e.g. aspersion-irrigation) were similar among farms.

Within the study area, we selected a total of 37 apple and 51 pear

trees, separated by at least 200 m and distributed across 88 different cultivated plots of similar size (c.a. 1.2 ha) nested within 22 different farms. To choose our focal trees, we focused on the Red Delicious (37 trees) apple variety, and Abate Fetel (25 trees) and Packham's Triumph (26 trees) pear varieties as those varieties were the most representative in this fruit-growing region. Packham's Triumph and Red delicious are self-incompatible and Abate Fetel is partially self-fertile (5–10% autogamy, Nyéki and Soltész, 2003). During the 2014 flowering season, the Abate Fetel variety was in bloom from September 6 to 17, Packham's Triumph from September 10 to 20, and Red Delicious from September 17 to 27. The number of different apple and pear varieties grown in each plot was counted as a proxy of cross-pollination potential.

2.2. Honey bee colony management

2.2.1. Colony characteristics

Orchards in the study area are usually supplemented with honey bee colonies at the onset of the flowering period of fruit trees. Farmers introduce honey bee colonies at a single location within the orchard or distribute one or two colonies per plot. In our study area, the mean prescribed density of colonies was 5 and 7 colonies ha⁻¹ for apple and pear trees, respectively. We introduced this density of high-quality colonies in 10 of the 22 study orchards, and left the farmers to manage pollination using conventional colonies in the other 12 orchards. Unlike conventional colonies, high-quality colonies were prepared following a standardised protocol. First, queens were stimulated to start to lay eggs earlier by feeding colonies with sugar syrup directly after the winter. Second, health of each colony was carefully monitored upon delivery. These colonies were free of American and European foulbroods, and they had a rate of *Varroa destructor* infestation < 5% (based on worker sealed brood) and were treated as necessary to maintain this health status. As a consequence, these colonies had a laying queen with a population of at least 20 000 bees when introduced into the orchards (based on the number of frames covered with bees; Vanengelsdorp et al., 2009).

During the flowering period of apple and pear trees (see above), we surveyed conventional and high-quality colonies once every week (in total 999 colonies were surveyed). At each survey, we counted the number of frames covered with bees as an estimation of colony strength (Vanengelsdorp et al., 2009). The number of frames covered with bees in conventional colonies was, on average, half that in high-quality colonies ($F = 133$; $P < 0.001$, mean \pm sd = 4.6 ± 0.3 vs. 9.7 ± 1.1 for conventional and high-quality colonies, respectively; Fig. 1). These differences were reflected in the price a farmer had to pay for colony rental (5 US\$ for a conventional colony and 20 US\$ for a high-quality colony for the whole pollination season).

2.2.2. Colony density around the focal trees

We counted the number of colonies present in a 200 m radius plot around each focal tree as a proxy for the potential honey bee forager density. This distance was chosen because the activity of *A. mellifera* in cultivated fields declines drastically over a few hundred meters (Cunningham and Le Feuvre 2013; Cunningham et al., 2015). Specifically, a 200-m radius plot will encompass most of the foraging honey bee individuals that will potentially visit a given focal tree. In addition, for each focal tree we measured the linear distance (m) to the closest colony.

2.3. Visitation rates

During the flowering period of each variety, we conducted censuses of bee visitation to each of the 88 focal trees. We conducted a minimum of two and a maximum of five 10-min observation periods for each tree over its flowering period depending on logistics and weather conditions, totalling 259 10-min censuses on the 88 focal trees. At the beginning of each census, we counted the number of open flowers on five

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