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Comparison of Honey Bee (Hymenoptera: Apidae) Colony Units of Different Sizes as Pollinators of Hybrid Seed Canola

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Abstract

We compare two different sizes of honey bee colony units: singles (one brood chamber) and doubles (two brood chambers) in hybrid seed canola pollination in southern Alberta in 2014 and 2015. Currently, canola seed production companies only contract double-brood chamber units to pollinate canola in southern Alberta, but it may be advantageous to the industry if singles could also be contracted for pollination, as they are in many other crops. To evaluate the differences between the colony units, we measured population size, nectar and pollen foraging, nectar and pollen load weights, pollen collection, and honey production. The colony populations of both the single- and double-brood chamber hives in this study were highly variable. In 2015, there was no difference between the single- and the double-brood chamber colonies in adult bee populations, and the singles had more sealed brood than did the double-brood chamber colonies. Our findings indicate that in comparison to doubles, on a per-frame basis, singles yield more pollen, more nectar foragers, similar or more pollen foragers, and similar amounts of honey. Therefore, we conclude that singles could be used to provide the same level of pollination services as doubles currently do in hybrid seed canola pollination, and growers should focus on receiving healthy populous colonies, regardless of the number of brood boxes.

Key words: canola, pollination, colony size, pollination management, honey bee management

In Canada, between 53,000 and 72,000 honey bee (*Apis mellifera* L.) (Hymenoptera: Apidae) colonies are contracted annually from beekeepers by canola seed production companies to pollinate hybrid seed canola in southern Alberta. Honey bee colonies are stocked on hybrid seed canola fields to transfer pollen from male-fertile (pollen-donor parent, “male”) rows to male-sterile (pollen-less “female”) rows. These female rows (or commonly bays of rows) are harvested at maturity to obtain hybrid canola seed, which is then sold and subsequently planted on millions of acres across the Canadian Prairies and elsewhere that canola is grown. This pollination event is integral to Canadian agriculture as the canola grown from this seed contributes \$26.7 billion CDN yearly to the Canadian economy and sales of canola comprise one-quarter of all farm cash receipts (Canola Council of Canada 2017).

Hybrid canola seed is produced by seed production companies, which contract farmers to grow the hybrid canola crop, and beekeepers and leaf-cutting bee producers to provide honey bee colonies and alfalfa leaf-cutting (*Megachile rotundata* F.) (Hymenoptera: Megachilidae) bees, respectively, to pollinate the crop when it is in bloom. A subset of the honey bee colonies in pollination are

inspected by the canola seed production companies, and the beekeepers are paid on a linear grading scale for number of frames in the colonies they deliver, from a minimum of 10 frames of bees to a maximum payment for 17 (Clay 2009). The stocking rate varies among seed canola production companies, but is usually between 1 and 1.5 honey bee colonies per acre. Hybrid canola seed fields in southern Alberta typically begin blooming in late June and finish at the end of July or early August. Colonies are delivered by beekeepers throughout Alberta and a few from the neighboring provinces of British Columbia and Saskatchewan. Canola is considered a good crop for honey bees as the floral resources include abundant high-quality pollen and nectar (Somerville 2002, Nedić et al. 2013). Colonies used to pollinate this crop typically increase in size over the month-long bloom, as well as producing excess honey, which is extracted by the beekeepers and subsequently sold.

Many crops requiring honey bee pollination have size standards or guidelines that only dictate the number of frames covered with bees, as opposed to the equipment used to contain the comb, brood, and bees. In Canada, generalized contracts in British Columbia (Government of British Columbia 2017) and Quebec (Canadian

Honey Council 2017) recommend minimum 8 and 10 frames of bees alongside brood and a laying queen, without mention of the number of boxes these frames must be in. Typically, additional fees are paid for strength above eight frames, up to a pre-determined maximum. Single-brood chamber colonies are often used to pollinate in Oregon and Washington State where the agricultural departments do not specify the type of colony used to pollinate field and orchard crops, simply that it should meet a minimum standard of 6–10 standard deep frames covered with bees, depending on grade. The minimum number of bees to meet this requirement was calculated by Sagili et al. 2011 to be 10,500 for orchard and 18,000 for field colonies to meet the lower Grade B standards and 14,000 for orchard use and 24,000 for field use for higher Grade A standard in Oregon, and 14,400 bees in Washington. Similarly, single-brood chamber colonies are often used in the largest global pollination market—the pollination of the almond crop in California in February. In this market, an average of eight frames of bees is common, with a six-frame minimum standard (Curtis et al. 2014). A lower rate per colony is paid under eight frames and a bonus above eight frames (Goodrich and Goodhue 2016).

Currently, honeybee colonies rented for hybrid seed canola pollination are normally required by the seed production companies to have two brood chambers, each typically filled with nine frames of comb suitable for brood-rearing (called “doubles”), with most colonies also having at least one honey super at all times. In doubles, the queen may lay eggs in either brood chamber at any time of year, whereas in singles the queen is restricted to one brood chamber. When honey supers are on top of the brood chamber, this is accomplished through the use of a queen excluder. Queen excluders are placed between boxes of comb and physically prevent the queen from entering other boxes of comb while still allowing workers to pass through. Doubles and singles may both have as many extra boxes (honey supers) as are required by the honey flow to provide space for bees and nectar collection; the terms refer only to the number of brood chambers used.

Pedersen et al. (1995) recommend singles as a management option for beekeepers because they have lower comb investment, the bees are more likely to put the honey up in the honey supers rather than storing a portion of it in the brood chambers, and the smaller number of brood combs facilitates cleaning, disease inspection and treatment, and finding of the queen. It has been shown that treatments for parasites such as *Varroa destructor* Anderson and Trueman (Parasitiformes: Mesostigmata) (e.g., oxalic or formic acids) can be more effective and less expensive (e.g., Apivar) in singles (Stanghellini and Raybold 2004, Skinner and Tam 2005). Beekeepers in Alberta are increasingly managing colonies such that they have only one brood chamber year-round (“singles”), estimated to be 0–15% of the total number of colonies overwintered by Alberta beekeepers, depending on region (Alberta Agriculture and Forestry, unpublished data).

If singles could also be contracted to pollinate hybrid seed canola, beekeepers with pollination contracts would have more management options, and additional beekeepers who manage singles only could accept pollination contracts. Importantly, given the high overwintering colony losses, which can occur some years in Canada (Currie et al. 2010), the inclusion of singles would decrease the risk to the hybrid seed canola industry by ensuring colony availability during years of higher losses. The introduction of new pest species can result in quarantines, which restrict the movement of bees, which can also limit hive availability for pollination markets. This occurred in Alberta in 2017 with the introduction of the Small Hive Beetle (*Aethina tumida*, Murray) (Coleoptera: Nitidulidae); a quarantine

zone was established in the Peace River Region of Alberta, and colonies from this zone were not permitted to move to southern Alberta for pollination (Nasr 2017). In addition, there may be logistical advantages to using single-brood chamber colonies, as more colonies can be included in a single load during the short temporal window for delivery to fields.

To determine the suitability of single-brood chamber colonies for the pollination of hybrid seed canola, and to provide information to companies and beekeepers to determine remuneration and stocking rates, we evaluated several indicators of foraging: population size, nectar and pollen foraging, nectar and pollen load weights, pollen collection, and honey production of singles and doubles in 2014 and 2015.

Experimental Methods

Colonies

In 2014, 160 commercial honey bee colonies were transported overnight 950 km from northern Alberta on 4 July at approximately 10% flowering and placed immediately adjacent to a field of hybrid seed canola near Taber, Alberta (49.706510, –111.957527), as part of a pollination contract. Two types of colonies were prepared and transported to the field (1) single-brood chamber colonies, which included one brood chamber, a queen excluder, and three honey supers ($n = 40$) and (2) double-brood chamber colonies with two brood chambers and two honey supers, and no queen excluder between the second brood chamber and the honey supers ($n = 120$). Experimental colonies were selected based on evenness of population within the two experimental hive types and the presence of a laying queen. The number of honey supers was not related to colony demand at this time; it was required to create an even load for transport. All boxes of comb (brood chambers and honey supers, were “Langstroth deep hive bodies,” approximately 24 cm deep $\times$ 47 cm long $\times$ 37 cm wide, 42.75 liters), with nine frames per box. A total of 31 singles and 28 doubles were checked to confirm the presence of laying queens and used in the trial. In 2015, 40 single- and 88 double-brood chamber colonies were moved a similar distance in the early morning of 2 July and placed adjacent to a field of hybrid seed canola south of Burdett, Alberta (49.7283399, –111.560861), which was approximately 50 km east of the 2014 experimental site. A total of 30 singles and 30 doubles were included in the experiment in 2015 based on evenness of population and the presence of laying queens.

Population Assessments

To compare the colony population sizes, we assessed the adult bee and sealed brood populations of both the singles and the doubles in both 2014 and 2015. In 2014, the area of adult bees and sealed brood of each colony was visually assessed during the early morning hours of 7–9 July prior to the commencement of bee flight. A grid divided into 2.54 cm² squares was placed over each side of each frame in the colony, and the area covered with adult bees and sealed brood was visually assessed and recorded. In 2015, the colonies were assessed 6–7 July using a photographic method whereby a high-resolution image is taken of each frame of bees and brood and later analyzed on a computer. All images of adult bees were taken in the early morning, before bee flight. Images of brood were taken later in the day after the adult bees had been brushed off the frames. The sealed brood photos were analyzed with the software HoneyBeeComplete 5.4 (WSC Scientific, Heidelberg, Germany) to determine the number of sealed brood cells per frame side. The total number of sealed brood cells for each side of each frame containing worker brood was summed to determine the total sealed brood population per colony.

To determine the population of adult bees, we developed a method based on Nelson and Jay (1972), where the adult bee photos were viewed on a computer, and compared to a wall of photos, with one example photo every 50 bees from 50 to 1100 (the “Photo Ladder”). An observer then estimated which category the photo fell into. A 10% subset of photos were later manually counted to validate the method, which was 94–95% correlated with the actual number and within 50 bees of the actual count 75–80% of the time.

To allow for comparisons between years, adult bee area and sealed brood area data from 2014 were transformed to number of bees and number of brood cells. A subset of brood photos and bee photos from 2015 were visually assessed once each by two observers using the 2014 grid method, which was plotted against the actual number of bees or brood in the photo to generate a linear regression of the relationship (see [Supp Table 1 \[online only\]](#)). The equation of the trend line at two points was then used to transform the data; the transformed data allowed for comparisons between years and was highly correlated ($R^2 = 0.987$) with the original data.

Pollen Trapping

To compare the pollen foraging effort of two colony sizes, we used pollen traps to collect pollen from each colony. Front mounting “porch style” pollen traps (Propolis-etc., Quebec) were mounted on the front entrance of all the colonies and used to obtain pollen from colonies throughout the canola bloom. All other entrances or cracks whereby bees could bypass the pollen traps were sealed. Pollen traps remained on the colonies for 48–72 h, after which the pollen sample was collected in re-sealable plastic bags and frozen at -20°C .

In 2014 colonies were trapped 8–10, 21–23, and 23–25 July, and the pollen was later dried in a food dehydrator (Nesco, Milwaukee, WI) for at least 8 h, cleaned of any debris, and weighed. In 2015 colonies were trapped from 7–10, 10–13, 20–22, and 22–24 July, and the pollen was dried in the lab in re-sealable plastic bags, which also contained organza pouches of orange indicating silica beads. Orange indicating silica beads turn green when saturated with moisture, so the pouches of orange indicating silica beads were replaced until the beads no longer turned green. The measurements of pollen collection on the different dates (three in 2014, four in 2015) were averaged per colony and expressed as average weight of pollen collected per day. Equal numbers of singles and doubles were trapped at each date.

Forager Observations

To compare the foraging force of each colony unit, we assessed the number of foragers returning to the singles and doubles during foraging hours when the crop was mid-bloom. Observers sat close to the colony without obstructing the flight path of returning foragers, and counted the number of foragers returning with pollen (pollen foragers) and without pollen (assumed to be nectar foragers) for 3 or 5 min through the aid of tally counters (Barker and Jay 1974). All observations were conducted on sunny days with little wind, between 10:00 and 15:00. In 2014, returning foragers were observed on 16–17, 19, 21, 23, and 28 July for 5 min (twice for each colony). In 2015, returning foragers were observed on 10, 13, 20, 22, and 24 July for 3 min (1–3 times for each colony). Data were expressed as average foragers per 10 min.

Forager Load Weights

To compare the foraging efforts of singles and doubles, we weighed the pollen and nectar load weights of foragers returning to the colonies. Returning foragers were randomly chosen and individually

sampled (10 without pollen and 10 with pollen visible on their corbiculae) from each colony during the flight hours of 10:00 a.m. to 2:00 p.m., and placed into 1.5 ml microcentrifuge tubes and subsequently frozen. The tubes were later thawed for 4 h in the laboratory prior to weighing of nectar and pollen loads. To weigh nectar loads, each bee was slowly squeezed from the tip of the abdomen toward the thorax, so that any nectar would be extruded. For pollen loads, one pollen pellet was weighed per forager. Foragers were caught on 16, 17, and 21 July in 2014 and 20, 22, and 24 July in 2015.

Honey Production

In 2014, all honey supers were marked and weighed 1 d after being moved from the canola production field. The average weight of one honey super filled with empty comb was subtracted from the net weight of each honey super, summed for each colony, and expressed as honey production (kg). Unfortunately, in 2015 the participating beekeeper was unable to weigh the honey, so no data were available.

Statistical Analysis

To evaluate the foraging of colonies relative to the size of the colony, and to reflect that beekeepers are paid for the number of frames of bees in the colony, several metrics (average weight of pollen collected, number of nectar foragers per 10 min, number of pollen foragers per 10 min, and honey production) were transformed to a per-frame basis. A frame was considered to be 1600 bees (two sides of 800 bees per frame side). Thus, the average output of a frame in a single or double colony could be compared and related back to the per-frame rental fee.

As the size of singles relative to the doubles was inconsistent between the two years studied, analyses with year as a factor resulted in many significant interactions; so each year was analyzed independently. The number of adult bees, number of brood cells, average weight of pollen collected, number of nectar foragers per 10 min, number of pollen foragers per 10 min, forager nectar load weight, and forager pollen load weight were compared between the singles and doubles at the colony level and frame level using Welch's unequal variances *t*-tests followed by Student's *t* means separation. All statistical analyses were performed using JMP Version 13 (SAS Institute, Cary, NC).

Results

In 2014 the singles had significantly smaller adult bee and sealed brood populations than the doubles, with roughly half the adult population, as would be predicted based on the number of brood chambers (Table 1; adult bee: singles 9403 ± 418 bees; doubles $21,102 \pm 948$ bees; sealed brood: singles 9380 ± 495 cells; doubles $16,140 \pm 598$ cells; Fig. 1A and B). However, in 2015, the population of adult bees was similar in both colony size units, and the brood area was larger in the single-brood chamber colonies than the double-brood chamber colonies (Table 1; adult bees: singles $14,853 \pm 640$ bees; doubles $15,899 \pm 894$ bees; sealed brood: singles $13,595 \pm 340$ cells; doubles $11,937 \pm 595$ cells; Fig. 1A and B).

While the singles and doubles collected similar total amounts of pollen per colony in 2014 (Table 1; singles 11.84 ± 1.90 g; doubles 9.66 ± 1.64 g; Fig. 2A), when the singles were less populous, the singles collected greater amounts of pollen per colony than did the doubles in 2015, when they had similar adult populations (singles 23.05 ± 2.49 g; doubles 10.99 ± 2.09 g; Table 1; Fig. 2A). This difference was highly significant at the frame level, where the singles collected more pollen per day per frame of bees than did the doubles

in both years (singles: 2.14 ± 0.38 g [2014], 2.57 ± 0.30 g [2015]; doubles 0.79 ± 0.12 g [2014], 1.18 ± 0.24 g [2015]; Table 2; Fig. 2B).

In 2014, more pollen and nectar foragers were observed per colony in the doubles than the singles (doubles: pollen 107 ± 8 foragers

Table 1. Results of *t*-tests performed comparing the singles and doubles per colony in 2014 and 2015

Year	<i>T</i>	<i>df</i>	<i>P</i>
Number of adult bees			
2014	-11.304	35.902	<0.0001
2015	-0.952	52.533	0.3455
Number of brood cells			
2014	-8.704	52.468	<0.0001
2015	2.421	46.121	0.0195
Average weight of pollen collected per day			
2014	0.866	49.977	0.3905
2015	3.921	50.820	0.0003
Pollen foragers per 10 min			
2014	-2.175	50.761	0.0343
2015	-1.446	54.431	0.1539
Nectar foragers per 10 min			
2014	-5.621	53.031	<0.0001
2015	4.852	55.225	<0.0001
Pollen load weight			
2014	-1.386	169.820	0.1675
2015	1.894	185.414	0.0598
Nectar load weight			
2014	-1.311	348.523	0.1907
2015	-0.998	219.930	0.3193
Honey production			
2014	-6.729	48.871	<0.0001

P values in bold indicate significant differences at the $\alpha = 0.05$ level.

per 10 min; nectar 821 ± 35 foragers per 10 min; singles: pollen 84 ± 6 foragers per 10 min; nectar 563 ± 30 foragers per 10 min; Table 1; Fig. 3A); however per frame of bees, significantly more pollen and nectar foragers were observed in the singles (pollen: singles 15 ± 1 foragers per 10 min; doubles 9 ± 1 foragers per 10 min; nectar: singles 102 ± 8 foragers per 10 min; doubles 66 ± 4 foragers per 10 min; Table 2; Fig. 3B). In 2015, in contrast, there was no significant difference in the number of pollen foragers observed per colony or per frame (per colony: singles 166 ± 11 ; doubles 191 ± 13 ; Table 1; Fig. 3A; per frame: singles 19 ± 2 ; doubles 22 ± 2 ; Table 2; Fig. 3B). The number of nectar foragers in 2015 was significantly greater in the singles than the doubles both per colony and per frame (per colony: singles 565 ± 25 ; doubles 400 ± 23 ; Table 1; Fig. 3A; per frame: singles 63 ± 3 ; doubles 45 ± 4 ; Table 2; Fig. 3B).

The pollen load weights of foragers did not vary significantly between the singles and doubles in either year (2014 singles 12.30 ± 0.81 mg; doubles 13.87 ± 0.78 mg; 2015: singles 14.25 ± 0.76 mg; doubles 12.20 ± 0.80 mg; Table 1). Similarly, the nectar load weights did not vary significantly in either year (2014: singles 22.11 ± 1.28 mg; doubles 24.49 ± 1.29 mg; 2015: singles 14.52 ± 1.19 mg; doubles 16.21 ± 1.19 mg; Table 1).

In 2014, the honey production per colony in the doubles was about twice that of the singles (singles 22.28 ± 2.88 kg; doubles 45.04 ± 1.77 kg; Table 1); however, there was no difference between the singles and doubles in the honey produced per frame of bees (singles 3.69 ± 0.50 kg; doubles 3.50 ± 0.13 kg; Table 2).

Discussion

The adult bee populations of the colonies in this study were highly variable within both the single- and double-brood chamber colonies and across both years of the study. This variability indicates that the

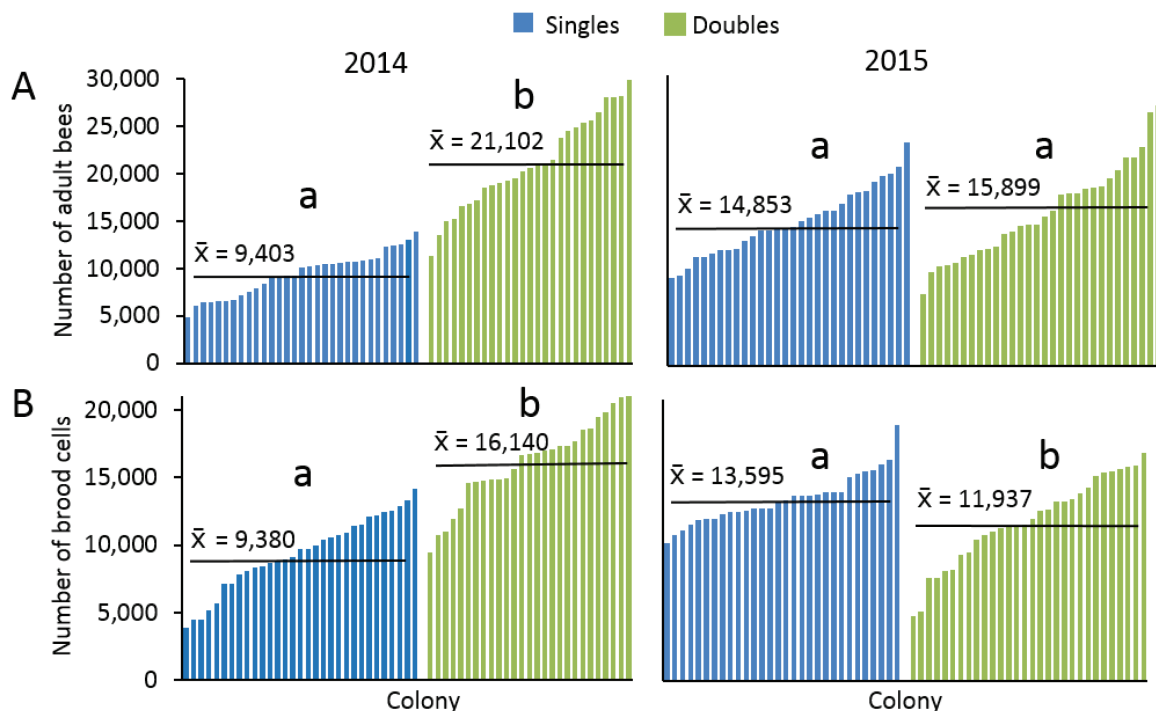


Fig. 1. (A) Number of adult bees and (B) number of sealed brood cells in the single-brood chamber (blue) and double-brood chamber (green) colonies in 2014 (left) and 2015 (right). Each bar represents an individual colony (sorted from smallest to largest), and the horizontal lines represent the mean of each group. Different letters above the groupings indicate significant differences within each year ($P < 0.05$).

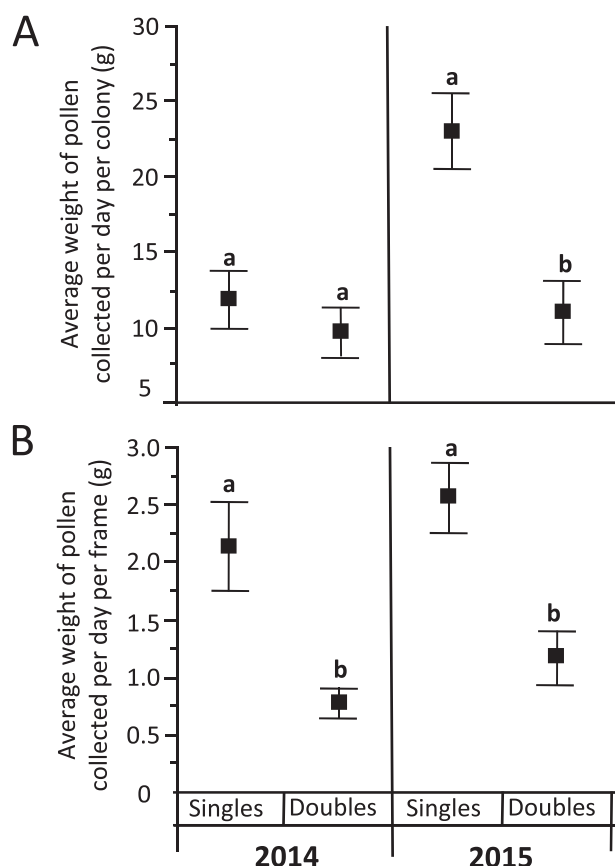


Fig. 2. Mean weight of pollen collected per day (24 h) ± SE at (A) the colony level and at the (B) frame level in the singles and doubles in 2014 (left) and 2015 (right). Different letters above the groupings indicate significant differences within each year ($P < 0.05$).

Table 2. Results of *t*-tests performed comparing the singles and doubles per frame of bees in each colony in 2014 and 2015

Year	<i>T</i>	<i>df</i>	<i>P</i>
Average weight of pollen collected per day			
2014	3.355	33.586	0.0020
2015	3.787	50.114	0.0004
Pollen foragers per 10 min			
2014	3.710	54.045	0.0005
2015	-0.955	52.702	0.3438
Nectar foragers per 10 min per frame			
2014	4.132	44.519	0.0002
2015	3.751	55.992	0.0004
Honey production			
2014	0.381	34.260	0.7053

P values in bold indicate significant differences at the $\alpha = 0.05$ level.

number of brood boxes is not a reliable indicator of colony strength or utility as a pollination unit. As these colonies were managed by a commercial beekeeper for canola pollination, the colony population within the hive equipment was dependent on the management by the beekeeper, which was reflected in the differences we observed between years. In 2015, the adult populations of the single- and double-brood chamber colonies were similar, clearly demonstrating that single-brood chamber colonies can be as large as pollination-grade doubles.

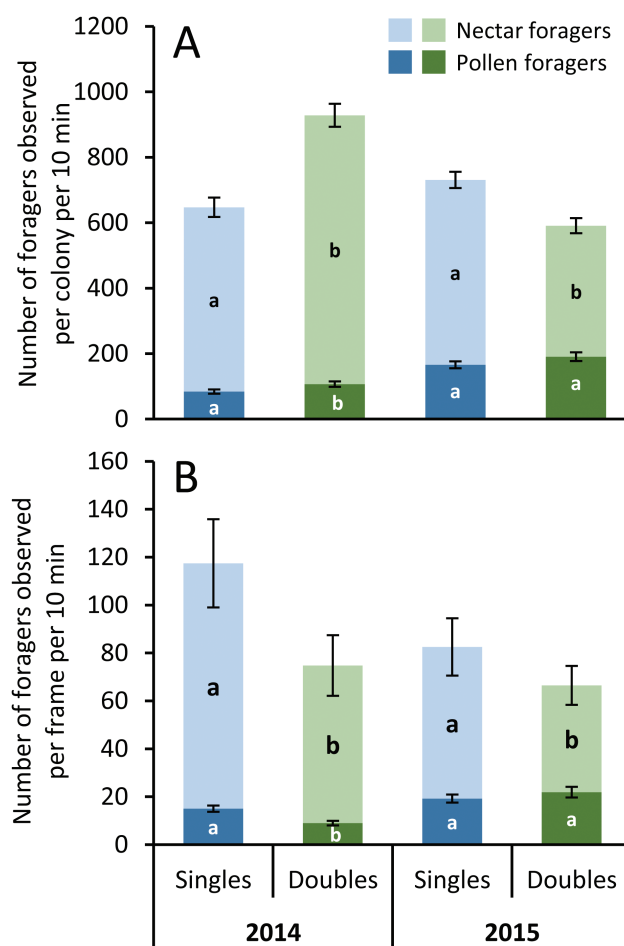


Fig. 3. Mean total number of foragers observed in 10 min, showing the number of nectar (light portion of each bar) and pollen foragers (dark portion) (A) per colony and (B) per frame of bees in single (blue) and double (green) brood chamber colonies, in 2014 (left) and 2015 (right). Different letters indicate significant differences between colony sizes within the year for each of nectar and pollen forager counts ($P < 0.05$).

In contrast to honey, which is largely stored in the honey comb in the supers above the brood chamber(s), pollen is normally only stored in the brood chamber where it can be used to rear brood. Therefore, constraining the area for brood-rearing would also limit the comb area available for pollen storage in singles. Honey bee colonies regulate pollen foraging closely according to need, and can respond quickly to changes in the demand for pollen for brood-rearing (Free 1967, Hellmich and Rothenbuhler 1986) or changes in the amount of pollen stored in the hive (Fewell and Winston 1992). The limited storage for pollen in singles may explain the elevated pollen collection evident in the singles compared with the doubles in this study, and could potentially enhance pollination services of some crops by increasing the amount of pollen foraging. Bees collecting pollen are often more effective pollinators than bees foraging only for nectar (Bosch and Blas 1994, Javorek et al. 2002, Monzón et al. 2004). However, in hybrid seed canola it is unclear whether nectar or pollen foragers contribute more to pollination (see discussion in Hoover and Ovinge 2018). Nectar foragers may transfer less pollen per visit, but are more numerous, and more likely to switch between male and female flowers (Waytes 2017). Pollen foragers, in contrast would likely transfer more pollen, but are fewer in number, and more likely to

be constant to male flowers (which have pollen, whereas female flowers do not) (Waytes 2017).

Studies directly contrasting colonies of different sizes in pollination or honey production are rare, and somewhat contradictory. Some literature exists on their performance overwintering; however, results are not consistent and depend on environmental and other management factors (Punnett 1986, Desai and Currie 2016). Results on foraging behavior are similarly variable. Similar to the results of our per-frame analysis, Beekman et al. 2004 found that that proportionally, smaller colonies collect more pollen and forage at more patches than larger colonies. Smaller colonies have also been found to bring back larger nectar loads and larger total amounts of sugar than larger colonies (Fewell et al. 1991). Barker and Jay (1974) found no difference between double- and single-brood chamber colonies in total foragers, pollen foragers, or pollen collection. In contrast, Farrar (1937) found that increasing colony size (incrementally from 15,000 to 60,000 adult workers) increased the proportional honey production of the colony, and Eckert et al. (1994) found that foragers from large colonies took longer foraging trips and collected larger nectar loads, and concluded that nectar foragers from larger colonies worked harder.

Waller et al. (1985) studied onion pollination using three colony sizes that were manipulated to include corresponding bee populations: 1) one brood chamber with a set amount of bees, 2) two brood chambers with double that amount of bees, and 3) three brood chambers with triple the amount of bees. Weight gain (a correlate of honey production), returning foragers, and bees exiting the hive per min were all correlated linearly with colony bee population, suggesting that remuneration at a flat rate per frame is appropriate. Gary et al. (1978) found that foragers returning from the crop were also linearly correlated with colony bee population. Together, these studies and our results demonstrate that the total size of the foraging force is the critical determinant of the value of a pollinating unit, and that total “frames of bees” is a good criteria to use to determine both stocking rates and remuneration.

A common stocking rate used for pollination of hybrid seed canola in southern Alberta is 160 double-brood chamber colonies per irrigated quarter-section, which translates to about 48.6 ha of actual crop within a circle pivot system. With canola seed production companies paying for 10–17 frames (Clay 2009), it can be inferred that the accepted stocking rate in frames of bees ranges from 33 to 56 frames per hectare, with most fields likely at the upper end of that range. As long as the number of frames of bees provided reaches that accepted stocking rate, both single- and double-brood chamber colonies could be effective management options. In addition, colonies could be moved into hybrid seed canola fields more quickly if singles were permitted. A standard tandem-axle truck used in Alberta can carry 160 double colonies (two brood chambers and one honey super). If that same truck were to be loaded with single colonies (one brood chamber and one honey super), it would hold 240 colonies. Given the time constraints in stocking the pollination fields at the appropriate time, the ability to move more colonies per night is of potential advantage to both beekeepers and canola seed production companies.

The management decisions beekeepers make directly affect the health and quality of their colonies, and therefore the yield and profit realized by growers of bee-pollinated crops. Geslin et al. (2017) demonstrated the importance of using populous, healthy bee colonies in apple pollination, where their use increased visitation rates to apple flowers, fruit set, fruit quality, subsequently increasing farmers' profits by 70% over standard colonies that were less healthy and had smaller populations. As some beekeeping operations manage some single-brood chamber colonies, or exclusively single-brood chamber

colonies, we suggest that pollination contracts should allow for flexibility in management to enable beekeepers to maximize colony health and population according to the environment and annual variations in weather.

Conclusions

This study is one of few that directly contrasts single- and double-brood chamber colonies as management options for honey bees. We show that per frame, singles produce more pollen, have a similar foraging force, and produce similar amounts of honey per frame of bees. As both single- and double-brood chamber colonies can vary in size, we suggest that instead of detailing the equipment used to contain the bees, contracts should focus on the provision of healthy colonies with a laying queen and all stages of brood, and a remuneration fee related to the number of frames covered by bees. Both single- and double-brood chamber units are appropriate for use to pollinate hybrid seed canola, given an effective stocking rate.

Supplementary Data

Supplementary data are available at *Journal of Economic Entomology* online.

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