TRAIT DEVELOPMENT FOR *APIS MELLIFERA* IN COMMERCIAL BEEKEEPING IN NEW ZEALAND

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SUMMARY

Honeybee populations have been modified for centuries by selection and culling, but traditional selection criteria are no longer sufficient to address the needs of modern beekeeping and to counter threats such as spread of disease. While evaluating selected honeybee traits for their relevance and measurability in commercial beekeeping and their presumed heritability and their scale of variation, we encountered a dichotomy in the requirements of small-scale hobbyist beekeepers and large-scale commercial beekeeping operations. A number of traditional traits feasible for selection under commercial conditions could be identified, eight out of which can be considered high-priority traits in the design of an industry-wide honeybee breeding objective: honey production, gentleness, colony strength, brood viability, wintering ability and disease resistance. However, the costs of hive evaluations are often prohibitive to implementation of breeding and selection schemes in commercial operations. This can be overcome with the deployment of remote beehive monitoring equipment that provides continuous observations on colony status in conjunction with Machine Learning tools to evaluate change in trait expression in different environmental conditions. Simultaneously, image analysis and hive telemetry provide opportunities for the definition of novel traits such as nectar reactivity or the pattern of honey deposition. Using these recent technological advances, bee breeding can be made accessible to large-scale commercial beekeepers as well as dedicated small-scale queen breeders.

INTRODUCTION

Since domestication, century-long breeding programmes have made dramatic changes to most livestock species, creating fit-for-purpose breeds adapted to their respective management systems which perform well across a range of environments (van der Werf *et al*. 2009). The development of specialised breeds has resulted in high within-species genetic and phenotypic diversity, making it a natural practice for farmers to choose a breed that suits the particular production systems.

These long-term developments are largely absent in beekeeping, the only exceptions being the establishment of the "Buckfast" bee, a hybrid of several honeybee sub-species (Brother Adam 1987) and the accompanying breed regulations (Gemeinschaft der Europäischen Buckfastimker e.V. 2016). Sustainable genetic improvement systems can only be established with strong support from commercial beekeepers, who tend to manage large parts of the national honeybee populations but are slow to adopt modern animal breeding methods. For the design of data-driven and economically focused genetic honeybee breeding schemes, traits need to be selected carefully to ensure that they are not only valuable parts of the breeding objective, but also feasible selection criteria in a commercial environment.

MATERIALS AND METHODS

A list of traditional honeybee traits was compiled and then grouped into areas that contribute to beekeeping profitability (see Table 1). While some of these traits had been advocated for up to a century (Armbruster 1919; Brother Adam 1987) and/or are currently being used by European breed associations, they had not been evaluated for their suitability within modern commercial honeybee populations.

Table 1. Traditional Honeybee traits with potential for incorporation into bee breeding schemes, with relevance and measurability

Area	Trait	Unit of measurement	Relevance	Measurability*
production	Honey production	kg / hive / season	✓	✓
	Wax production	kg / hive / season	✗	✗
workability	Gentleness	subjective score (1-5)	✓	✓
	Docility / Calmness	subjective score (1-5)	✓	✓ (grey)
	Swarming urge	attempts / season	✓	✓
strength	Brood strength	No of full frames of brood	✓	✓
	Colony strength	No of full bee spaces	✓	✓
	Spring growth	rate of growth in spring	✓	✓ (grey)
health	Brood viability	percentage	✓	✓ (grey)
	Disease resistance	*variable*		
queen	Q: laying pattern	pass / fail	✓	✓ (grey)
health	Q: laying capability	laying rate in eggs / day	✓	✗
	Q: longevity	weeks grafting to failure	✓	✓ (grey)
robustness	Wintering index	% of surviving bees	✓	✓ (grey)

*Grey tick marks indicate traits that can be measured in a queen breeding operation but cannot be readily measured in most commercial operations due to management strategies.

Traits were evaluated with regards to their relevance to commercial beekeeping and their practical measurability in the field, based on the published literature as well as discussions with commercial beekeepers. Trait heritabilities were compiled from the scientific literature.

RESULTS AND DISCUSSION

Only a small number of traits had been previously been investigated for their genetic parameters and were generally found to be of medium to high heritability (see Table 2), with the exception of swarming urge, which was found to have low heritability.

Table 2. Heritability estimates for selected honeybee traits. Estimates marked with ⁑ are for Africanised honeybees (hybrids between African and European subspecies of *A. mellifera*, common beekeeping in South America)

Area	Trait	Heritability (Standard Error)
production	Honey production	0.27 (0.06) (Brascamp *et al.* 2016); 0.54 (0.18) (Bar-Cohen *et al.* 1978)
workability	Gentleness	0.37 (0.06) (Brascamp *et al.* 2016)
	Docility / Calmness	0.38 (0.05) (Brascamp *et al.* 2016)
	Swarming urge	0.06 (0.04) (Brascamp *et al.* 2016)
strength	Brood strength	0.10 (0.10) (Bar-Cohen *et al.* 1978)
	Colony strength	0.49 (0.44) (Koffler *et al.* 2017)

Most traits in Table 1 were found to be relevant to commercial beekeeping operations. However, evaluations under commercial conditions and with non-destructive methods were found to be too expensive to be feasible for honey production or pollination companies and require specialised queen breeders to evaluate their stock (see grey ticks under "Measurability" in Table 1). While evaluation costs can be prohibitive for commercial operators, the same is not true for dedicated queen breeders, who can expect to recover the costs of queen evaluation and selection in returns from the sale of elite breeding stock. When establishing an industry-wide honeybee breeding programme, both of these levels need to be taken into account, since the success of elite queen breeders (or academically-driven breeding programmes established by universities) hinges on the continuous adoption of their improved stock by commercial operators (Ibrahim *et al.* 2007).

These findings suggest that while there are a number of feasible traits for the development of economically sustainable honeybee breeding schemes, there is a need in the beekeeping industry for the development and deployment of low-cost alternatives to the hands-on and visual inspection / evaluation of honeybee colonies. Machine vision tools can be used to rapidly evaluate brood-related traits such as worker brood viability and brood pattern / queen laying pattern. Novel phenotyping technologies exist (although the hardware is often still in development) and could facilitate the establishment of industry-wide genetic improvement schemes by bridging the gap between elite queen breeders and the commercial beekeeping operators that are essentially their clients.

Table 3. Honeybee traits for commercial honeybee breeding that could benefit from novel phenotyping strategies

Area	Trait	would benefit from novel phenotyping technology
production	Pattern of honey deposition	✓
workability	Swarming attempts	✓
strength	Colony strength	✓
health	Worker brood viability	✓
	Wintering Index	✓
queen health	Queen: laying pattern	✓
pollination ability	Spring population growth	✓
	Flight temperature	✓

There are a number of feasible honeybee characteristics that could form the basis of a bee breeding scheme for commercial beekeeping. However, some of the relevant traits are currently not feasible in commercial operations because the costs associated with recording are too high.

Nevertheless, breeding of improved stock would be an efficient and permanent way to address the challenges that honeybee breeders and commercial beekeepers are facing today, and recent advances in science and technology allow for innovative solutions to be developed. Technology surrounding data collection and analysis both at the hive level and at honey extraction is leaping forward, with more and more automated systems breaking into the market (e.g. www.arnia.com, www.hivemind.co.nz). This creates an opportunity for the development of a cutting-edge honeybee genetic improvement programme in collaboration with commercial beekeepers.

Honey yield and temperament are the traits currently most modified by queen breeders and are also the ones that should be treated as paramount in the definition of a New Zealand honeybee breeding objective. They are highly relevant to the beekeeper, relatively easy to record and have been shown to be heritable. A third highly relevant trait, winter survival, needs to be investigated further, as there are currently no estimates of genetic parameters for this trait available. However, since low winter survival presents a crucial issue to beekeepers worldwide, it should be included in breeding programs from the beginning. New Zealand beekeepers currently export upwards of 25,000 packages of live bees containing queens every year (New Zealand Ministry for Primary Industries 2018), mainly to

Canada, which continues to experience annual winter losses of ~30%. Doubts have been voiced on the suitability of New Zealand queen genetics for the harsher Canadian winters (Harpur *et al*. 2015) and although New Zealand is currently not experiencing high colony mortality over winter, inclusion of winter survival as a key trait would be a valuable step towards future-proofing the beekeeping industry and making New Zealand genetics desirable overseas.

Additional traits that should be prioritised are colony strength, brood viability and disease resistance. However, some of these high-priority traits can be expected to be costly to measure and novel phenotyping methodologies such as machine vision (image analysis supported by artificial intelligence) or remote hive monitoring / hive telemetry systems will need to be developed allow measurement to be practiced.

CONCLUSION

Novel automated phenotyping systems can support modern honeybee breeding programmes to support large-scale commercial beekeeping industries such as in New Zealand. These programmes can be expected to have a positive long-term impact on both domestic bee productivity and health as well as the survival and overall quality of bees exported to e.g. North America by being able to incorporate standardised data from all around the globe.

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