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Research

Honey Bee Queen Production: Canadian Costing Case Study and Profitability Analysis

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Abstract

The decline in managed honey bee (Hymenoptera: Apidae) colony health worldwide has had a significant impact on the beekeeping industry. To mitigate colony losses, beekeepers in Canada and around the world introduce queens into replacement colonies; however, Canada's short queen rearing season has historically limited the production of early season queens. As a result, Canadian beekeepers rely on the importation of foreign bees, particularly queens from warmer climates. Importing a large proportion of (often mal-adapted) queens each year creates a dependency on foreign bee sources, putting beekeeping, and pollination sectors at risk in the event of border closures, transportation issues, and other restrictions as is currently happening due to the 2020 Covid-19 pandemic. Although traditional Canadian queen production is unable to fully meet early season demand, increasing domestic queen production to meet mid- and later season demand would reduce Canada's dependency. As well, on-going studies exploring the potential for overwintering queens in Canada may offer a strategy to have early season domestic queens available. Increasing the local supply of queens could provide Canadian beekeepers, farmers, and consumers with a greater level of agricultural stability and food security. Our study is the first rigorous analysis of the economic feasibility of queen production. We present the costs of queen production for three Canadian operations over two years. Our results show that it can be profitable for a beekeeping operation in Canada to produce queen cells and mated queens and could be one viable strategy to increase the sustainability of the beekeeping industry.

Key words: Honey bees, economics, queen breeding, honey bee importation, Covid-19

In Canada, managed honey bee colonies (*Apis mellifera* L.) contribute to the pollination of many crops including tree fruits, berries, cucurbits, and oilseeds, especially production of hybrid canola seed. In 2016, honey bee contribution to Canadian food crops was estimated at $4–$5.5 billion (Mukezangango and Page 2017). Canadian beekeepers managed 803,352 colonies over the 2018–2019 season (CAPA 2019), an increase of over 16,000 colonies from the previous year; however, beekeeper revenues have been decreasing due to falling honey prices (Phipps 2017) and increased colony mortality (CAPA 2019).

Canadian honey bee colony winter mortality has been significant throughout the past decade (CAPA 2019). Losses of Canadian honey bee colonies over the recent 2018–2019 winter season was 25.7%, ranging by province from 19 to 54% (CAPA 2019). The 2018–2019 colony mortality follows the previous year's losses which reached 32%, the second highest mortality on record since 2008 (CAPA 2019) and more than double the 15% yearly loss that is considered sustainable by apiculturists (Furgala and McCutcheon 1992, vanEngelsdorp et al. 2007). Causes of colony mortality are multifaceted in Canada and world-wide (Currie et al. 2010, Potts et al. 2010, vanEngelsdorp et al. 2013) with the predominant factors being *Varroa destructor* (Le Conte et al. 2010, Guzman-Novoa et al. 2010) and queen issues (CAPA 2010, Bixby et al. 2019, Brown and Robertson 2019) such as queen health and queen age (Genersch et al. 2010, Spleen et al. 2013, vanEnglesdorp 2013, Liu, et al. 2016). Despite significant colony losses, beekeepers are able to mitigate high colony mortality by splitting their colonies each spring and installing new queens.

There are an estimated 250–500 beekeepers (less than 5% of all Canadian beekeepers) in Canada who produce queens to supply their own operations and/or sell to other Canadian beekeepers (Bixby et al. 2019). Provincial survey data from 2017 to 2018 suggests that approximately 100,000 queens were produced in Canada (BCBPS 2016, QIS 2018), a fraction of what is required to support the national population of over 800,000 Canadian colonies (CAPA 2019). As a conservative estimate, one half of colonies need to replace their queens each season (Amiri et al. 2017), meaning that Canada's queen producers would need to produce at minimum 400,000 queens each season to maintain the current number of colonies, an outcome that historically has been a challenge due to Canada's restricted queen rearing season. Canadian beekeepers are legally allowed to import queen bees from warmer honey bee-producing climates such as Hawaii, California, New Zealand, and Australia (BCMA 2015). Large numbers of queens are imported in the spring from California where breeding can be done much earlier than northern climates. Queens are also imported from regions with contra-seasonal weather such as New Zealand and Australia as well as from aseasonal climates such as Hawaii where queens are reared year-round. In 2018, Canadian beekeepers imported 262,118 queens from warmer climates (Mukezangango and Page 2017) to establish new colonies or to re-queen existing units.

Queen importation, however, is a double-edged sword, simultaneously supplying essential resources for our beekeeping and pollination sectors while risking the introduction of new and potentially resistant pests and diseases, undesirable genetics including bees with limited adaptations to Canada's unique climate and conditions and/or bees negatively affected by transportation (CFIA 2013). During transportation, queens can be exposed to temperature extremes that may affect their stored sperm, which, in turn, can reduce laying success and ultimately impact colony productivity (Pettis et al. 2016, McAfee et al. 2020). Canada's dependency on foreign queen sources also imposes another potential risk on our beekeeping and other agricultural sectors as prohibitions to importation could result in Canadian beekeepers facing the sudden loss of a quarter of a million queens that the industry is currently unprepared to supply domestically. This is a scenario that Canadian beekeepers are currently struggling with during the Covid-19 crisis where many of the package and queen shipments from the United States are either not being filled or being delayed with significant cost increases due to restricted air and ground transportation or being delayed with significant cost increases. Accompanying the risks of importation and the increasing awareness of these risks within the Canadian beekeeping community, has been an unprecedented rise in the prices of imported queen bees from $7.50 in 1988 to $32.50 in 2017 (2017), an increase of 333%. Adjusting for inflation, real prices rose from just over $12 per imported queen in 1988 to over $32 per imported queen in 2017 (BOC 2019).

Queen bees are responsible for all of the reproductive duties within a colony and as a result play a critically important role within the complex division of labor inside a honey bee hive. The queen mates with between 8 and 25 drones (males), with an average of ~14 drones, over several mating flights (Simone-Finstrom and Tarpy 2018). These mating flights occur very early in her adult life and she stores sperm in her spermatheca for the remainder of her life. To maintain the required worker population, a queen will lay up to 1,500 fertilized eggs/d (Winston 1987, Moore et al. 2019), and the resulting female worker bees in the colony are tasked with all nonreproductive colony duties, including caring for the queen, nursing brood, cleaning, and foraging for food. As a result of this matriarchal familial system, the quality of the queen has a direct impact on the colony's health, productivity, and ultimately survival (Nelson and Smirl 1977; Tarpy et al. 2000, 2012; Rangel et al. 2013; Simeunovic et al. 2014, Amiri et al. 2017; Eccles et al. 2017, Guarna et al. 2017). Rearing a queen can involve a rigorous selection process to ensure the new queen carries desirable attributes. This type of selective queen breeding is a specialized skill performed by a small subset of beekeepers. These breeders select for a set of criteria such as honey production, varroa resistance, wintering performance, hygienic behavior, and/or temperament.

Once the queen and drone mother colonies are selected, a process that can be done by the queen producer or within a separate breeding program, the queen producer uses a queenless cell starter colony to rear the queen cells. One-day-old larvae from the selected mother colony are grafted into queen cups and placed into the cell starter colony for the nurse bees to rear. After 24–48 h, the queen cells are moved into a finishing colony where they will be reared for eight days until they are ready to be sold as queen cells or introduced into small, queenless colonies (mating nuclei) to be mated. These steps of queen production result in daughter queens that can be used in the originating operation or sold to other beekeepers (Laidlaw and Page 1997). Alternatively, a colony can contribute to the production of mated queens by acting as a drone source colony for mating with virgin queens.

In this paper, we present the first comprehensive Canadian queen production costing case study. The objective of this study was to evaluate the costs that an experienced beekeeper would incur to rear queen cells and mated queens using the operations' existing colonies and bees (costs for acquiring queen specific equipment such as cages and cell cups are included in queen rearing materials). We tracked three domestic beekeeping operations over two years, and explored the profitability of queen production given current prices and various levels of queen production experience as well as variable queen grafting and mating success rates. This study provides the economic foundation necessary to support the expansion of Canada's queen production sector in providing a sustainable source of queens for our beekeeping and agricultural industries.

Materials and Methods

We chose three queen breeding operations in Canada each led by an apicultural researcher with a range of queen production experience. The first operation, OP1, was located near Moncton, New Brunswick in Atlantic Canada where historically there has not been a large honey bee queen production industry. OP1 produces several hundred splits each summer with a focus to pioneer rigorous breeding research in eastern Canada using a relatively large number of colonies. The operation was led by apicultural researchers with in-depth beekeeping knowledge but limited queen breeding experience. OP2 was located in Lethbridge, in southern Alberta, in close proximity to many commercial beekeepers, and where honey bee colonies are frequently used for canola pollination. OP2 collaborated with two commercial beekeepers with large operations but virtually no queen breeding experience. OP2 was led by a researcher with many years of beekeeping experience, including experience with queen rearing and selective breeding. While OP2 had diverse queen production experience, the beekeepers leading OP2 had collectively less experience than OP3 in large-scale queen production. OP3 was located in Beaverlodge, Alberta, on the campus of Beaverlodge Research Farm (BRF), Agriculture and Agri-Food Canada, a federal government research facility. The BRF is located in the Peace Region, the center of Alberta's prolific honey producing area where honey per colony is typically well above the nation's average of 55 kg (Emunu 2017, Mukezangango and Page 2017). OP3 was led by an experienced queen breeder.

Table 1 lists relevant attributes of the three breeding operations including location, bee forage, cell and queen numbers, as well as grafting and mating success rates. Grafting success is calculated by the number of successful queen cells in which larvae were successfully reared compared with the number of cups into which larvae were grafted. Mating success refers to the number of emerged virgin queens that are mated (as determined by the queen producer who observes egg laying in the mating colony) compared with the number of virgin queen cells that were introduced into mating colonies or nuclei. Through the springs and summers of 2018 and 2019, the three breeding operations tracked all inputs into both queen cell and mated queen production including bee feed, materials, and labor. Due to the sequential and additive nature of queen cell into mated queen production, inputs into grafting and rearing cells are also included as inputs into mated queens. Thus, mated queen costs are a function of queen cell costs, in addition to costs specific to rearing and mating queens postcell stage.

Selection methods to choose queen genetics for grafting vary widely between breeders and can be carried out within a specialized breeding program after which the genetics are transferred to queen producers to rear cells and mated queens. For the purposes of this queen production study, the costs associated with genetically selecting the queen and the record keeping to improve stock are not added to the queen production costs. For each individual queen rearing operation, the selection methods and inputs are unique and their impact on overall production costs and profitability can be significant and must be taken into account on a case-by-case basis. Selection and production are two distinct processes and our focus in this paper is to examine the latter.

For this analysis, we are considering only existing beekeepers as viable players to enter the queen production industry due to the high level of skill and beekeeping experience required for queen production. We assume that these beekeepers will use their current operation's beekeeping equipment such as land, colonies, and bees to conduct their queen rearing. In all three operations, cell builders and mating nuclei were derived from using existing colonies. Once grafting was complete, the colonies from the cell builders were returned into honey production and the mating nuclei developed into strong productive colonies post queen rearing. Additional resources used only for cell and queen production including queen rearing materials and feed are included in the cost analysis for 2018, whereas only additional materials (cell cups, queen cages, feed) that are typically not re-used are included for year 2.

Table 2 lists all materials required for cell and queen production along with their unit prices and sources. For cell production, each operation tracked the number of cell builders used, the number of cups grafted, the amount of sugar syrup used ($3.21/U.S. gallon), and the number of pollen patties used ($2.82 per patty). The materials required for cell rearing were also tracked including cell cups ($0.20 per cup), grafting frames ($12.95 per frame) and a grafting tool ($5.95) as well as the labor used to prepare and transport the colonies and to graft and check the cells (total hours per activity for all cell builders at $20/h). Each operation also kept track of the number of successfully grafted cups that became queen cells. To calculate the total feed cost for all cups that were grafted, the total amount of feed was multiplied by the unit price of each. To calculate the total materials cost for all grafted cups, the number of materials used were multiplied by their respective unit prices and the total labor costs for all cups grafted were calculated by multiplying the total number of hours by the hourly labor wage ($20/h). All labor wages for both queen cells and mated queens were paid at a wage of CDN$20/h to account for both higher skilled labor, less skilled labor, and unpaid family labor (Laate 2017). Cell rearing labor is listed in Table 3 as the number of hours for a given cell rearing activity. For example, (241) means that 24 h of labor were required for activity 1, which is preparing and transporting colonies (see Table 2 for all labor activities). Both the total cost per grafted cup (calculated as the total cost of feed, materials, and labor for all grafted cups divided by the total number of grafted cups) and the total cost per successful queen cell (calculated as the total cost of feed, materials, and labor for all grafted cups divided by the total number of successful queen cells) is shown in Table 3.

For queen production, each operation tracked the number of queen cells used and the total cost of these cells (as calculated above). We tracked the total feed required for rearing mated queen by the

Table 1. Breeding cost case study operation demographics

	Location	Years of intensive breeding experience	Forage	Surroundings	No. of Queen cells/ no. of cups grafted (2018, 2019)	Grafting success rate (2018, 2019)	No. of Queens successfully mated/no. of queen cells (2018, 2019)	Mating success rate (2018, 2019)
OP1	Moncton, NB	3.	Bramble, goldenrod, clover	Somewhat isolated	359/450, 202/270	80%, 75%[a]	40/60, 80/116	67%, 69%
OP2	Lethbridge, AB	10	Canola, sweetclover	City, other bee yards, Ag. areas	36/90, 675/945	40%, 71%	30/36, 356/430	83%, 83%
OP3	Beaverlodge, AB	15	Canola, alfalfa	Isolated from other yards	125/140, 50/58	90%, 86%	119/125, 50/50	95%, 100%

The operation (OP1, OP2, OP3) location, the number of years of breeding experience of the lead researcher/producer, and the available forage in that location for the bees as well as the level of density of surrounding bee yards is listed to give an overview of the operations. The number of cups grafted compared to the number of queen cells for each operation in each of the two production years is listed along with the explicit grafting success rate for each operation in each year. The number of queen cells used and the number of successfully mated queens are listed for each operation over two years along with the explicit mating success rates for those 2 yr for each operation.

[a]OP1 conducted their 2019 queen production over two subsequent rounds that are merged together for this costing analysis; however, it is important to note that the grafting success increased from 59% in round 1 to 91% in round 2, indicating potential for rapid skill acquisition for newer queen producers. Potential reasons for low grafting success for OP1 in Round 1 (as self-reported) were identified as: 1) presence of a laying worker in cell builder #2; 2) presence of queen cells in the upper box of cell builders; 3) poor grafting technique; and 4) weak cell builders.

Table 2. Materials and labor pricing

Materials (ea.)	Unit Price (ea.)	Price calculation	Source	Laboura	Activities
				Cells	
Sugar syrup (G)	$3.21	$17.00 for 20kg sugar ($0.85/kg or $3.21/U.S. Gallon (G))	www.wholesaleclub.ca	1	Preparing cells and transporting colonies
Pollen patty	$2.82	40 patties @ $112.95	www.countryfields.ca	2	Grafting cells
Cell cup	$0.20	100 cups for $20.00	www.dancingbeeequipment.com (2019 pricing)	3	Checking cells
Grafting frame (with bars)	$12.95	1 @ $12.95	www.dancingbeeequipment.com		
Grafting tool	$5.95	1 @ $5.95	www.dancingbeeequipment.com	*Mated Queens:*	
Queen cage	$0.45	1 @ $0.45	www.dancingbeeequipment.com	4	Preparing and transporting colonies and preparing mating yard
Queen candy	$0.005	1 mini marshmallow (1g ea.) @ $0.5/100g	www.walmart.ca	5	Installing cells and marking queens[b]
Marking pen	$8.95	1 @ $8.95	www.dancingbeeequipment.com	6	Checking colonies for laying pattern, staff breaks and clean up

Each material used in our three operations for both cell and queen rearing are listed. Each material's unit price and calculation is listed as well as the source for each of these materials. The labor column indicates the number attributed to each of the labor activities. Numbers 1,2,3 correspond to queen cell labor activities and 4,5,6 correspond to mated queen labor activities along with a description of each of these activities. The numbers allocated to each labor activity are also used in Tables 3 and 4.

[a]The labor numbers and activities correspond to the labor listed in Tables 3 and 4 for cell and mated queen rearing.

[b]In nonresearch based operations, there may not be any labor attributed to queen marking.

amount of sugar syrup used (in U.S. gallons for all cells) and the materials required for mated queen production including queen cages ($0.45 per cage), queen candy ($0.005 per candy), and a marking pen ($8.95 per pen). The unit price calculations and sources for all queen materials are listed in Table 2. The operations also tracked the labor used to prepare and transport the colonies and mating nuclei, to install the cells and mark the queens, to check colonies for laying patterns and for staff breaks and clean-up. To calculate the total feed cost for all cells that were used, we multiplied the total feed by the unit cost. The total materials cost for all cells used was calculated by multiplying the materials by their respective unit prices. Total labor costs for all cells used were calculated as the number of hours required for all mated queen activities multiplied by the hourly labor wage ($20/h). Both the total cost per queen cell used (calculated as the total cost of feed, materials, and labor for all queen cells divided by the total number of queen cells installed) and the total cost per successfully mated queen (calculated as the total cost of feed, materials, and labor for all queen cells divided by the total number of successfully mated queen) is shown in Table 4. The additional costs to rear a mated queen from a successful queen cell is also shown in Table 4.

The operation (OP1, OP2, OP3) location, the number of years of breeding experience of the lead researcher/producer, and the available forage in that location for the bees as well as the level of density of surrounding bee yards is listed to give an overview of the operations. The number of cups grafted compared with the number of queen cells for each operation in each of the two production years is listed along with the explicit grafting success rate for each operation in each year. The number of queen cells used and the number of successfully mated queens are listed for each operation over two years along with the explicit mating success rates for those 2 yr for each operation.

Both queen cells and mated queens can be sold by producers to local beekeepers and mated queens can be shipped and sold to beekeepers further afield. To calculate the profitability of selling these hive products, we used a range of prices for queen cells (from $8 to $15 per cell (AR 2019, ZQ 2019) and mated queens (from $30 to $50 per queen (Bixby et al. 2019)). Profit per queen cell was calculated by subtracting the per cell cost from a range of per cell prices. We used the cost per successful queen cell in order to capture the impact of grafting success on profitability and the reality that only successful cells will earn revenue. To calculate profit for a mated queen, the cost to produce a successfully mated queen was subtracted from the range of prices to evaluate the impact of both mating success and price on profitability.

Results

Table 2 lists pricing and describes the labor activities associated with the labor activity numbers given in Tables 3 and 4. Tables 3 and 4 show the inputs and costs associated with cell and queen rearing, respectively, for all three operations in both years. Feed costs in 2018 for cell production were $0.24 per cup for OP, $0.06 per cup for OP3, and $0.30 per cup for OP2. In 2019, feed costs were $0.21 per cup for OP1, $0.07 per cup for OP2, and $0.10 per cup for OP3. In 2018, OP2 and OP3 paid $0.50, $0.70, and $0.61 per cup, respectively, for materials whereas in 2019, materials costs were $0.20, $0.34, and $0.20 per cup for OP1, OP2, and OP3. Labor costs in 2018 were $1.42 per cup for OP1, $0.89 per cup for OP2, and $1.57 per cup for OP3, whereas in 2019 OP1 paid $1.00 per cup, OP2 paid $0.60 per cup, and OP3 paid $3.45 per cup for labor. For mated queens, the input cost also varied between operations and years. Operation 1 paid $3.21 per queen cell in feed costs in both 2018 and 2019, whereas both OP2 and OP3 relied on honey flows and had zero additional feed costs for their mated queen production. Materials costs for queen production in 2018 were $0.68 per cell, $0.75 per cell, and $0.53 per cell for OP1, OP2, and OP3. In 2019, OP1 paid $0.57 per cell, OP2 paid $0.51 per cell, and OP3 paid $0.63 per cell in material costs for queen production. Labor in 2018 for mated queen production was $12 per cell for OP1, $13.19 per cell for OP2, and $7.28 per cell for OP3. Mated queen labor costs in 2019 were $5 per cell for OP1, $8.91 per cell for OP2, and $6.20 per cell for OP3.

Table 3. Queen cell breeding costs for three operations

	OP1 2018	OP1 2019	OP2 2018	OP2 2019	OP3 2018	OP3 2019
Number of cell builders used	4	6	3	15	3	2
Number of queen cells/ number of cups grafted	359/450	202/270	36/90	675/945	125/140	50/58
Feed for all cell builders						
Pollen patties (*n*)[a]	20	6	6	15	3	2
Sugar syrup[b] (U.S. Gallon(G))	16	12	3	7.5	0	0
Total pollen patty cost ($)	56.4	16.92	16.92	42.3	8.46	5.64
Total sugar syrup cost ($)	51.36	38.52	9.63	24.08	0.00	0.00
Total feed cost[c] ($)	**107.76**	**55.44**	**26.55**	**66.38**	**8.46**	**5.64**
Feed cost per cell cup ($/cup)	*0.24*	*0.21*	*0.30*	*0.07*	*0.06*	*0.1*
Materials						
Cell cups (*n*)	450	270	90	945	140	58
Grafting frames (w/bars) (*n*)	10	Re-using	3	9	4	Re-using
Grafting tool (*n*)	1	Re-using	1	2	1	Re-using
Total materials cost ($)	**225.45**	**54.00**	**62.80**	**317.45**	**85.75**	**11.60**
Materials cost per cell cup ($/cup)	*0.50*	*0.20*	*0.70*	*0.34*	*0.61*	*0.20*
Labor[d]						
Number of hours (h)(activity e.g., 1,2,3, see Table 2)	24(1), 8(2)	8(1), 4.5(2), 1(3)	2(1),1.5(2), 0.5(3)	11.41(1), 15.33(2), 1.5(3)	7(1), 3(2), 1(3)	7(1), 3(2)
Total duration (h)	32	15.5	4	28.24	11	10
Min/cup	4.27	3.44	2.67	1.79	4.71	10.34
Total labor cost ($)	**640.00**	**270.00**	**80.00**	**564.80**	**220.00**	**200.00**
Labor cost per cell cup ($/cup)	1.42	1.00	0.89	0.60	1.57	3.45
Total cost (TC) for all cups used ($)	**973.21**	**379.44**	**169.35**	**948.63**	**314.21**	**217.24**
TC per cell cup ($/cup)	*2.16*	*1.41*	*1.88*	*1.01*	*2.24*	*3.75*
TC per queen cell ($/cell)	***2.7108***	***1.8784***	***4.7042***	***1.40537***	***2.5137***	***4.3448***

The number of cell builders used in each operation is listed along with the number of queen cups grafted and the number of successful queen cells that developed. The inputs required for cell rearing for our three beekeeping operations are listed in one of three categories: feed, materials, and labor. The amount of feed (U.S. gallons of sugar syrup, number of pollen patties), materials (cups, frames, tools), and labor (number of hours corresponding to each of the activities outlined in Table 2) are listed for each of the three operations over the two production years. The total costs for each category (feed, materials, and labor) are listed as well as the total aggregate costs for all of the inputs into queen cell production. The total costs are calculated as the total aggregate costs for all cell cups that were grafted, the total cost per cell cup that was grafted (the total cost divided by the number of cell cups used) and the total cost per successfully grafted queen cell (the total cost divided by the number of successfully grafted cells).

[a]Pollen patties consist of some or all of the following: vitamins, lemon juice, yeast, pollen, sugar, dried egg, honey, and oil.

[b]Sugar syrup consists of some proportion of sugar to water depending on the desired outcome (1:1 or 2:1).

[c]The costs per cup for feed, materials, and labor are calculated using the total number of grafted cups, not the total number of cells that grafted successfully. The total cost per successfully grafted cell is shown below.

[d]Labor is costed here at CDN$20/h.

Figures 1 and 2 show the overall costs per cell and the additional costs to rear a mated queen as well as the % reduction/increase in costs within an operation between years. Additional queen costs refer to the costs that the beekeeper incurred to rear a mated queen from the cell stage (not including the costs to rear that cell). In 2018, the three breeding operations had a range of overall costs for producing queen cells of $2.5l to $4.70 per successful queen cell and an additional $8.33 to $24.85 for producing a successfully mated queen. OP3 had the lowest costs in 2018 for both outputs with $2.51 per cell and an additional $8.33 per mated queen compared with OP1 with costs of $2.71 per cell and an additional $24.85 per mated queen. Costs for OP2 to rear a queen cell in 2018 were nearly double those of OP1 and OP3 at $4.70/cell with an additional $17.62 to rear a mated queen, higher than OP3 but not as high as OP1.

In 2019, the three breeding operations had a range of overall costs of producing queen cells from $1.18 per cell to $4.34 per cell and from $6.84 per mated queen to $13.32 per mated queen in addition to the queen cell costs. Cell rearing costs for OP1 and OP2 fell in 2019 to $1.88 per cell and $1.41 per cell, respectively. Cell rearing costs for OP3 increased in 2019 to $4.34 per cell. OP1 and OP2 also had reductions in the additional mated queen rearing costs in 2019 to $13.32 per mated queen for OP1 and $11.55 per mated queen for OP2. OP3's higher cell costs in 2019 resulted in higher overall mated queen costs at $11.18 per mated queen (including the cell costs); however the additional queen costs for OP3 fell from $8.33 per mated queen in 2018 to $6.84 per mated queen in 2019. The mean cost for rearing one successful queen cell over the three operations was $3.11 in 2018 and $2.54 in 2019. In 2018, the mean cost for producing a successfully mated queen (including cell costs) over the three operations was $20.20 and the mean cost in 2019 was $13.11. The additional mean costs in 2018 for rearing a mated queen for the three operations was $16.93 per mated queen and in 2019 the additional mean cost was $10.57 per mated queen.

Each material used in our three operations for both cell and queen rearing are listed. Each material's unit price and calculation is listed as well as the source for each of these materials. The labor column indicates the number attributed to each of the labor activities. Numbers 1,2,3 correspond to queen cell labor activities and 4,5,6 correspond to mated queen labor activities along with a description of each of these activities. The numbers allocated to each labor activity are also used in Tables 3 and 4.

The number of cell builders used in each operation is listed along with the number of queen cups grafted and the number of successful

Table 4. Mated queen breeding costs for three operations

	OP1 2018	OP1 2019	OP2 2018	OP2 2019	OP3 2018	OP3 2019
Number of total queen cells used	60	116	36	430	125	50
Number of successfully mated queens	40	80	30	356[a]	119	50
Total cost for queen cells[b] ($) (number of queen cells used)	162.6535 (60)	217.8962 (116)	169.3500 (36)	604.3092 (430)	314.2125 (125)	217.2400 (50)
Feed						
Sugar syrup (U.S. Gallon (G))	60	116	Honey Flow*	Honey Flow*	Honey Flow*	Honey Flow*
Total sugar syrup cost ($)	**192.6**	**372.36**	**0.00**	**0.00**	**0.00**	**0.00**
Total feed cost ($)	**192.60**	**372.36**	**0.00**	**0.00**	**0.00**	**0.00**
Feed cost per cell ($/cell)	*3.21*	*3.21*	*0.00*	*0.00*	*0.00*	*0.00*
Materials						
Queen cage (*n*)	40	80	30	356	119	50
Queen candy (*n*)	40	80	30	356	119	50
Marking pen (*n*)	1	1	1	2	1	1
Total materials cost[c] **($)**	**27.15**	**45.35**	**22.60**	**179.88**	**63.01**	**31.70**
Materials cost per cell ($/cell)	*0.68*	*0.57*	*0.75*	*0.51*	*0.53*	*0.63*
Labor						
Number of hours (h)(activity e.g., 1,2,3, see Table 2)	18(4), 8(5), 10(6)	14(4), 15(5&6)	19.25(4), 2(5), 2.5(6)	109.1(4), 51.1(5), 31(6)	20(4), 4(5),21.5(6)	11(4), 1.5(5), 3(6)
Labor	**720.00**	**580.00**	**475.00**	**3830.00**	**910.00**	**310.00**
Total number of hours (h)	36	29	23.75	191.2	45.5	15.5
Min/cell	36.00	15.00	39.58	26.68	21.84	18.6
Labor cost per cell ($/cell)	*12.00*	*5.00*	*13.19*	*8.91*	*7.28*	*6.20*
Total cost for Q rearing ($) (including cell costs)	**1,102.40**	**1,215.61**	**666.95**	**4614.19**	**1287.31**	**558.94**
Total cost per queen cell used ($/cell)	***15.89***	***8.78***	***13.94***	***9.42***	***7.81***	***6.83***
Total cost per successfully mated Queen ($/Q)	***27.56***	***15.20***	***22.23***	***12.96***	***10.82***	***11.18***
Total *additional* cost per successfully mated queen ($/Q) (subtract cell costs)	**(27.56–2.71) *24.85***	***(15.20–1.88) 13.32***	**(22.32–4.70) *17.62***	***(12.96–1.41) 11.55***	**(10.82–2.51) *8.33***	***(11.18–4.34) 6.84***

The number of queen cells that each operation used to rear queens in both production years (2018, 2019) are listed along with the number of successfully mated queens. The total cost for all of the queen cells that were used in each operation for both years is also listed. The inputs required for queen rearing for our three beekeeping operations are listed in one of three categories: feed, materials, and labor. The amount of feed (U.S. gallons of sugar syrup), materials (queen cage, candy, marking pen), and labor (number of hours corresponding to each of the activities outlined in Table 2) are listed for each of the three operations over the two production years. The total costs for each category (feed, materials, and labor) are listed as well as the total aggregate costs for all of the inputs into mated queen production. The total costs are calculated as the total aggregate costs for all inputs into queen rearing that were used including the cost of the cells themselves, the total cost per queen cell that was used (the total cost divided by the number of queen cells used) and the total cost per successfully mated queen (the total cost divided by the number of successfully mated queens). The total additional cost to rear a mated queen, not including cell costs, is also listed.

[a]In some queen production operations, beekeepers will perform another round of cell introductions to compensate for any poor laying in their mating colonies, this would increase the mating success rate and reduce per queen costs.

[b]To calculate the per cell cost, the cost that was incurred to produce each successful cell was used (ranging in Table 1 from $1.41 to 4.70).

[c]In non-research based operations the queen producer may not use marking pens. In the case of a queen producer using their queens within the operation and thus not for sale, queen cages and candy may not be necessary.

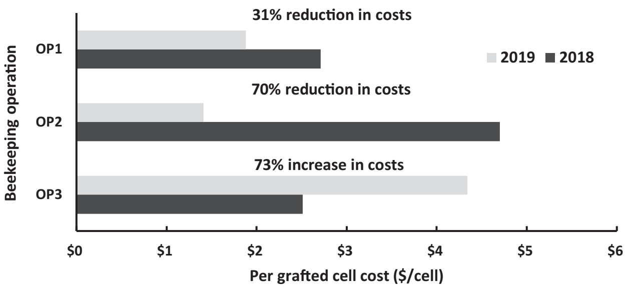

Fig. 1. Queen cell cost comparison between operations (OP1, OP2, OP3) for 2018 and 2019. Costs are in absolute values ($ per cell) with the % change in costs from 2018 to 2019 for each operation.

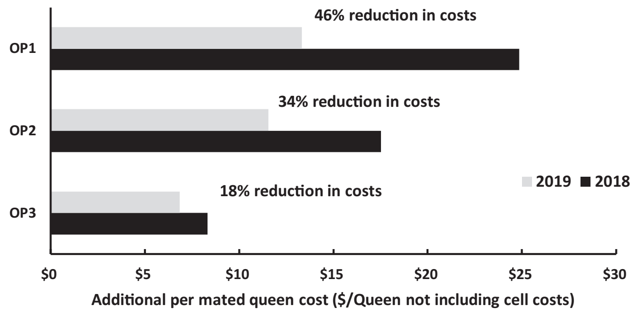

Fig. 2. Additional queen rearing costs for the three operations (OP1, OP2, OP3) over two production years (2018, 2019). These costs are the additional cost incurred to produce a mated queen from the queen cell stage with the % change in costs from 2018 to 2019 for each operation.

queen cells that developed. The inputs required for cell rearing for our three beekeeping operations are listed in one of three categories: feed, materials, and labor. The amount of feed (U.S. gallons of sugar syrup, number of pollen patties), materials (cups, frames, tools), and labor (number of hours corresponding to each of the activities outlined in Table 2) are listed for each of the three operations over the two production years. The total costs for each category (feed, materials, and labor) are listed as well as the total aggregate costs for all of the inputs into queen cell production. The total costs are calculated as the total aggregate costs for all cell cups that were grafted, the total cost per cell cup that was grafted (the total cost divided by the number of cell cups used), and the total cost per successfully grafted queen cell (the total cost divided by the number of successfully grafted cells).

The number of queen cells that each operation used to rear queens in both production years (2018, 2019) are listed along with the number of successfully mated queens. The total cost for all of the queen cells that were used in each operation for both years is also listed. The inputs required for queen rearing for our three beekeeping operations are listed in one of three categories: feed, materials, and labor. The amount of feed (U.S. gallons of sugar syrup), materials (queen cage, candy, marking pen), and labor (number of hours corresponding to each of the activities outlined in Table 2) are listed for each of the three operations over the two production years. The total costs for each category (feed, materials, and labor) are listed as well as the total aggregate costs for all of the inputs into mated queen production. The total costs are calculated as the total aggregate costs for all inputs into queen rearing that were used including the cost of the cells themselves, the total cost per queen cell that was used (the total cost divided by the number of queen cells used), and the total cost per successfully mated queen (the total cost divided by the number of successfully mated queens). The total additional cost to rear a mated queen not including cell costs is also listed.

The three operations reared cells and mated queens for the purposes of this study and these hive products were not sold but used within each operation. As a result, the operations did not earn profits on their cells and queens and the following results refer to potential profits that could have been earned by the operations had the products been sold. In 2018, potential queen cell profit ranged from just over $3 per cell for OP2 at a price of $8 per cell to over $12 per cell for OP3 at a higher price of $15 per cell. Given the costs and price range, the potential mean profits for the three operations in 2018 would have been $8.96 per cell for OP1, $6.97 per cell for OP2, and $9.16 per cell for OP3 (Fig. 3). In 2019, potential profits for selling queen cells ranged from $3.66 per cell for OP3 at a price of $8 per cell up to $13.59 per cell for OP2 at a price of $15 per cell. The potential mean profits for the three operations in 2019 would have been $9.79 per cell for OP1, $10.26 per cell for OP2, and $7.33 per cell for OP3 given the prices of $8, $12, and $15 per cell (Fig. 3). For an operation selling mated queens, the range of potential profit given costs and prices (using the full cost of rearing a mated queen including the cell costs) was $2.44 per queen for OP1 at a price of $30 per queen up to $39.18 per queen for OP3 at a price of $50 per queen (Fig. 4). The mean potential profits for our operations from selling mated queens in 2018 were $12.44 per queen for OP1, $17.77 per queen for OP2, and $29.18 per queen for OP3. In 2019, potential profits from selling mated queens ranged from $14.8/queen for OP1 at a price of $30 per queen up to $38.82 per queen for OP3 at a price of $50 per queen. The potential mean profits for the operations in 2019 were $24.8 per queen for OP1, $27.04 per queen for OP2, and $28.82 per queen for OP3.

Discussion

Cell and mated queen rearing costs varied between operations and from one production year to the next. The amount of feed per cell builder and mating nuclei was up to the discretion of the queen producer and varied between operations due to forage availability and management decisions. OP1 fed the mating nucleus colonies sugar syrup as there was not a sufficient honey flow to provide sustenance for the colonies, unlike OP2 and OP3 who both had strong honey flows at the time of queen rearing and mating. The same materials were used in all three operations and only small differences in cost arose due to the number of grafting frames used with fixed numbers of bars and space for cups. Depending on the number of cups that the researcher chose to graft, some of the equipment was not utilized to full capacity (each frame has three bars and each bar has space for 15 cups) and thus affected the per cup cost. Each operation spread the cost of the grafting tools and pens over the specific number of cells or queens, resulting in some cost variability. For example, OP1 used one grafting tool in 2018 at a price of $5.95, a cost that was spread out among all 359 queen cells (a per cell cost of $0.02), whereas OP2 also used one grafting tool in 2018, but the cost of $5.95 was spread out over only 36 queen cells (a per cell cost of $0.17), a seemingly small difference at this scale, however, when queen producers scale up their operations these additional costs play an increasingly important role in profitability. The operations were able to re-use production equipment such as frames, tools, and pens, reducing the costs in 2019. We observed a consistency of cell and queen rearing material costs across operations and across time which highlights a systematic cell and queen production process and suggests that we may be able to extrapolate these results to a wider queen production sector.

Labor costs varied between operations for both cells and mated queen and were a function of breeder experience, management objectives, and the amount of time the researcher/producer was able to

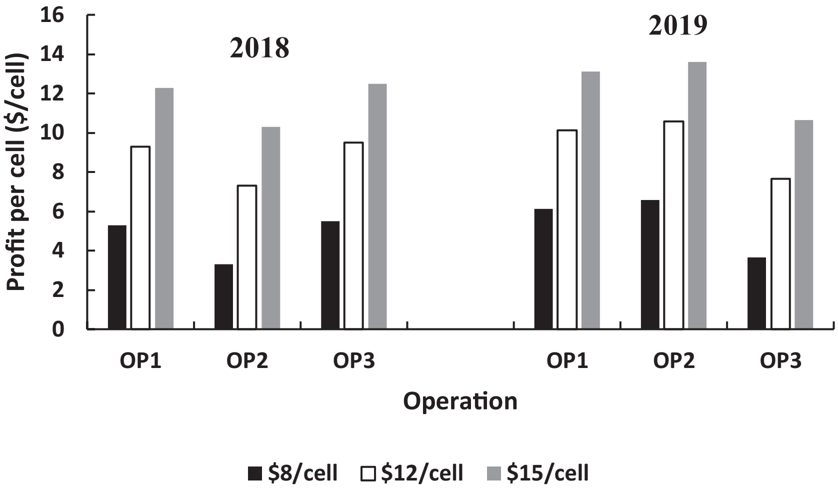

Fig. 3. Queen cell profit for three operations (OP1, OP2, OP3) over two production years (2018, 2019). Per queen cell profit is shown given a range of cell prices and for each operation in 2018 and 2019.

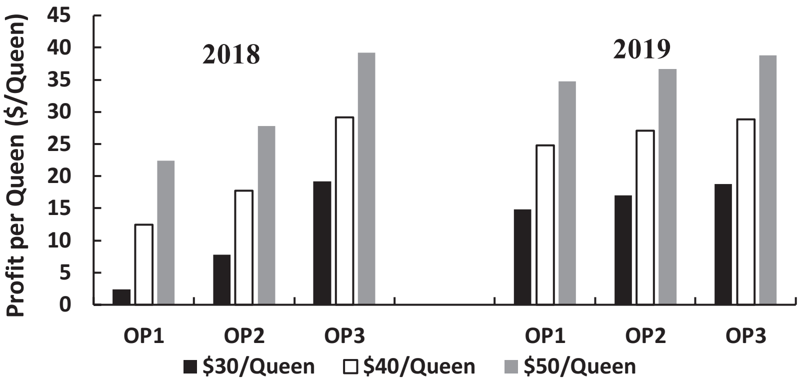

Fig. 4. Mated queen profit for the three breeding operations (OP1, OP2, OP3) given a range of queen prices for 2018 and 2019. Queen costs used for profitability calculations here are the full cost of rearing a mated queen including the costs of producing the cells.

allocate to cell and queen rearing that season. As well, there was an economy of scale that developed as the number of queens produced increased while other costs remained static such as travel time to apiaries and some of the general labor involved. These more fixed inputs (and associated costs) are incurred regardless of the number of queens, thus as the number of queens produced rises, the per cell or per queen costs decrease. In 2018, OP3 had slightly higher per cell labor costs than OP1; however, OP2 had much lower labor costs, a result of the producer not having much time to allocate to that component of the study. For mated queens in 2018, OP2 had the highest per unit labor costs followed closely by OP1, whereas OP3 had much lower costs, likely a function of streamlining tasks with highly experienced and skilled labor.

For OP1 and OP2 there were reductions in materials and labor costs within operations from year to year suggesting both efficiency from materials re-use as well as a skill and knowledge acquisition leading to increased labor efficiencies. OP3 experienced an uncharacteristically wet and cold summer with significantly more rain and colder temperatures in 2019 compared with both 2018 and 2017 (GCMCS 2019) making queen rearing more difficult and more than doubling the cost of labor required per grafted cup. As a result, the overall cost to rear queen cells for OP3 nearly doubled from 2018 to 2019. The researcher/beekeeper managing OP3 has extensive queen rearing expertise and thus it would be less likely for OP3 to experience significant skill acquisition and labor cost savings year to year, as labor efficiencies are likely already optimized. Furthermore, given the extreme environmental conditions in 2019 for OP3, the increase in labor costs were not unexpected and in spite of the poor conditions for queen rearing, the experienced beekeeper managed to attain high levels of grafting success.

For each round of queen production, final per cell and per queen costs were highly dependent on both grafting and mating success rates, which varied between operations and over time (Table 1). Total per cell costs for rearing a successful queen cell in 2018 were similar between OP1 and OP3; however, OP2's overall costs per cell were nearly twice as high as the other two operations, a result of poor grafting success rates which meant higher per cell costs. As grafting success increases with breeder experience and optimal management and environmental conditions (Emsen et al. 2003, AV 2017), mated queen profitability increases although because the impact of grafting success on mated queen costs is relatively small, the increase in queen profits is also small. For an increase in grafting success from 50 to 75%, we see an increase in queen profits of less than 6% and for a jump in grafting success from 75 to 100%, we see an increase in mated queen profits of <3%. Mating success has a more significant effect on per mated queen profits than grafting success. A rise in mating success from 60 to 80% results in a 19% mated queen profitability increase while an increase from 80 to 100% in mating success results in a 10% rise in profits per mated queen.

Although selling queen cells can be profitable, and in some cases, more desirable than mated queens given that queen cells require fewer resources and can be produced in larger quantities, queen cells present a higher risk to the buyer as the queen has not yet emerged or successfully mated and they are extremely sensitive to transport (McAfee et al. 2020). Introducing a queen cell will also require a period of queenlessness for a colony while mating takes place resulting in lost production. As a result of these challenges, demand for queen cells in Canada is much less than the demand for mated queens. As well, given the recent trend of rising imported queen prices (Page 2017), the increased demand for local queens in response to uncertain global factors and the willingness of Canadian beekeepers to pay a premium for locally bred queens (Bixby et al. 2019), domestic queen prices are now in the range of $30–$50 per queen (Bixby et al. 2019) with mated queen sales representing a much larger share of the queen production market than queen cells.

This detailed economic breakdown of Canadian queen production provides evidence that queen cell and mated queen production in Canada has the potential to be profitable even with variable grafting and mating success and poor environmental conditions. As experienced beekeepers choose to enter the queen production industry, it is important to consider that first year expenditures are higher than in subsequent years. However, even a newly established queen production operation could be profitable given certain environmental and pricing conditions and a skilled beekeeper with some queen experience. Also, as new selective breeding technologies become available to the wider market, Canadian queen production will yield stronger, more highly selected queens that command higher prices. One of the more significant challenges for increasing domestic supply of queens in Canada is the condensed queen rearing season due our northern climate. Our results indicate that queen producers can earn healthy profits given the current cost and pricing paradigms, however, to effectively grow this industry, we must also see positive outcomes from on-going research exploring the potential to overwinter queens in Canada for use in the early spring. As queen rearing in Canada continues to proliferate in response to producers experiencing positive profit margins as well as the continued import risks and supply shortages as a result of incidents such as Covid-19, production methods will be streamlined even further. As beekeepers experience positive profits from queen production, the number of queen operations and availability of skilled labor should increase, particularly as we see encouraging results from overwintering research in Canada, ultimately resulting in financial autonomy and sustainability for our beekeeping industry.

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