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SUMMARY

Due to the increased honeybee colony losses, the demands for honeybee colonies are growing annually. To regain the lost colonies or to increase the apiary size, the beekeepers need to purchase the new colonies or to prepare the new ones during the season. The aim of this study was to investigate the technological and economic efficiency of the three different methods of honeybee colony production, deploying one, two, or four combs of capped brood with the adhering bees and a mated queen. The study was conducted in northeastern Croatia from May 2019 to April 2020. At the end of the first season, there were no significant differences between the groups in the number of combs occupied with the brood and the bees. The production of colonies with one brood comb provides the beekeeper with an opportunity to multiply more colonies, while the colonies established using four brood combs during an early season produced honey during the main summer nectar flow. All three methods of colony production have scored a positive economic result and have demonstrated positive profitability rates.

Key words: Apis mellifera, colony production, economics

INTRODUCTION

Honeybees (*Apis mellifera* L.) are among the most important pollinators in the agro-ecosystem (Gallai et al., 2009; Hung et al., 2018). They live in a colony consisting of a queen, several hundred drones, tens of thousands of workers, brood, and food resources (honey, pollen). Honeybee colonies reproduce by swarming during the spring period and favorable environmental conditions. However, in the beekeeping practice, swarming is mostly undesirable, as it may reduce honey production (Winston, 1987), and if the swarm is not caught by a beekeeper, the bees are lost, as well as the value and productive capacity of the colony. The apicultural sector is facing the challenging times, with a high winter colony loss report (Brodschneider et al., 2016; Requier et al., 2018; Brodschneider et al., 2018) pertaining to a high direct economic loss being caused worldwide (Popovska Stojanov et al., 2021). The main reasons reported and pertaining to the colony losses are related to starvation, queen failure, weak colonies and the *Varroa destructor*, in addition to the associated viruses as a prime drive of colony losses (Le Conte, Ellis & Ritter 2010; Döke, Frazier & Grozinger, 2015; Noël, Le Conte & Mondet, 2020). To compensate for the colony losses or to expand the beekeeping operations, the beekeepers need to purchase or to produce the new colonies. This is usually done by forming the new colonies (i.e., the splits or nuclei) with brood combs and the adhering bees and a mated queen or by a package of bees with a mated queen (Johansson & Johansson, 1970; Ambrose, 2008).

If a beekeeper is expanding the operation by splitting the existing colonies, one of the questions is how to establish the new colonies—that is, how many brood combs should be placed in a new colony. With a limited number of donor colonies, establishing a multi-frame colony reduces the possibility of creating a larger number of colonies, while at the same time the colonies formed with one or two brood frames are not capable of producing extra honey in the first season. In a colony built with several brood combs, the young queen quickly lays a lot

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of eggs, while in a small colony the young queen does not use her full egg-laying potential because it takes few months for the colony to fully develop. To render our assistance to a decision-making process pertaining to the different methods of establishing the new colonies, we performed a field experiment, in which we compared the honeybee colony development, honey production, and the *Varroa destructor* infestation among three different methods of swarm, nucleus, and colony production. Furthermore, we conducted an economic analysis of costs, revenues, and end values gained while applying these different methods.

MATERIALS AND METHODS

Colony establishment and inspections

The experiment took place in northeastern Croatia, in the temperate climate conditions. New honeybee colonies were established on 10 May 2019 in Kozarac, Osijek-Baranja County (N 45.708605, E 18.672054), during the black locust (*Robinia pseudoacacia*) nectar flow. For the production of new colonies, twenty donor colonies were used, from which three to four brood combs with the adhering bees and three to four combs with honey and pollen were taken. Three different groups, each consisting of ten colonies, were formed: the colonies with one brood comb with the adhering bees and a newly mated queen (B1), the colonies with two brood combs with the adhering bees and a newly mated queen (B2), and the colonies with four brood combs with the adhering bees and a newly mated queen (B4). Each colony was installed in a standard Langstroth-Root (LR) hive, and all queens were the young, naturally mated sister queens from the same batch. Each colony received four combs with honey and pollen, while the rest was filled with the combs containing wax foundations. All established nuclei were fed with 5 kg of sugar syrup (water-to-sugar ratio amounting to 1:1). The entrances to the new colonies were closed, so that the bees could not return to their original hives, and the colonies were moved on the same day to another apiary in Vardarac, Osijek-Baranja County (N 45.625670, E 18.774523), where the trial took place. A total of nine inspections was performed (generally on a monthly basis) for a number of combs with the bees and brood up to April 2020. Honey production was measured during the honey harvest season in August 2019 by weighting the amount of extracted honey (Costa et al., 2012). The infestation of colonies with the *Varroa* mites was estimated by the washing method (Dietemann et al., 2013) prior to the treatment being applied, and the number of mites per 10 g of bees was calculated. The overwintering index (OI) was calculated as a proportion of bees present in the colonies on the occasion of the first spring inspection in 2020, in comparison with the last autumnal inspection in 2019.

Economic analysis

For the sake of an economic analysis, the prices valid on the market in 2019, when the experiment was conducted, were used. The price of the mated queens was obtained from queen breeders' website (*Udruga uzgajivača selekcioniranih matica*, 2023), honey price was obtained from the Croatian Beekeepers' Association (HPS, 2023), and the prices pertaining to the wax foundation and a treatment against the *Varroa destructor* were obtained from the website of PIP d.o.o. (2023). The prices pertaining to the calculation of costs and incomes pertaining to the colony production and maintenance are presented in Table 1.

We made a calculation on the financial result, cost-effectiveness and profitability of production of each type of colony in this study (Ranogajec, 2009). Further, we made a model calculation for different strategies when using 20 donor colonies to prepare new colonies, from which it is possible to produce either 70 colonies with 1 brood comb, 35 colonies with 2 brood combs or 18 colonies with 4 brood combs. The financial result is calculated by deducting the cost from the income. Cost-effectiveness is obtained by dividing income by cost. Profitability is calculated by dividing the financial result with the cost and multiplying it by 100.

Table 1. The elements used in the economic analysis of cost and income.

Tablica 1. Elementi korišteni u ekonomskoj analizi troškova i prihoda.

Elements		Value in EUR
Cost	Mated queen	9.33
	Wax foundations	1.33 / piece
	Treatment against *Varroa destructor*	4.00 / colony
	Supplementary feeding with 5 kg of sugar (syrup 1:1)	3.50 / colony
	Labor	6.75 / Hour
Income	Honey (bulk price)	2.66 / kg
	Colony sells value in the next spring	100

Statistical analysis

The ANOVA was used to determine the effect of the group for all measured parameters, with the LSD post-hoc test being applied if a significant effect was detected. Statistical analysis was performed using the *Statistica*® software, version 13.4.0.14 (1984–2018 TIBCO Software Inc., California, USA).

RESULTS AND DISCUSSION

Colony losses and overwintering success

In the study area, the main spring nectar flow of the black locust was a perfect moment to produce the new colonies. By removing three to four brood and bee combs from the fully developed colonies during the main spring nectar flow, the swarming tendency in donor colonies was reduced. Brood reduction at this moment did not negatively affect honey production (Maul, Klepsch & Assmann-Werthmüller, 1988), the Varroa mite population was reduced (Büchler et al., 2020), and the acceptance rate of the queens in the newly established colonies was high, which was documented in this study. Out of a total of thirty honeybee colonies, established at the beginning of the study during the black locust nectar flow, twenty-nine queens, or 96.67%, were accepted (i.e., one queen in the Group B4 was not accepted). During the course of the study, five additional colonies were lost. In the Group B4 , three colonies were removed, in the Group B2 one colony was lost, and in the Group B1 one colony was lost, all because of the extremely high *Varroa* infestation or as a winter loss. Out of twenty-six colonies entering the winter, two were recorded as a winter colony loss (7.7 %). In Croatia, winter losses differ from season to season, with the highest average loss being reported in the winter of 2018–19, amounting to 20.4% (Brodschneider et al., 2016; Brodschneider et al., 2018). This is much higher than the winter loss of 7.7%, being reported in our study for the season of 2019–20, which again was characterized by high winter colony losses (Gray et al., 2022). However, the main losses (13.3%) were reported during the summer season: one queen was not accepted, one queen was lost, and two colonies were removed because of a high infestation rate of more than eight mites per 10 g of bees. This highlights the importance of monitoring the summer colony losses in addition of monitoring the winter colony losses and shows that approximately 20% of the newly established colonies were lost and another 80% have successfully entered the next season during the course of the aforementioned season. Although no significant differences were detected in the OI ($F (2,23) = 0.387$, $p = 0.684$, mean $\pm$ SD = 80.47 $\pm$ 25.15%), the Group B1 had an overwintering success amounting to 86.55%, thus being comparatively higher than that of the Group B2 (76.60%) and the Group B4 (77.96%) groups by almost 10% . The overwintering success, measured by the calculation of overwintering index, was very similar to the results obtained by Kovačić et al. (2020) in the same environmental conditions and therefore seems to represent an expected overwintering success in the study area if the colonies are prepared well for the hibernation.

Colony development

Upon the first out of the two control inspections, the colonies differed in terms of bee population and the amount of brood (Figs. 1 and 2), as expected. Upon the third inspection, in July—that is, two months thereafter—the colonies were established, but all groups still differed in the number of bee combs ($F (2,26) = 20.874$, $p < 0.01$). Concerning the number of brood combs, significant differences were found ($F (2,26) = 4.061$, $p = 0.029$), with the Group B1 having significantly fewer brood combs when compared to the Groups B2 ($p=0.034$) and B4 ($p=0.014$), respectively, and no difference was observed between the Group B2 and the Group B4 . The following inspections at the end of July demonstrated significant differences between the groups in the number of bees ($F (2,24) = 49.975$, $p < 0.01$), with the Group B1 being weaker than the other two groups ($p < 0.01$). With regard to the amount of brood ($F (2,24) = 10.429$, $p < 0.01$), however, the Group B1 was again weaker than the other two ($p < 0.01$) groups. The inspections in August manifested the same trend as the previous ones, with significant differences in the number of bee combs ($F (2,23) = 8.180$, $p = 0.002$, Group B1 being weaker than the other two groups) and brood combs ($F (2,23) = 5.003$, $p = 0.016$, Group B1 being weaker than the other two groups). Upon the last inspection in the first season, the colonies did not differ in the number of bee combs ($F (2,23) = 0.072$, $p = 0.931$) and number of brood combs ($F (2,23) = 0.650$, $p = 0.531$). On the occasion of the two inspections in the spring of 2020, there were no significant differences between the groups both in the number of bees and in the brood combs.

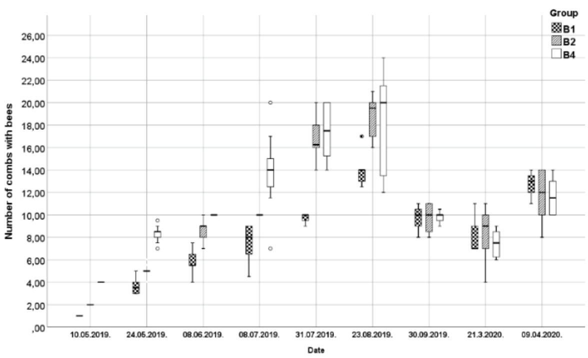

Figure 1. A box plot of combs with the bees for the three different groups during the study.

Grafikon 1. Box-plot grafikon broja okvira s pčelama za tri različite skupine tijekom istraživanja.

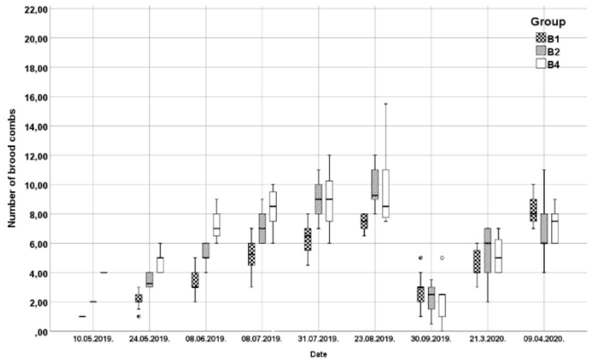

Figure 2. A box plot of brood combs for the three different groups during the study.

Grafikon 2. Box-plot grafikon broja okvira s leglom za tri različite skupine tijekom istraživanja.

The colonies established with two and four brood combs during the black locust flow—namely, two months later—were almost equal in the number of brood combs, and both groups managed to reach almost ten brood combs during August. Also, these two groups equalized in the number of combs with bees during July and had an almost identical development through the rest of the study. On the other hand, the colonies from the Group B1 were weaker both in terms of a brood and in terms of the bees through the whole summer; yet, upon the final seasonal inspection, all groups were of a very similar strength, confirming the results of other studies (Punnett and Winston, 1989; Maucourt, Fournier & Giovenazzo, 2018). At the beginning of April 2020, all groups had averagely seven to eight brood combs and were on the course of their full developments during the time of the black locust flow. This circumstantiates that the colonies established from a single brood comb in the study area, which featured a queen mated early in the season, have managed to be fully developed up to the end of the season and have overwintered well. Puškadija et al. (2008) conducted a similar study under the same environmental conditions, having compared the development of colonies established from three brood combs with the colonies established out of the package bees. The development of colonies established with three brood combs lay perfectly between the Groups B2 and B4 of our study.

Honey production

Significant differences were found among all groups in the amount of extracted honey ($F (2,25) = 90.452$, $p < 0.01$). The highest average amount of extracted honey was recorded in the Group B4 (mean $\pm$ SD = 16.11 $\pm$ 2.02 kg), followed by the Group B2 (7.3$\pm$3.29) and the Group B1 (0.89$\pm$1.36), respectively, from which only few honey combs in total could be extracted. If the honey is the main interest, the stronger nuclei should be established, but then the one can produce a smaller number of nuclei. The stronger nuclei, with a higher number of foragers and a good storage of honey, enable faster development and consequently more nectar intake during the summer (Hoopingarner & Waller, 2008). The average production of 16 kg of honey per colony for the Group B4 in the first season has almost repaid the invested value.

Varroa infestation

There were no significant differences between the groups detected in the infestation of colonies with the Varroa mites during the inspection prior to the treatment at the end of July ($F (2,26) = 2.331$, $p = 0.117$). As expected, the colonies from the Group B4 had the highest infestation rate, and the only two extremes of more than eight mites per 10 g of bees were recorded in this group (Fig. 3). In the two colonies of this group, the infestation rate was higher than 8% by the end of July, which greatly exceeded the reported threshold values of 3-4 % (Genersch et al., 2010; Giacobino et al., 2015). It is important to mention that an additional benefit of removing the brood combs from the donor colonies comes from the reduction of varroa infestation in the donor colonies (Maucourt, Fournier & Giovenazzo, 2018).

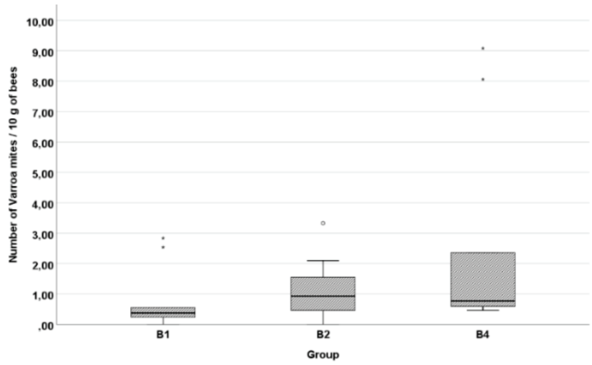

Figure 3. A box plot of infestation with the *Varroa* on 31 July 2019, prior to the treatment.

Grafikon 2. Zaraženost zajednica grinjom **Varoa destructor** *31. srpnja 2019., prije tretmana.*

Economic analysis

The economic calculation of different types of colony production is shown in the Table 2. In all three methods of colony formation, a positive financial result is reported. The calculations showed that the highest financial results were obtained from the Group B4 colonies, mostly due to the honey production in the first season. In calculations, brood and honey combs were not considered a production cost of new colonies because the new colonies that have used the brood combs from the already existing colonies in the apiary were established in this experiment, which is the most common beekeeping practice in the establishment of the new colonies. The reason that lies behind the establishment of the new colonies determines what kind of colonies should be established. If more colonies are necessary, less brood would be used, but if honey production is of the greatest interest, then the colonies with four brood combs, or even the stronger ones, should be established. However, the establishment of four brood comb colonies reduces the number of possibly established colonies.

Table 2. A calculation of financial result, cost-effectiveness, and profitability for the nuclei production.

Tablica 2. Kalkulacija financijskoga rezultata, isplativosti i profitabilnosti proizvodnje rojeva.

	B1			B2			B4		
	Amount	Price	Total	Amount	Price	Total	Amount	Price	Total
Sell Value	1	100	100.00	1	100	100.00	1	100	100.00
Honey	0.89	2.66	2.37	7.3	2.66	19.42	16.11	2.66	42.85
INCOME	102.37			119.42			142.85		
Queen	1	9.33	9.33	1	9.33	9.33	1	9.33	9.33
Labor	2	6.75	13.50	4	6.75	27.00	4	6.75	27.00
Foundations	5	1.33	6.65	4	1.33	5.32	2	1.33	2.66
Treatment	1	4	4.00	1	4	4.00	1	4	4.00
Feeding	1	3.5	3.50	1	3.5	3.50	1	3.5	3.50
COST	36.98			49.15			46.49		
Financ.res.	65.39			70.27			96.36		
Cost-effect.	2.77			2.43			3.07		
Profitability	176.82			142.97			207.28		

Table 3. A model of financial result calculation, cost-effectiveness, and profitability for the nuclei production using twenty donor colonies.

Tablica 3. Model izračuna financijskoga rezultata, isplativosti i profitabilnosti proizvodnje rojeva korištenjem dvadeset donorskih pčelinjih zajednica.

	B1			B2			B4		
	Amount	Price (€)	Total (€)	Amount	Price (€)	Total (€)	Amount	Price (€)	Total (€)
Queen	70	9.33	653.10	35	9.33	326.55	18	9.33	167.94
Foundations	490	1.33	651.70	210	1.33	279.30	72	1.33	95.76
Treatment	70	4	280.00	35	4	140.00	18	4	72.00
Feeding	70	3.5	245.00	35	3.5	122.50	18	3.5	63.00
Labor (hours)	140	6.75	945.00	140	6.75	945.00	72	6.75	486.00
COST (€)	2774.80			1813.35			884.70		
Sell value (€)	70	100	7000.00	35	100	3500.00	18	100	1800.00
Honey (kg)	56	2.66	148.96	252	2.66	670.32	694.26	2.66	1846.73
INCOME	7148.96			4170.32			3646.73		
Loss of 20 % of colonies									
INCOME	4.374,16			2.356,97			2.762,03		
Fin.res.	724,53			72,23			1.324,92		
Cost-effect	1.26			1.04			2.50		
Profitability	26.11			3.98			149.76		

In our study, twenty donor colonies were used, having provided seventy brood combs. Of this material, it is possible to establish seventy B1 colonies, thirty-five B2 colonies, or eighteen B4 colonies. Having applied this approach, we have made a calculation of financial result, cost-effectiveness, and profitability while employing all brood combs to form one of the three different group of colonies presented in the Table 3. In this calculation, we have included a loss of 20% of the colonies that occurred in our study from May 2019 to April 2020. The highest income was obtained if all colonies were established of one brood comb (Group B1), considering the fact that all colonies were established to be sold on the market. However, other economic indicators showed that the highest financial results, cost-effectiveness, and profitability was obtained in the Group B4. Interestingly, in all calculations the Group B2 scored the lowest results, which leads to the conclusion that it is best to make the nuclei from one brood comb if the goal is to increase the number of colonies for the next season, or the nuclei from four brood combs if the aim is to produce honey in the same season. It should be emphasized that this is a valid scenario when the new colonies are established during the main spring nectar flow in the area of temperate continental climate.

CONCLUSION

The aim of the study was to investigate the different models of new honeybee colony's production from a technological and economic aspect while using the existent donor colonies. The results have shown that the colonies established during the black locust flow with one brood comb will not achieve the highest honey production but will develop well until winter, enabling a beekeeper to produce the highest number of new colonies. On the other hand, the colonies established of four brood combs achieved the highest honey production and developed well until winter. All models of colony production showed positive results, while the B4 group was the most profitable one.

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TEHNOLOŠKA I EKONOMSKA OPTIMIZACIJA PROIZVODNJE PČELINJIH ZAJEDNICA (*Apis mellifera* L.)

SAŽETAK

Zbog povećanih gubitaka pčelinjih zajednica, potražnja za njima raste iz godine u godinu. Kako bi nadoknadili izgubljene pčelinje zajednice ili povećali veličinu pčelinjaka, pčelari moraju kupiti nove zajednice ili ih mogu sami proizvesti tijekom sezone. Cilj ovoga rada bio je ispitati tehnološku i ekonomsku učinkovitost triju različitih metoda proizvodnje pčelinjih zajednica: korištenjem jednoga, dvaju i četiriju okvira saća s poklopljenim leglom i pripadajućim pčelama kojima je dodana sparena matica. Istraživanje je provedeno u sjeveroistočnoj Hrvatskoj od svibnja 2019. do travnja 2020. Na kraju prve sezone nije bilo značajnih razlika između skupina u broju okvira zauzetih leglom i pčelama. Proizvodnja zajednica s jednim okvirom poklopljenoga legla omogućuje pčelaru proizvodnju većega broja pčelinjih zajednica, dok su se pčelinje zajednice proizvedene na početku sezone s pomoću četiriju okvira poklopljenoga legla dovoljno razvile i proizvodile med tijekom glavne ljetne pčelinje paše. Sva tri načina proizvodnje pčelinjih zajednica pokazala su pozitivan ekonomski rezultat i stopu isplativosti.

Ključne riječi: Apis mellifera L., proizvodnja pčelinjih zajednica, ekonomika

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