Application of a Modified Selection Index for Honey Bees (Hymenoptera: Apidae)

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ABSTRACT Nine different genetic families of honey bees (*Apis mellifera* L.) were compared using summed z-scores (phenotypic values) and a modified selection index (I_{mod}). I_{mod} values incorporated both the phenotypic scores of the different traits and the economic weightings of these traits, as determined by a survey of commercial Ontario beekeepers. Largely because of the high weight all beekeepers place on honey production, a distinct difference between line rankings based on phenotypic scores and I_{mod} scores was apparent, thereby emphasizing the need to properly weight the traits being evaluated to select bee stocks most valuable for beekeepers. Furthermore, when beekeepers who made >10% of their income from queen and nucleus colony sales assigned relative values to the traits used in the I_{mod} calculations, the results differed from those based on weightings assigned by honey producers. Our results underscore the difficulties the North American beekeeping industry must overcome to devise effective methods of evaluating colonies for breeding purposes.

KEY WORDS *Apis mellifera*, bee breeding, beekeeping, honey production, mite resistance, z-scores

HONEY BEES (*Apis mellifera* L.) are an essential part of agrifood systems. Their estimated economic value to the United States economy was recently assessed at U.S. $ 14.6 billion annually (Morse and Calderone 2000). Although production of honey and other bee-related products is significant, their main value derives from their role as the most important managed pollinator of horticultural and seed crops.

Several bee breeding projects have endeavored to improve the floral visiting capacity of honey bees by selecting for better honey producing or pollinating abilities. Although several of these efforts have been successful (Nye and Mackensen 1968, Hellmich et al. 1985, Szabo and Lefkovitch 1987, Page et al. 1995), honey bee breeding has lagged behind the considerable advancements made with other important agricultural organisms (Rinderer 1986). The lack of progress is largely attributable to the complex genetic composition of honey bee colonies (Moritz 1986, Moritz and Brandes 1987), the mating behavior of queens and drones (Laidlaw and Page 1984, Ruttner 1985, Koeniger 1986, Taylor and Rowell 1987), the sex-determination mechanism and associated negative consequences of inbreeding (Woyke 1986, Laidlaw and Page 1997), and the inability to artificially store honey bee germplasm for prolonged periods (Stort and Goncalves 1986).

Honey bee colonies are composed of tens of thousands of worker bees. Although all the adult bees within a colony share the same mother, they do not all share the same father, because the queen mates with between seven and 18 drones (Koeniger 1986, Estoup et al. 1994). The relatedness between worker bees within a colony therefore varies from 0.25 (for workers with unrelated fathers) to 0.75 (for super-sisters who share the same father) (Laidlaw and Page 1997). The interaction that occurs between these different kinship groups has an effect on bee behavior (Moritz 1986, Moritz and Brandes 1987, Moritz and Southwick 1987, Page and Robinson 1991, Fuchs and Schade 1994). Colony behavior has also been shown to be strongly affected by the environment (Brandeburgo et al. 1982, Rinderer et al. 1983, Bienefeld and Pirchner 1991). These confounding interactions make it difficult to predict the outcome of particular crosses and selection, and consequently complicate the breeding of superior bee lines (Page and Laidlaw 1982b, Moritz 1986, Moritz and Brandes 1987). Even when selection of superior bee lines is successful, maintenance of these desirable lines is difficult, largely because of the substantial decreases in colony vigor caused by honey bee inbreeding and the lethal action of homozygosity of sex alleles (Mackensen and Nye 1969; Page and Laidlaw 1982a, 1982b, 1985; Page et al. 1983, 1985; Laidlaw and Page 1997).

Commercial beekeepers in North America lack an objective standard by which to evaluate different honey bee stocks (Sugden and Furgala 1982a, Rinderer 1986, Bienefeld and Pirchner 1991). Widespread acceptance of the use of selection indexes for honey bee breeding is potentially a valuable tool for overcoming this difficulty. Selection indices are frequently used in breeding programs for other livestock animals (Lasley 1978, Henderson 1990). The selection index operates under the premise that the value of an animal

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stock can be expressed as a single value, I. Ideally, I should incorporate the phenotypic values of several characteristics of importance to the breeder, the heritabilities of these characteristics, the correlations of these characteristics with other important traits, and finally the economic values of each characteristic (Rinderer 1986). By objectively evaluating the positive and negative attributes of colonies, appropriate breeder queens and drone mothers can be selected. In theory, by selecting breeder colonies and drone mother colonies with the highest selection indexes and by controlling mating, a superior line of honey bees should result. Use of a selection index to estimate the value of individual colonies or families (daughters of a single queen) would also facilitate exchange of superior genetic material between bee breeders.

Rinderer (1986) mathematically defined the honey bee selection index as equation 1:

$$I = Z_1 V\left(\frac{h_1^2}{h_2^2}\right) + Z_2(1 - r_g) \qquad [1]$$

where Z_1 = z-score for trait 1; Z_2 = z-score for trait 2; V = economic value of trait 1 relative to trait 2; h_1^2 = heritability of trait 1; h_2^2 = heritability of trait 2; and r_g = genetic correlation that exists between traits 1 and 2, and

$$Z = \frac{X - M}{s} \qquad [2]$$

where: Z = z-score; X = phenotypic value for a given trait; M = apiary average for a given trait; and s = standard deviation for the trait.

The selection index outlined by equation 1 is limited to two colony traits. If more than two traits are to be incorporated into a selection index, a complex formula that includes multiple regression and covariance components must be developed (Rinderer 1986).

The selection index outlined by equation 1 is considerably simplified if heritability (h^2) and correlation (r) values are excluded. This exclusion may be justifiable, considering the wide range or lack of estimates reported for h^2 and r values for most traits (Szabo 1980, Collins 1986, Harbo and Harris 1999). Furthermore, the complexity of worker bee relatedness and interactions make both h^2 and r values difficult to determine (Rinderer 1977a, Oldroyd and Moran 1983, Collins et al. 1984, Bienefeld and Pirchner 1991). For commercial bee breeding, the complexity and additional effort needed to calculate h^2 and r values make use of both parameters impractical.

Rinderer (1986) stated that in the absence of accurate heritability and correlation estimates, an approximate selection index or modified selection index (I_{mod}), which only incorporates z-scores (z) and relative economic values (v), is acceptable (equation 3):

$$I_{\text{mod}} = \sum_{1}^{n} Z_i V_i \text{ for n traits} \qquad [3]$$

This formula has the further advantage of easily accommodating more than two evaluated traits without requiring complex computations.

In this study we used a survey of commercial beekeepers to estimate the economic values (V-values) of several traits of honey bee colonies, and then used these V-values and the measured phenotypes of numerous colony characteristics to calculate modified selection indexes (I_{mods}) for nine families of honey bees. We used selection indexes that incorporate economic values of traits of bees as determined by beekeepers.

Materials and Methods

Surveys were sent to all beekeepers (n = 157) in Ontario, Canada, who were registered with the provincial apiarist as having ≥100 hives. This criterion ensured that only commercial beekeepers would respond. Respondents were asked to assign relative weights to the following traits by distributing a total of 100 points between them: honey production, resistance to tracheal mites, resistance to nosema disease, resistance to American foulbrood, resistance to chalkbrood; resistance to varroa mites, colony overwintering ability, spring build-up; cessation of brood rearing in the fall, late summer food storage in the brood chamber and winter honey consumption, tendency not to swarm; temperament, and behavior on combs (e.g., calm versus nervous/runny). The respondents were allowed to include in their summary of economic values other colony traits that they felt had importance. They were encouraged to assign a value of zero to traits that they felt had no economic value. Average relative values (the V-values used in equation 4 below) were easily calculated for any particular set of respondents.

Finally, the questionnaire asked respondents to indicate the value of different bee-related activities and products from which they derived their income. The possible income sources listed in the survey included hive rental for pollination, farm gate honey sales, self-packaged honey sold in stores, bulk or wholesale honey sales, queen bee sales, nucleus colony and package bee sales, other hive products (e.g., propolis, wax, and pollen), and processed bee products (e.g., hand creams, honey butter). As before, they were asked to weight each income source by assigning points (total 100) to indicate the proportion of income derived from each activity. Respondents were also given the opportunity to list any other sources of bee-related income and to assign values to them. Respondents were instructed to assign a weight of zero to those sources that did not provide income.

The surveys, sent on 5 December 1994, were accepted for a 3-mo period. To determine if the relative values beekeepers assigned to colony traits were influenced by their sources of income, a series of comparisons were made between weights assigned by beekeepers in each single income category (see preceding paragraph) compared with those given by all other beekeepers combined (e.g., beekeepers deriving >10% of their income from queen and nucleus sales versus all other beekeepers). These comparisons were made using chi-square analyses (PROC FREQ, SAS Institute 1985). The results of these analyses allowed us to identify groups of beekeepers who derived their income from different sources.

The equations given by Rinderer (1986) were adjusted to exclude heritabilities and correlations between traits (see equation 3). The resulting modified selection index is given in equations 4 and 5:

$$I_{mod} = z_{hp}V_{hp} + z_{tr}V_{tr} + z_{hy}V_{hy} + z_nV_n + z_{ow}V_{ow} + z_{sb}V_{sb} + z_{wf}V_{wf} + z_{sw}V_{sw} + z_{tp}V_{tp} + z_{st}V_{st} \quad [4]$$

where I_{mod} = modified selection index for a genetic family of bees. z_{hp} = honey production z-score, derived from weight of extracted honey. V_{hp} = the average economic value assigned by a set of beekeeper respondents. Other V_i-values in the equation were similarly the averages of values assigned by beekeepers in the questionnaire except for V_{hy}, as explained below. z_{tr} = tracheal mite z-score, derived from bees sampled in November 1994 and analyzed for tracheal mite prevalence and abundance (see below), and multiplied by −1. For bee families for which no data were available, the average z-score was awarded. z_{hy} = hygienic z-score, derived from hygienic behavior (e.g., removal of worker pupae in 24 h from three sets of seven capped cells pricked with a pin (Newton and Ostasiewski 1986). V_{hy} = the average economic value assigned to hygienic behavior. This value was derived from summing the weights assigned by beekeepers for chalkbrood (Gilliam et al. 1983), American foulbrood (Rothenbuhler 1964, Thompson 1964), and half (arbitrarily determined) the value for *Varroa* mites (Boecking et al. 1993, Szabo 1993, Boecking and Spivak 1999). z_n = Nosema z-score, derived from analyses of samples of 25 bees per colony (see below); z-scores were multiplied by –1 to account for the fact that lower Nosema counts are preferable. z_{ow} = overwintering ability z-score, derived from the percentage of colonies in a genetic family surviving the winter of 1993–1994. z_{sb} = spring build-up z-score, derived from the sum of ½ the z-score of cluster size and ½ the z-score of spring brood area. z_{wf} = z-score for winter food storage and use, derived from the sum of ½ the z-score of brood chamber weight gain and −½ the z-score of total stores consumed. z_{sw} = swarming tendency z-score, derived from rating of swarming tendency. z_{tp} = temperament z-score, derived from defensiveness scores. z_{st} = comb-behavior z-score, derived from rankings of stability on the comb. Details of the methods used to evaluate colony characteristics can be found in van Engelsdorp (1995).

Z-scores are calculated as follows:

$$z = \frac{T - L}{S_L} \quad [5]$$

where z = z score for a genetic family of bees, T = average value for a given trait of a genetic family, L = average value for a given trait for all nine families of bees, and S_L = the variance for a given trait for all colonies. This modified selection index was applied to each of the nine genetic families of bees under evaluation for tracheal mite resistance and other characteristics (van Engelsdorp 1995). As used here, a family of bees is defined as a set of colonies headed by sister queens.

The nine families chosen for this study came from three different breeding efforts. Three families were used to represent the Buckfast bees currently being bred by Ontario Buckfast breeders for their honey bee tracheal mite (HBTM) resistance. Three families represented British Colombia bee breeders' stocks selected resistance to HBTM. Finally, three families where chosen to represent Ontario commercial stock that had not experienced any selection pressure for HBTM resistance.

As discussed by Danka et al. (1995), van Engelsdorp (1995), and Lin et al. (1996), mite prevalence alone may not be a reliable estimate of relative tracheal mite resistance. Consequently, the z-score for tracheal mite resistance was derived from the average of the z-scores of tracheal mite prevalence and abundance, as determined from November 1994 samples of bees. Nosema incidence was estimated by counting spores from samples of 25 bees taken from colonies on 25 April 1994. The z-scores for tracheal mite infestations, nosema spore counts, and winter food consumption were all multiplied by –1 to account for the fact that small rather than large z-scores are preferred by beekeepers for these traits. The z-score for spring build-up was derived from the average of the z-scores of both cluster size and brood area measurements, as both are important contributors to spring build-up (Sugden and Furgala 1982b, Woyke 1984, Harbo 1993). Likewise, the need to feed colonies in the fall (V_{wf}) was determined from both how much honey colonies stored in their brood chambers (e.g., increase in brood chamber weight during the summer) and how much honey was consumed during winter (with the values for this latter component multiplied by –1).

Results

Of the 153 surveys sent, 64 were returned within 3 mo. Six were incomplete, yielding a successful return of 37.9%.

Comparisons of beekeepers who derive their income from different sources demonstrated a significant difference ($P < 0.05$) only between the economic values given to traits by queen and nucleus producers (n = 8; respondents receiving >10% of their bee-related income from queen and nucleus sales) and honey producers (n = 50; respondents who obtained <10% of their income from queen and nucleus sales) (Table 1). Queen and nucleus producers valued honey production, tracheal mite resistance, and varroa mite resistance less than honey producers. Conversely, queen and nucleus producers felt that overwintering ability, low swarming tendency, and temperament were more important than did the honey producers (Table 1).

Table 1. Comparative value of colony traits and beekeeping-related income, as derived from a survey of 58 Ontario beekeepers who owned or operated 100 or more hives

	% response		
	Honey producers	Queen and Nuc producers	Total
No. of respondents	50	8	58
Colony trait			
Honey production	35.4 ± 2.59	27.3 ± 5.36	34.4 ± 2.40
Resistance to tracheal mites	9.1 ± 0.88	7.4 ± 0.84	8.8 ± 0.79
Resistance to nosema	3.3 ± 0.56	3.6 ± 0.50	3.4 ± 0.40
Resistance to American foulbrood	6.9 ± 1.08	5.5 ± 0.72	6.4 ± 0.90
Resistance to chalkbrood	3.0 ± 0.42	3.3 ± 0.59	3.0 ± 0.40
Resistance to varroa mite	10.6 ± 1.70	7.0 ± 0.99	9.9 ± 1.50
Overwintering ability	9.3 ± 0.86	14.6 ± 2.28	10.0 ± 0.80
Spring brood build-up	6.4 ± 0.84	6.1 ± 0.94	6.4 ± 0.70
Fall termination of brood rearing	2.0 ± 0.33	2.9 ± 1.06	2.2 ± 0.33
Ability to store winter food	1.9 ± 0.40	2.8 ± 0.88	2.0 ± 0.40
Tendency to swarm	3.8 ± 0.56	8.0 ± 0.94	4.3 ± 0.50
Temperament	5.3 ± 0.68	7.0 ± 0.87	5.5 ± 0.60
Stability/calmness on the comb	2.3 ± 0.46	3.3 ± 0.59	2.5 ± 0.40
Other	0.6 ± 0.52	0.6 ± 0.52	0.5 ± 0.32
Source of bee related income			
Pollination	5.4 ± 1.47	9.8 ± 2.97	6.0 ± 1.17
Farm gate honey sales	24.5 ± 3.88	14.6 ± 3.18	22.7 ± 3.48
Self packed honey retail	20.2 ± 4.02	16.3 ± 5.22	20.1 ± 3.58
Bulk honey sales	37.4 ± 5.26	32.1 ± 7.21	37.0 ± 4.70
Queen sales	0.2 ± 0.15	4.0 ± 1.09	0.8 ± 0.35
Nuc/colony/package sales	0.6 ± 0.24	15.8 ± 3.62	2.7 ± 0.94
Other bee products (e.g., wax)	4.2 ± 0.69	2.5 ± 0.72	4.1 ± 0.62
Processed bee products	0.3 ± 0.15	4.6 ± 3.07	0.9 ± 0.55
Other	5.0 ± 2.33	0.0 ± 2.33	4.4 ± 2.03

Beekeepers who obtained >10% of their income from queen and nucleus sales were considered "Queen and nuc producers." Column totals may not add to 100 because of rounding.

Some respondents indicated other traits of importance, including willingness to draw out foundation, appearance of wax cappings on comb honey, and absence of burr comb. The respondents who valued these traits listed the sale of comb honey or beeswax candles as other sources of income.

Z-scores for each trait were calculated for each of the nine honey bee families studied (van Engelsdorp 1995) (Table 2). Because z-scores are both positive and negative and centered around zero, when the z-scores for a particular trait in all the families of bees are summed, a value of zero is obtained. Z-values reflect not only the relative rank order of each family in comparison with the others, but also the magnitude of the differences between the families for a given trait. For example, the tendency of colonies not to swarm was found not to differ significantly among families, and the range of z-score values for this trait (−1.831 to +1.064) was smaller than the range of z-scores for hygienic behavior (−1.216 to +2.240), a trait for which significant differences between families were detected.

When the z-scores for all traits of a bee family are summed (i.e., the sum of the phenotypic scores with equal values given to all traits; Table 3), the Bkf ug4 family (colonies headed by daughters of the Bkf ug4 queen) appears to be the best, followed in rank by the BC2, Cnd BC, and Bkf ug3 families. The Cnd UG family ranked last with respect to phenotypic scores when compared with the other eight families.

I_{mod} values (Table 3) were calculated using equations 4 and 5, the z-score values (Table 3), and the V-values (derived from Table 1) assigned by honey producers, queen and nucleus producers, and all beekeepers combined. The Cnd BC family had the highest I_{mod} value regardless of whether the V-values for honey producers, queen and nucleus producers, or all producers were used. The queen and nucleus producers would have ranked the BC2 family second compared with the other genetic families, whereas the honey producers would have ranked this family fifth. Furthermore, honey producers would have ranked the Bkf ug4 family second, whereas the queen and nucleus producers would have ranked this family third. These differences are largely accounted for by

Table 2. List of z-scores calculated using equation 4 for honey production (z_{hp}), tracheal mite resistance (z_{tr}), hygienic behavior (z_{hy}), nosema resistance (z_n), overwintering ability (z_{ow}), spring build-up (z_{sb}), ability to store winter food supplies in the brood chamber (z_{wf}), tendency not to swarm (z_{sw}), temperature (z_{tp}), and stability on the comb (z_{st})

	Z-score for colony traits									
	z_{hp}	z_{tr}	z_{hy}	z_n	z_{ow}	z_{sb}	z_{wf}	z_{sw}	z_{tp}	z_{st}
BC1	0.101	0.571	−0.336	−2.577	1.106	0.640	−0.027	−0.383	−0.222	−0.323
BC2	−1.109	1.393	2.240	0.580	−0.230	−0.926	−0.382	1.064	0.817	1.222
BC3	−1.763	0.000	−0.363	0.824	−2.329	−1.985	−0.706	0.883	0.797	0.790
Bkf ug1	0.407	−1.668	−0.961	0.666	0.215	−0.109	−0.008	−0.546	−0.122	0.141
Bkf ug3	0.596	0.586	−0.542	0.515	−0.037	−0.346	0.653	0.702	0.358	−0.045
Bkf ug4	0.469	0.493	−0.625	−0.645	1.106	−0.210	1.440	1.064	1.057	1.037
Cnd BC	0.926	−0.486	1.011	0.418	1.106	1.373	−0.579	−1.831	0.378	0.234
Cnd PM	−1.225	0.000	0.792	−0.604	−0.898	0.344	−0.056	0.575	−0.402	−0.539
Cnd UG	1.598	−0.889	−1.216	0.824	−0.039	1.218	−0.334	−1.528	−2.661	−2.517
Mean	21.41 kg	—	63.22	1.67×10^3 spore/bee	86.0%	—	—	4.01 rank	4.07 rank	4.12 rank
SD	7.13	—	10.87	1.73	12.48	—	—	0.55	0.50	0.32

Means and standard deviations are given in all cases when the z-score was calculated using only one set of measurements. z_{tr} was calculated using both mite prevalence and abundance, z_{ab} was calculated with pre-nectar flow cluster size and brood area measurements, and z_{ff} was calculated by total weight consumed and total brood chamber weight gain (van Engelsdorp 1995).

Table 3. Comparison of summed z-scores (not adjusted by economic value) and modified selection indexes

Honey bee lines	Summed z-scores		Modified selection index honey producers ($n = 50$)		Queen and nucleus producers ($n = 8$)		All beekeepers ($n = 58$)	
	z-score	Rank	I_{mod}	Rank	I_{mod}	Rank	I_{mod}	Rank
BC1	−1.450	5	0.059	6	−0.017	5	0.070	6
BC2	4.671	2	0.121	5	0.879	2	0.116	4
BC3	−3.853	8	−0.909	9	−0.950	9	−0.902	9
Bkf ug1	−1.985	6	−0.143	7	−0.435	7	−0.137	7
Bkf ug3	2.440	4	0.232	3	0.056	4	0.232	3
Bkf ug4	5.185	1	0.332	2	0.251	3	0.355	2
Cnd BC	2.549	3	0.582	1	0.796	1	0.570	1
Cnd PM	−2.011	7	−0.409	8	−0.117	6	−0.408	8
Cnd UG	−5.546	9	0.134	4	−0.463	8	0.104	5

Calculation of the modified selection indices takes into account the relative economic values (V-values) of individual traits, as determined from a survey of commercial Ontario beekeepers. Three sets of I_{mod} values are presented using the v-values (Table 1) assigned by honey producers, queen and nucleus producers, and all respondents combined.

the different values honey producers and queen/nucleus producers place on honey production, tendency not to swarm, temperament, and stability on the comb. The BC3 family had the lowest I_{mod} values regardless of which of the three sets of V-values were used.

Discussion

When making comparisons between different genetic lines or families of bees, one could weight each trait equally and simply add the z-scores for different traits to obtain an overall phenotypic score. Alternatively, one could calculate a selection index, which takes into account the relative value of each trait. The latter method is more realistic when beekeepers themselves assign the V-values. The comparison of these two methods here clearly demonstrates the benefits of including the economic value of traits when comparing honey bee lines. For example, the Cnd BC line, ranked third on the basis of its overall phenotypic score, was ranked first using I_{mod} scores (Table 3). This difference can be explained by the relatively high value all beekeepers placed on honey production, disease resistance (expressed in this survey as hygienic behavior), overwintering ability, and spring build-up. In all of these traits the Cnd BC family performed relatively well.

The difference in the rankings of I_{mod} values for particular bee lines as determined for honey producers and queen/nucleus producers is significant in that it suggests that bee breeders may not be producing bees that have the traits desired by honey producers. For example, a bee breeder might have used a queen from the BC2 family as a breeder because it ranked second using the V-values assigned by the queen and nucleus producers (Table 3), largely because of good overwintering ability and its low tendency to swarm. This same BC2 family, however, would not have been the most appropriate genetic stock for honey producers, largely because of its poor honey production.

Differences in the selection criteria of honey producers and queen/nucleus producers are relatively small in Ontario because all beekeepers derive the majority of their bee-related income from honey production. In contrast, queen and package bee producers in the United States represent a distinct group of beekeepers who derive most of their income from the sale of bees, not honey. They may inadvertently select stock that overwinters with large bee populations and starts spring brood rearing early in the year, traits that are not valued and are even disliked by commercial honey producers, particularly those whose bees live in regions with cold climates. Beekeepers who obtain most of their income from pollination services may have yet a different set of selection criteria. For example, it has been recently demonstrated that strains of bees selected for pollen-hoarding, a trait that is enhanced at the expense of nectar foraging (Page and Fondrk 1995), are better pollinators of cranberries (Cane and Schiffhauer 2000). A partial solution to resolve these differences is practiced by some commercial queen producers who request that their major customers return to them queens from exceptionally productive colonies, which will be used as breeder queens the next year. However, this practice lacks objectivity and is based almost exclusively on honey production.

The use of I_{mod} scores as outlined here would allow any colony or genetic line of bees to be objectively evaluated once appropriate V-values for traits of concern are agreed upon. This would facilitate the exchange of queens of known characteristics between bee breeders. Similarly, if the traits under evaluation and z- or I_{mod} scores were available for the breeder queens of queen producers, beekeepers with specific needs could make informed decisions when purchasing queens. Currently, such information is not available. Some bee breeders have adopted standardized evaluations. For example, Buckfast bee breeders in Scandinavia use a standard evaluation scheme that allows for queens produced by different beekeepers to be compared objectively on the basis of five different traits. Cobey and Lawrence (1988) have published a relatively simple evaluation scheme that they have used in the improvement of the New World Carniolan bee stock. The general absence of standardized evaluations in North America currently limits the rate at which bee breeding can progress.

The idea of using selection indexes has been advanced previously (Rinderer 1977b 1986) but there has been little progress in this direction. We chose to adopt a modified selection index (Rinderer 1986) that ignores genetic concerns, largely because heritabilities of traits and correlations between them are difficult to determine and likely to remain poorly understood. Our approach is the first to incorporate V-values assigned by beekeepers. It offers a method of objectively evaluating bee stocks that could be adopted by the beekeeping industry. We have also demonstrated that it is sensitive to the different values assigned to various traits by specific groups of beekeepers.

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