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Economic aspects of honey bee queen breeding: insights from a European study

Lazo Dimitrov[a,b*], Aleksandar Uzunov[c,d*], Sreten Andonov[c,e], Cecilia Costa[f], Marina D. Meixner[g], Yves Le Conte[h], Fanny Mondet[h], Marin Kovačić[i], Norman L. Carreck[j,k], Benjamin Basso[h], Malgorzata Bienkowska[l], Raffaele Dall'Olio[m], Leonidas Charistos[n], Fani Hatjina[n], Ursula Wirtz[o] and Ralph Büchler[p]

[a]Ss. Cyril and Methodius University in Skopje, Institute of Agriculture, Skopje, Republic of Macedonia; [b]Terra Consulting, Skopje, Republic of Macedonia; [c]Ss. Cyril and Methodius University in Skopje, Faculty of Agricultural Sciences and Food, Skopje, Republic of Macedonia; [d]State Key Laboratory of Resource Insects, Institute of Apicultural Research, Chinese Academy of Agricultural Sciences, Beijing, China; [e]Swedish Agricultural University, SLU, Uppsala, Sweden; [f]CREA Research Centre for Agriculture and Environment, Bologna, Italy; [g]LLH Bee Institute Kirchhain, Germany; [h]INRAE UR406 Abeilles et Environnement, Avignon, France; [i]University of J.J. Strossmayer in Osijek, Faculty of Agrobiotechnical Sciences Osijek, Osijek, Croatia; [j]Carreck Consultancy Ltd, Shipley, West Sussex, United Kingdom; [k]University of Sussex, Falmer, Brighton, East Sussex, United Kingdom; [l]National Research Institute of Horticulture, Puławy, Poland; [m]BeeSources, Bologna, Italy; [n]Department of Apiculture, Institute of Animal Science, ELGO 'DIMITRA', Nea Moudania, Greece; [o]ConsulTech, Berlin, Germany; [p]ApiPhil, Kirchhain, Germany

ABSTRACT
In 2017, the European Commission initiated the EurBeST study to explore the possibilities of using selective breeding of honey bees to increase Varroa resistance traits. One of the specific aims of the study was to assess the process of honey bee queen breeding through an economic analysis. The methodology for calculating the costs of queen production (queen rearing and mating), colony evaluation and expenses for estimating breeding values is based on the Cost of Production (CoP). Cost data were collected *via* tailor-made questionnaires and interviews performed in five European countries (France, Germany, Greece, Italy, and Poland). The sample population consisted of 20 queen producers and 20 performance testers who participated in the study. The results showed that the average costs for queen production amounted to 22.58 € per queen, ranging from 8.22 € in Poland to 37.30 € in France. The difference between the selling price and the production cost was on average 3.08 € per queen, ranging from 15.86 € in Germany to −12.30 € in France. On average, the colony evaluation costs were 193.40 € per colony. The average cost for breeding value estimation per queen was 8.09 €. Thus, the average total cost per selected queen was 224 €. The selective breeding of honey bees is an efficient way to increase productivity, reduce colony losses, improve bee health and enable profitable operations, but it is expensive, is usually promoted, practiced and implemented by scientists and researchers, and in most cases is financed by external sources.

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Economy; cost of production; queens; breeding; Varroa resistance; honey bee; beekeeping

Introduction

Beekeeping is a significant source of income and an important economic activity for the livelihood of many people. Because the majority of beekeepers in Europe are hobbyists, it is, however, often not perceived as an important economic sector, and there is a lack of knowledge and research on its economic aspects.

Honey is by far the most important apicultural product, and is globally traded (García, 2018), so existing economic analyses have predominantly been orientated towards honey. Lately, other honey bee products (pollen, propolis, royal jelly, bee venom, and beeswax) have become more important for production, as they can have a high economic value, due to their pharmaceutical properties (Nainu et al., 2021). Recently, the relevance of apitourism and apitherapy is also increasing.

Live materials such as honey bee colonies, nucleus colonies, package bees, drone semen and queen bees are, however, additional hive products and their economic importance should not be neglected, given current difficulties in honey production and marketing.

Over the last 15 years, economic research has focused more on the value of the ecosystem services that beekeeping provides for agriculture and biodiversity, rather than on the profitability of

CONTACT Lazo Dimitrov L.Dimitrov@zeminst.ukim.edu.mk, L.Dimitrov@zeminst.edu.mk
*Joint first authors: Dimitrov and Uzunov et al., 2023.

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beekeeping. Honey bees are universally recognized as economically important managed pollinators for both crops and wild plants (Gallai et al., 2009; Khalifa et al., 2021; Klein et al., 2007; Potts et al., 2016). However, considering that the total number of beekeepers in the EU is around 606 thousand, in China about 308 thousand (Tang et al., 2020), in South America 250–350 thousand (Maggi et al., 2016), in USA 212 thousand, in Turkey around 60 thousand (Çakmak & Sevencakmak, 2016) and in Canada 10 thousand, it seems that across the world there is also a significant socio-economic impact of beekeeping on family incomes and security. Thus, losses of honey bee colonies, which are caused by multiple factors (Neumann & Carreck, 2010; Liu et al., 2016), among which the parasitic mite *Varroa destructor* (Le Conte, 2010; Guzmán-Novoa et al., 2010), land management and pesticide use (Dicks et al., 2021) and queen issues such as queen health and age (Genersch et al., 2010; Spleen et al., 2013) have extensive economic consequences. A study in three European countries focusing on the direct economic impact of winter honey bee colony losses on the apicultural sector showed that the estimated economic losses were 32 M € in Austria, 21.4 M € in the Czech Republic and 3 M € in Macedonia (Popovska Stojanov et al., 2021). However, honey bee colony losses can be compensated by division of existing colonies, which results in stable or even increasing numbers of managed colonies in certain regions (Brodschneider et al., 2019; Moritz & Erler, 2016; Van Engelsdorp & Meixner, 2010).

The Varroa mite is considered to be the main biotic factor threatening beekeeping worldwide (Rosenkranz et al., 2010; Traynor et al., 2020), but solutions to fight it efficiently and to prevent colony losses remain limited (Noël et al., 2020). One potential sustainable solution is the selection and breeding of honey bee populations that are resistant to Varroa, either by propagating offspring from naturally resistant colonies (Dietemann et al., 2012), or by deliberate selection and breeding for specific traits related to resistance (Le Conte et al., 2020).

In 2017, the Agriculture Directorate of the European Commission called for a study to explore the possibilities for increasing Varroa resistance traits of commercially available honey bees by selective breeding, and to analyze ways to improve beekeepers' access to resistant material (Büchler et al., 2022; EurBeST, 2018). The study, named "EurBeST" (European honey Bee-breeding and Selection Team) comprised both field and desk studies and ran from 2018 to 2021. The EurBeST team estimated the annual production of queens in the EU to be nearly two million. More than one-third of these queens are produced in Italy (700,000), followed by Poland with 280,000 and France with 150,000 (EurBeST, 2018). Queen producers, performance testers and commercial beekeepers from these countries were included in the EurBeST field study. Most of these queen producing operations are large-scale and commercial, and in the case of Poland, the final products are mostly virgin queens. In addition, the number of queens produced in Germany (60,000) and Greece (55,000) contribute significantly to the overall queen production in the EU. Moreover, in most of these countries, selection for improved Varroa resistance has already been established or is currently becoming one of the prime traits of interest in breeding programs.

One of the aims of the EurBeST study was to assess the cost of honey bee breeding through an economic analysis of the queen rearing, colony evaluation and selection of the preferred genotypes (in this case queens) as parents of the next generation. In addition, we estimated the costs and benefits of using stock selected for improved Varroa resistance compared to the stock commonly used in commercial beekeeping operations ("own production").

To our knowledge, this is the first study addressing the economic aspects of breeding for the genetic improvement of honey bee stock, in particular those aspects intrinsic to breeding towards improved Varroa resistance.

Materials and methods

Methodology

The study estimated the costs and expenses for organizing and executing the basic elements of the breeding cycle: queen rearing including mating; colony evaluation (performance testing and specific tests); and estimation of breeding values (EBV) for the evaluated traits.

The methodology for calculation of the queen production cost includes queen rearing and queen mating, based on the Cost of Production (CoP). As an economic indicator, CoP or the production price is the average cost for producing one unit of product (one queen). At the same time, CoP represents the break-even price to manage production without losses, covering all production costs. The methodology for the assessment of CoP of queen production was calculated using a tailor-made methodology for the project, which follows the general standard methodology used in the relevant literature (Ciaian et al., 2013; FAO, 2019; Kay et al., 2014).

The calculation of the queen CoP is based on the costs for queen rearing (labor, transport, feeding, protection from pests and pathogens, and required equipment), marketing, the value of assets and other costs. Additionally, before marketing, newly produced queens are usually mated, where the three main types of practice (open mating, mating with the use of mating stations, and instrumental insemination), have different levels of effort and costs.

The CoP (€ /queen) is calculated based on the following:

$$\text{CoP} = \text{TC}/\text{Y}$$

TC - Total yearly costs (in €)
Y - Number of produced queens

The total costs represent the sum of variable and fixed queen CoP:

$$\text{TC} = \text{VC} + \text{FC}$$

VC - Variable costs (in €)
FC - Fixed costs (in €)

The yearly variable costs are the sum of the direct costs used for queen rearing: labor, transport, feeding, protection from pests and pathogens and required equipment, marketing and other costs.

The value of fixed costs is calculated based on the costs of annual depreciation (D in €) of the assets for queen production:

$$\text{D} = \text{VA} \times \text{DR}$$

VA - Value of the asset (in €)
DR - Depreciation rate (in %, DR = 1 ÷ Years of asset utilization)

Additionally, the methodology for the total breeding cost of honey bee queens includes the costs for performance tests for colony evaluation. All data required for this calculation were recorded by performance testers who participated in the study, and a separate estimation of costs for EBV was included, based on experts' experience and current prices for this kind of service.

The colony evaluation is based on the standard guidelines for basic performance testing, Varroa infestation monitoring, and tests for Varroa specific traits (Büchler et al., 2013, 2024; Mondet et al., 2020; Uzunov et al., 2021). The number of tests, the time needed for one test, and the number of necessary apiary visits were assessed based on the EurBeST team experts' experience and estimations (Supplementary material: Table S1). The total costs consist of labor, transport, and additional costs such as the depreciation of the equipment needed for performing Suppressed Mite Reproduction (SMR), Recapping of infested brood cells (REC) and Varroa Sensitive Hygiene (VSH) tests. The proposed methodology recommends 12 colonies per testing apiary, and investment in equipment of 2,000 €, with a 10-year life.

Labor costs are calculated including labor time for carrying out colony tests, travelling time to and from the apiary (based on an estimation of one hour as the average time needed to travel 50 km) and labor time for data management (recording and entering data) with hourly payment fees. Transport costs are calculated based on the apiary distances and average fuel costs. The basic performance testing costs are calculated based on the labor, labor transport, and transport costs for performing the testing of five traits: colony strength in terms of bee population (number of occupied combs); colony strength in terms of brood area (number of combs); honey production (net weight); swarming (score); and gentleness (score) (Uzunov et al., 2021). Labor costs for data management are allocated according to the proportion of these basic tests to the total number of tests conducted.

Costs for traits of Varroa resistance, as part of colony evaluation costs, are calculated based on the labor, labor transport and transport costs for performing Varroa infestation monitoring and specific tests. Additionally, labor costs for data management were allocated according to the proportion of these specific resistance tests to the total number of tests conducted, plus the share of depreciation of equipment necessary for evaluating SMR, REC, and VSH.

Varroa infestation monitoring costs are calculated based on the labor costs for monitoring three different parameters: adult bee infestation; brood infestation; and natural mite mortality.

Costs for testing hygienic behavior, SMR & REC and VSH, as Varroa specific test methods, are calculated based on the individual costs for performing each test. In addition, the relative amount of labor for data management, and 50% of the total depreciation of equipment for performing SMR & REC and VSH tests, are allocated to the costs of these tests.

Finally, the costs for estimating breeding values (EBV) are added to the total breeding cost. The methodology for calculation of the cost for EBV is based on the average national labor costs, for example, increased by a factor of four, as the EBV cannot be performed by the performance testers themselves, but requires staff with specialized skills and expertise (Uzunov et al., 2023) which is usually more expensive. According to the EurBeST experts' experience, the EBV of 200 colonies (queens), on average, requires around 30 h of labor time. Additionally, the software license costs are around 1,000 € per year, which means extra costs of 1 € per queen for performing the EBV for a total of 1,000 queens per year.

Approach

Tailor-made questionnaires were designed to be used in a personal interview, and an electronic Excel version of the questionnaire for entering the data was developed. The interviews were performed with queen producers by the EurBeST team, and replies were based on the normal/typical year of production with the last 5 years (prior to 2019) as reference.

Additional information and expert estimation were used in a later phase of economic analysis.

Sample

The sample population consisted of 20 queen producers and 20 performance testers who participated in the EurBeST field study, located in five European countries (Germany, Greece, France, Italy, and Poland; Table 1). The queen producers interviewed in Germany rear *Apis mellifera carnica* and "Buckfast". In Greece, they use *Apis mellifera macedonica*. French queen producers opt for hybrids, while Italians use *Apis mellifera ligustica* on the mainland and *Apis mellifera siciliana* in Sicily. The interviewed Polish queen producers use exclusively *Apis mellifera carnica*. Some of the queen producers, who perform their own colony evaluations were also surveyed as performance testers.

The total annual production of those queen producers who participated in the study was 101,853 queens, representing more than 5% of the total estimated annual production of two million queens in the EU. As participation in the study was voluntary, it was hard to ensure equal/balanced sample coverage across the countries.

Results

The average costs for queen production amount to 22.58 € per queen, ranging from 8.22 € in Poland to 37.30 € in France. The main share of the costs comes from labor costs, which significantly vary between cases and countries.

The difference between the selling price and the production price is, on average 3.08 € per queen, ranging from 15.86 € in Germany to −12.3 € in France (Table 2).

A positive balance per queen was calculated for Germany (15.86 €), Poland (3.82 €) and Greece (1.26 €), while the balance was negative in France (−12.3 €) and Italy (−3.82 €). The negative balance results from the

Table 1. Sample size and number of cases.

Country	DE	EL	FR	IT	PL	Total / Average
No. of queen producers	6	4	3	4	3	20
Estimated total annual queen production per country	60,000	55,000	150,000	700,000	280,000	1,245,000
Total annual production of queens by the producers in the study	20,405	16,690	9,750	13,508	41,500	101,853
Queens production by sample producers of total	34.0%	30.3%	6.5%	1.9%	14.8%	8.2%
Average number of queens produced per queen producer per year	3,401	4,173	3,250	3,377	13,833	5,093
No. of performance testers	6	2	3	6	3	20

Note: DE = Germany; EL = Greece; FR = France; IT = Italy; PL = Poland.

Table 2. Parameters and estimated costs for queen production (rearing and mating) per one queen (€).

Queen rearing	DE	EL	FR	IT	PL	Avg.	Min	Max	Standard deviation
1. Queen rearing									
Labor costs	17.17	5.75	20.90	8.44	4.97	11.87	2.42	55.70	12.39
Transport costs	3.39	0.73	1.45	0.34	0.17	1.47	0.03	18.57	4.06
Feeding	1.84	1.72	4.62	2.12	0.23	2.16	0.12	8.00	2.58
Protection (disease treatment)	0.25	0.17	0.22	0.98	0.11	0.37	0.02	1.90	0.47
Equipment (1-year use)	0.56	0.58	0.25	0.38	0.05	0.43	0.03	1.47	0.42
Total queen rearing costs	23.21	8.96	27.45	12.26	5.53	16.15	3.33	83.84	18.19
2. Marketing									
Package, transport, labelling	0.75	0.83	0.00	0.23	0.48	0.73	0.09	2.04	0.61
Promotion and marketing	0.00	0.13	0.10	0.03	0.08	0.15	0.01	0.30	0.11
Total marketing costs	0.75	0.96	0.10	0.26	0.56	0.71	0.07	2.04	0.60
3. Other costs									
Veterinary services	0.00	0.04	0.00	0.02	0.02	0.06	0.01	0.14	0.06
Other services and support	0.41	0.00	0.19	0.17	0.09	0.40	0.00	1.51	0.49
Water, electricity, heating	0.22	0.16	0.29	0.59	0.23	0.45	0.01	2.13	0.58
Insurance	0.07	0.01	1.81	0.22	0.07	0.47	0.01	2.16	0.75
Other general costs (administration, telephone, accounting, etc.)	0.13	0.12	0.52	2.63	0.18	0.92	0.01	7.12	1.85
Income tax	0.00	0.58	1.38	0.78	0.28	1.16	0.12	4.00	1.34
Total other costs	0.82	0.91	4.20	4.40	0.87	2.43	0.18	12.26	3.09
4. Assets									
Total depreciation queen production	4.47	4.16	5.55	2.99	1.26	3.99	0.26	11.28	3.30
(A) Total cost queen production (1 + 2 + 3 + 4)	29.24	14.99	37.30	19.91	8.22	22.58	5.00	92.01	20.93
(B) Average queen selling price	45.10	16.25	25.00	16.63	12.04	23.32	9.00	60.00	15.41
Difference queen selling price (B) and production cost (A).	15.86	1.26	−12.30	−3.28	3.82	3.08	−46.91	39.87	21.02

Note: DE = Germany; EL = Greece; FR = France; IT = Italy; PL = Poland.

Table 3. Average colony evaluation costs per colony (€).

Queen evaluation	DE	EL	FR	IT	PL	Average	Min	Max	Standard deviation
Labor costs	246.82	54.30	236.18	126.17	64.26	162.39	356.27	39.08	98.05
Transport costs	9.22	13.60	12.08	25.11	5.81	14.34	44.00	0.22	12.06
Depreciation of equipment	16.67	16.67	16.67	16.67	16.67	16.67	16.67	16.67	0.00
Total costs	272.71	84.57	264.92	167.95	86.73	193.40	380.27	64.55	98.67

Note: DE = Germany; EL = Greece; FR = France; IT = Italy; PL = Poland.

Table 4. The costs for breeding per element and queen (€).

	DE	EL	FR	IT	PL	Average
Queen production	29.24	14.99	37.3	19.91	8.22	22.58
Colony evaluation	272.71	84.57	264.92	167.95	86.73	193.40
Costs of breeding evaluation per queen	10.89	7.05	9.87	6.19	5.20	8.09
Total cost for breeding (per queen)	312.84	106.61	312.09	194.05	100.15	224.07

Note: DE = Germany; EL = Greece; FR = France; IT = Italy; PL = Poland.

combined effect of high production and other costs (administration, insurance, taxation) and a low selling price per queen.

Colony evaluation costs (Table 3) are highest in Germany and France (273 € and 265 € per colony), while the costs in Greece and Poland are lowest (85 € and 87 € per colony).

The differences are primarily the result of national labor market conditions and labor costs. These consist of labor for colony evaluation, but also include a significant amount of travel, given the distances between apiaries, and labor time needed for data management (Supplementary material: Figure S1). The costs for basic colony performance testing (honey yield, gentleness and swarming scores) amount to about 20% of the total colony evaluation costs (Supplementary material: Figure S2). The main proportion of the total costs derives from the monitoring and testing for Varroa resistance. Monitoring of Varroa infestation levels and testing for hygienic behavior, together amount to almost 20% of total costs, while the highest share of the colony evaluation costs, with more than 60% of the total, results from assessing the SMR, REC and VSH traits. As for breeding costs, testing costs are highest in France and Germany, where they are around three times higher than the costs in Greece and Poland (Supplementary material: Figure S3).

On average, the basic performance testing costs are 36 € per colony, traditionally practised by most breeders. Costs for applying additional and specialized testing methods for colony evaluation are 158 € per colony, out of which, the average costs for monitoring Varroa infestation are 22 €, 16 € for hygienic behavior testing costs, 53 € for SMR and REC and 67 € per colony for VSH.

The average costs for EBV are 8.09 € per queen, based on a model of labor costs increased by a factor of four (specialized expert labor; Supplementary material: Table S2). Finally, the average total cost for breeding per queen amounts to 224 € as the sum of the costs for queen production, colony evaluation and selection (EBV). The highest breeding costs occur in Germany and France at around 312 €, and the lowest in Poland, at around 100 € (Table 4).

During the EurBeST field study, the colonies in the performance testing apiaries were managed without any kind of Varroa treatment (Büchler et al., 2022), so the data obtained allow us to calculate the average costs of a survival test (value of lost colonies and honey) based on different loss rates. The costs of running a one-year survival test show huge variations across the different case studies, caused by different loss rates and different colony values (Supplementary material: Figure 4). The country where the survival test costs are highest is France, and the lowest is Greece.

If a survival test (Büchler et al., 2014; Keffus et al., 2012) is performed as a regular part of the breeding process, the average breeding cost will increase from 224 € by an additional 160 € and will result in a total of 384 € per queen.

Discussion

Selective breeding of honey bees is an efficient way to increase productivity, reduce colony losses, and improve bee health and resilience, thus increasing the profitability of beekeeping operations. Selective breeding, by increasing resistance to parasites, also contributes to environmental protection by reducing the use of chemicals (EurBeST, 2022). The results of this study, although with limitations due to the small sample size, clearly show that selection for Varroa resistance is an expensive process. Additionally, production costs varied significantly among respondents due to the use of different beekeeping approaches and practices and variations in the national labor market and cost.

As a result of our interviews, we can conclude that in general, queen production is perceived and organized as an “economy of scope”, so the cost of their production should reduce the costs of related hive products, predominantly honey. For almost all queen producers, queen production is an “add-on” to honey production which is the core business activity, the main source of income and usually covers the costs and losses generated by the queen production.

There are different motives and driving forces that stimulate beekeepers to start queen production. In most cases, economic factors (to satisfy consumer request, to ensure balanced annual cash flow or to make rational use of available resources such as primary labor) are the main driving force. The second most common motive is to ensure quality reproductive material (queens) for their own day-to-day beekeeping activities. There are also motives going beyond economic logic which are mainly driven by tradition, prestige and status in the beekeeping world to possess and produce the best quality queens, followed by the second most common motive, to be confident and to ensure quality reproductive material (queens) for their own day-by-day beekeeping activities, production and needs.

There were only a few cases where queen production was declared as the main business model, based on the theory of "economy of scale", where queens are viewed as a single (primary) output of a good and a core source of income. Even in these rare cases, however, the income from honey production is substantial and counterbalances the outcomes from queen production activities.

Tradition and market situation, followed by a lack of studies concerning the cost of production, fixed and variable costs, general costs of business within the beekeeping and queen producer sector, may result in lower selling (market) prices compared to the actual cost of production (production price). This is the case in almost half of the sample population (8 out of 20 queen producers).

Additionally, we should bear in mind that market and breeding traditions have an impact on beekeeper practices, behavior and the demand for quality queens. The selling prices are driven by the market demand for quality queens and the preparedness or willingness of beekeepers to pay higher (i.e., realistic) prices for higher quality, based on the principle of value for money. It is evident that countries with a long tradition of bee selection and organized breeding programs have higher market prices (e.g., Germany: 45.10 €), as a result of recognition, demand and preparedness to pay for this higher (proven) quality. In contrast, in Poland the market prices are the lowest, which corresponds to a huge production (offer) of queens in reply to high demand. Market demand can be one of the potential consequences and drivers for most of the queens produced in Poland being virgin (unmated) queens, due to efforts of queen producers to reduce production costs.

With this study we observed and can conclude, that true selective breeding that includes Varroa resistance traits is only initiated, practiced and implemented by scientists and researchers, and in most cases financed by specific support programs. Improving the selection for Varroa resistance by performing additional and specialized testing methods for colony evaluation, poses significant additional costs (158 per queen). These costs are much higher if a survival test is a regular part of the breeding process which, on average, will increase from 224 € by an additional 160 €, resulting in a total of 384 € per queen.

Thus, special attention needs to be given to the choice of testing methods for Varroa resistance traits. Considering the correlation found between reduced Varroa infestation and hygienic behavior measured with the pin-test method (EurBeST, 2022) and its low cost, it seems worthwhile to promote this test for the wide-scale testing of hygienic behavior.

Queen producers are recognized as multiplicators of breeding success (Uzunov et al., 2017) and therefore can benefit from cooperation with the performance testers and scientific breeding centers. Such cooperation can result in the improvement of genetic traits of the overall reproductive material and ensure that breeding stock with good local adaptation is made available to the final customers, the beekeepers. Indeed, previous research has shown that a sustainable beekeeping operation relies on the availability of local breeding stock (Büchler et al., 2014; Costa et al., 2012; Hatjina et al., 2014, Uzunov et al., 2014). In other words, because of strong genotype-environment interactions, it is recommended to obtain stock from breeders in the same region, selected under similar colony management conditions (Meixner et al., 2015).

Currently, only a few breeding programs in Europe rely on EBV as a routine procedure in their selection strategy. There is, however, an increased interest in using this methodology as a breeding tool in well-established systematic breeding programs for the genetic improvement and conservation of honey bees (Uzunov et al., 2023).

The implementation of these breeding programs depends, however, on collaboration by beekeepers among and between many stakeholders such as scientists, extension specialists, public and local authorities and in some cases, media-related experts. With support from science, the selection criteria can be further optimized, and new techniques like genetic markers and EBV can be introduced and implemented to contribute to an overall increased breeding success. Policy-makers, and in particular local authorities, have a major role in the provision of the conditions for execution of the elements such as performance testing and mating control (EurBeST, 2022).

Finally, as the costs for implementing a breeding program are significant, and difficult (almost impossible) to incorporate into a business model covered only by the market price of queens, public funding of well-defined breeding activities is recommended to enhance and accelerate the selection success, and to ensure the long-term sustainability of beekeeping.

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Disclosure statement

The authors report that there are no competing interests to declare.

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ORCID

Lazo Dimitrov http://orcid.org/0000-0003-0476-8511
Aleksandar Uzunov http://orcid.org/0000-0003-1240-868X
Sreten Andonov http://orcid.org/0000-0002-5844-9420
Cecilia Costa http://orcid.org/0000-0001-9985-2729
Marina D. Meixner http://orcid.org/0000-0002-7785-4894
Yves Le Conte http://orcid.org/0000-0002-8466-5370
Fanny Mondet http://orcid.org/0000-0002-7737-0101
Marin Kovačić http://orcid.org/0000-0002-3782-6733
Norman L. Carreck http://orcid.org/0000-0001-7779-9736
Benjamin Basso http://orcid.org/0000-0003-4289-2898
Malgorzata Bienkowska http://orcid.org/0000-0001-6297-0254
Raffaele Dall'Olio http://orcid.org/0000-0003-4168-2194
Leonidas Charistos http://orcid.org/0000-0002-1279-1300
Fani Hatjina http://orcid.org/0000-0001-6506-5874
Ursula Wirtz http://orcid.org/0000-0003-4110-1468
Ralph Büchler http://orcid.org/0000-0001-7749-1870

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