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Evaluation of the functional characteristics of selected breeding lines of Carniolan bees (*Apis mellifera carnica*)

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The aim of this study was to evaluate the functional and biological characteristics of the Pogórska (Cb) and Austrian (Ca) lines of Carniolan bees. The study was conducted in four consecutive nectar flow seasons at a stationary apiary in the north-west Opole region. Honey yield, spring development, dynamics of development, swarming, defensive behaviour, and overwintering of colonies were evaluated. Honey yield assessment was based on the number of kilograms of honey harvested from each colony, and the remaining features were rated on a scale of 0 to 3. In the overall assessment the Ca line achieved better results than the Cb line. The Ca line had the highest rating in terms of honey yield (18.2 kg), spring development (2.98 pts.) and dynamics of development (2.97 pts.). The Cb line was rated higher in terms of overwintering (2.89 pts.). In the case of swarming, both lines were rated at 2.96 points. Gentleness was also comparable in the two lines. The 4-year study demonstrated that the year (weather conditions) had a significant impact on the assessment of the individual breeding lines. The overall assessment showed statistically significant differences between the breeding lines only in terms of the honey yield of the bee colonies.

KEY WORDS: ***Apis mellifera carnica*** **/ breeding lines / performance characteristics**

The economic outcomes of beekeeping are closely associated with the climate and meteorological conditions in a given region and with the honey bees themselves. The climate affects the type of vegetation in the area, while the weather influences nectar secretion and pollination of flowers, as well as the possibility and intensity of the work of forager bees. Achieving satisfactory results in the apiary requires botanically diverse and abundant bee pastures at a suitable distance from the hive (up to 2.5 km) and strong honey bee colonies during flowering of honey plants.

The productivity of the honey bee colony depends on numerous factors, including the breed of the bees and the distance they must travel to find material and transport it to the nest [10, 12, 24].

Environmental conditions in Poland vary considerably in terms of the length and severity of the winter, the earliness and length of spring, the length of the growing season, the richness of vegetation constituting nectar sources, and weather patterns during the season. Honey bees in different parts of the country must therefore be adapted to different environmental conditions. For this reason, the task of breeding work conducted on honey bees of different breeds is to produce new lines within a given breed that are adapted to the weather and nectar flow conditions in a given region. Likewise, the varied environmental conditions in Poland are the main reason that queen bees of different breeding lines are subject to evaluation at the apiary and in the field. The scope of evaluation at the apiary and the methods used are established by breeders on the basis of minimum requirements for queen bees entered in the books or registers, and in connection with the specification of selection thresholds. The scope of the assessment of traits at the apiary is adjusted individually to the breeding standard for each breeding line [22]. Evaluation of the breeding value of honey bees is much more difficult than in the case of other livestock species, as the characteristics of the honey bee family depend on the traits of the queen, the drones and the workers [2]. The main purpose of evaluation at the apiary is to improve the breeding material by selecting for reproduction bees with high breeding and use value. Equipped with the results of the assessment, beekeepers can more easily choose a queen from the breed or breeding line best suited to an apiary in a given area with specific environmental conditions [22]. For breeding to produce the expected results, the selection of pairs must be controlled. In the case of the honey bee, this is only possible when queen bees are artificially inseminated with the semen of drones of known origin. Controlled selection of pairs for breeding makes it possible to conduct breeding work to obtain separate lines within bee breeds.

Carniolan honey bees are adapted to the specific climatic and nectar flow conditions of Europe. During their adaptation to new conditions they lost some of their original traits. By crossing with local populations in different parts of Europe, they produced heterotic interbreed crosses, which led to the displacement of local bees that were well matched to local conditions, such as the European dark bee [17].

The Pogórska (Cb) line of the Carniolan honey bee was bred in Poland. It is adapted to the climate and nectar flow conditions of the south-western part of the country, the foothills, the coastal belt and Masuria. As a result of many years of inbreeding, the line is now in an advanced stage of inbreeding depression. It is very gentle and characterized by early spring development and a low swarming tendency [21].

The Austrian line of Carniolan honey bee (Ca) was imported from Austria (Lower Austria). Due to their very early spring development, it is popular in south-western Poland, where early-flowering plants (e.g. orchards and winter rapeseed) are its main source of nectar. Bees of this line are gentle, but have a tendency to swarm, especially when nectar is lacking or during long periods of bad weather [21].

During assessment at the apiary, particular attention is paid to honey yield (the most important production characteristic), overwintering, swarming tendency, gentleness or defensive behaviour (character), and colony development, i.e. earliness and dynamics of development.

Overwintering and colony development are the most important traits in terms of productivity, because they directly determine the strength of the colony, i.e. the number of workers in the colony. Swarming tendency, as a primitive feature of the honey bee, is eliminated in large-scale farming, because swarming colonies substantially increase the labour required to run the apiary while decreasing its productivity. Overly aggressive bees are more difficult to work with and can pose a threat to people and animals in the vicinity of the apiary [19].

Strong honey bee colonies are in a state of natural biological balance, owing to which they exhibit their full production potential in conditions of abundant nectar flow. A disturbance of this state, e.g. by disease, lack of a queen, swarming impulse or faulty work by the beekeeper, can affect the bees' productivity, including the honey yield. Honey production is affected by the interaction of the bees' hereditary traits, such as egg-laying intensity or the lifespan and diligence of the workers, with appropriate environmental conditions (e.g. weather and nectar flow). Another important factor is how the beekeeper guides the development of the colony with respect to the nectar flow period. During the period when nectar flow is highest, there should be many workers in the hive and not much bee brood, especially open brood. This relieves the bees of labour-intensive work in the nest (feeding the brood) so they can devote their efforts to collecting nectar [6, 9]. Temperature conditions during flowering of plants are also very important. Hot weather significantly reduces honey and pollen yield in bees [1, 3]. The return of the bee colony to its original state takes at least 40 days [4].

Our study analysed selected functional and biological traits of two breeding lines of Carniolan honey bees: Pogórska (Cb) and Austrian (Ca). Honey yield, spring development, dynamics of development, swarming tendency, gentleness (intensity of defensive behaviour), and overwintering of colonies were evaluated. The aim of the study was to determine which of the breeding lines has better breeding potential in the natural conditions of south-western Poland.

Material and methods

The study was conducted in a stationary apiary in four successive nectar flow seasons, 2007-2010. The honey bees were kept in Dadant hives. All queens used in the bee colonies were artificially inseminated, using semen from drones of the same breeding line and from one breeding apiary. The research material consisted of 25 colonies from Carniolan queen bees of two breeding lines: Pogórska (Cb) and Austrian (Ca). The queens in the colonies were replaced every two years or as needed. During the study 117 queens were evaluated, including 59 from line Ca and 58 from line Cb.

The use and breeding value assessment of the honey bees, conducted at the apiary, included honey yield, spring development, dynamics of development, overwintering, swarming tendency and gentleness (intensity of defensive behaviour). Honey yield was assessed on the basis of the number of kilograms of honey obtained from each colony in successive nectar flow seasons.

The measure of spring development was the number of combs covered by bees and the number of combs with brood during the first spring inspection (inspection I – late March/early April) and during full flowering of apple trees (inspection II – late April/early May), as well as colony strength during the main honey flow period (inspection III – late May/early June). Dynamics of development was assessed on the basis of the increase in the number of combs with brood from the inspection during full flowering of apple trees to the inspection during acacia bloom (Table 1). During the main honey flow period a queen excluder was used in all the hives with sufficiently strong families, leaving 10 combs per brood chamber.

Table 1

Criteria for evaluation of the dynamics and earliness of bee colony development in the spring

Scoring	Hive examination						Dynamics of development	Spring development
	I		II		III			
	combs[1]	brood[2]	combs[1]	brood[2]	combs[1]	brood[2]		
0 pts	≤4	0	≤5	1	≤6	2-3	stagnation	very late development
1 pts	≤4	1-2	5-6	3-4	7-9	4-5	low	late development
2 pts	5-6	3-4	7-8	5-6	10-12	6-7	medium	mid-early development
3 pts	7-8	5-6	9-10	7-8	13-15 + super	9-10	high	early development

[1]Number of combs covered by bees
[2]Number of combs with brood

Winter hardiness was assessed on the basis of the state of the colony (number of combs covered with bees) after the end of autumn egg laying (second half of October), colony strength after overwintering (number of combs covered with bees), the need to reduce the number of combs, winter death, moisture in the nest, and the occurrence of dysentery after winter (Table 2).

Swarming tendency was evaluated on the basis of cessation of brood production during the season, egg laying in queen cells and building of queen cells, number of queen cells, reaction to anti-swarming treatments, and swarming of the colony, if any (Table 2).

Table 2
Point assessment of selected biological traits

Trait	Scoring			
	3 pts	2 pts	1 pts	0 pts
Swarming tendency	no tendency to swarm, no queen cells	fast reaction to anti-swarming treatments; single queen cells	no reaction to anti-swarming treatments; numerous queen cells	colony swarmed
Winter hardiness	good	medium	poor	bees died during overwintering
Defensive behaviour	very gentle	gentle	vicious	very vicious

Intensification of defensive behaviours was assessed on the basis of bee behaviour during each inspection. Maximum points were assigned to calm bee behaviour, even under difficult conditions, during long inspections (Table 2).

Statistical analysis of the results was performed using the SAS package ver. 9.0 [20]. Means and standard deviations were also calculated for individual characteristics (proc MEANS) and Pearson's correlations between the characteristics were estimated.

Statistical calculations were performed using the SAS GLM procedure [20] with a linear model that included the following effects:

$$y_{ijk} = \mu + \alpha_j + \beta_k + (\alpha \text{ x } \beta)_{jk} + e_{ijk}$$

where:

y_{ijk} – observed value of feature

μ – mean value of feature in the population

α_j – effect of breeding line (1, 2)

β_k – effect of year (1, 2, 3, 4)

$(\alpha\beta)_{jk}$ – effect of interaction between breeding line and year

e_{ijk} – sampling error

Significance of differences between pairs of means was tested by Duncan's test.

Results and discussion

The assessment of the honey yield of the bee colonies showed that the Ca line was more productive. On average 18.2 kg of honey per season was obtained from the colonies of this line, as compared to only 15.3 kg ($p \leq 0.01$) from the Cb line. In successive years, from 16.8 to 20.5 kg of honey on average was obtained from the Ca bees (Table 3). Different results were reported by Roman and Bursy [18], who obtained 18.8 kg of honey from Carniolan honey bees of the Ca line and over 24.9 kg from the Cb line. Statistically significant differences were noted in honey production within the lines between the years of the study (Table 3). This was also confirmed by Gontarz [7], who found that the year had a very significant influence on the honey yield of bee colonies. According to Prabucki and Chuda-Mickiewicz [17], in the climatic conditions of Poland the honey yield of Carniolan honey bees (13.61% and 9.07%) is lower than that of European dark bees (23.07% and 17.10%). The introduction of purebred queens into commercial apiaries has improved the honey yield of colonies in different degrees: the effect has been most beneficial in the European dark breed, and less so in Carniolan honey bees. A study by Prabucki and Chuda-Mickiewicz [17] on the honey yield of Polish lines of the European dark bee and their crosses with other breeds have shown that the pure lines of this honey bee had a yield of 10.2 to 27.0 kg of honey per season.

Table 3
The honey yield of bee colonies from selected breeding lines of Carniolan bees from 2007 to 2010

Specification	Years								Average from 4 years	
	2007		2008		2009		2010			
	Ca	Cb	Ca	Cb	Ca	Cb	Ca	Cb	Ca	Cb
Minimum	9.4	7.8	11.3	9.2	11.2	8.8	8.9	8.3	13.6	10.5
Maximum	22.9	21.0	29.1	26.6	26.2	21.8	27.9	19.5	23.7	19.5
Average	16.8^{A}	15.4^{A}	20.5^{*Bb}	18.4^{*B}	17.6^{**A}	14.1^{**A}	18.0^{**a}	13.4^{**A}	18.2^{**}	15.3^{**}
SD	3.78	3.7	5.09	4.4	4.15	3.4	5.47	3.31	2.45	1.72

*Significant differences between breeding lines in a given year, $p \leq 0.05$
**Highly significant differences between breeding lines in a given year, $p \leq 0.01$
a, b – significant differences between the years of research for individual lines, $p \leq 0.05$
A, B – highly significant differences between the years of research for individual lines, $p \leq 0.01$

In 1992, a study at the Regional Animal Breeding Station in Szczecin [14] demonstrated that the honey yield of crossbreds of the European dark bee with the Carniolan honey bee was as much as 60% higher than that of Carniolan bee colonies. However, in conditions of moderate nectar flow, Carniolan honey bees achieved the best results. During periods of abundant continuous and interrupted nectar flow, the honey yield of the European dark bee was 25% to 38% higher than that of Carniolan honey bees. The estimates presented by Prabucki and Chuda-Mickiewicz [16] indicate that Carniolan crossbreds achieve better production results than purebred Carniolan honey bees.

In the conditions of south-western Poland, the main nectar source for honey bees is winter rapeseed, which usually begins flowering in early May. In order for colonies to make maximum use of this nectar, they must have sufficient strength at that time. For this reason, the climate and nectar flow conditions of this region require bees with rapid spring development. The results of the four-year study indicate that the two lines were similar in this respect. On average for the entire period, the Ca line achieved a score of 2.98 points and the Cb line had 2.94 points. Only in the first year (2007) was the Ca line significantly

Table 4
Evaluation of biological traits of selected breeding lines of Carniolan bees from 2007 to 2010

Trait	Line		Years				Average
			2007	2008	2009	2010	
Spring development	Ca	mean	2.98**	2.95	2.99	3.00	2.98
		SD	0.13	0.21	0.11	0.0	0.14
	Cb	mean	2.49**A	2.97B	2.97B	2.88B	2.94
		SD	0.23	0.12	0.16	0.32	0.25
Dynamics of development	Ca	mean	2.95	2.95	2.98	3.00*	2.97
		SD	0.21	0.21	0.16	0.0	0.17
	Cb	mean	2.89	2.99	2.95	2.85*	2.92
		SD	0.32	0.10	0.22	0.37	0.28
Swarming	Ca	mean	3.00b	2.96	2.85a	3.00b	2.96
		SD	0.0	0.19	0.39	0.0	0.22
	Cb	mean	3.00b	3.00b	2.79a	3.00b	2.96
		SD	0.0	0.0	0.61	0.0	0.29
Winter hardiness	Ca	mean	2.90b	2.50a	2.80	2.80	2.75
		SD	0.35	0.82	0.42	0.38	0.51
	Cb	mean	2.90	2.85	2.90	2.90	2.89
		SD	0.33	0.36	0.32	0.25	0.32
Defensive behaviour	Ca	mean	2.98	3.00	3.00	2.96	2.98
		SD	0.13	0.0	0.0	0.21	0.16
	Cb	mean	2.92	2.94	2.97	3.00	2.96
		SD	0.26	0.28	0.16	0.0	0.20

*Significant differences between breeding lines in a given year, $p \leq 0.05$
**Highly significant differences between breeding lines in a given year, $p \leq 0.01$
a, b – significant differences between the years of research for individual lines, $p \leq 0.05$
A, B – highly significant differences between the years of research for individual lines, $p \leq 0.01$

inferior to the Cb line, with only 2.49 points (Table 4). Statistically significant differences were noted in the spring development of the Cb line between the first year and the remaining years of the study.

The climatic conditions of south-western Poland in recent years have delayed the flowering of early spring plants, while that of later plants has accelerated. This has resulted in the simultaneous blooming of most pollen and honey plants in a relatively short time. Strong bee colonies that reach the peak of their development early were needed to exploit such rich resources. According to a study by Gromisz [9], Carniolan honey bees are characterized by intense spring development, which contributes to better utilization of early spring nectar sources. Hellmich et al. [10] demonstrated that honey bee yield can be additionally modelled through appropriate breeding work, especially by selection taking into account the desired performance traits.

In terms of dynamics of development, the Ca line was superior, with 2.97 points, while the Cb line had 2.92 points. Only in the last year of the study was the Ca line was clearly better ($p<0.05$), with a score of 3.00 points, while the Cb line had 2.85 points (Table 4). Tests carried out at the apiary of the Regional Animal Breeding Station in Szczecin [14] have shown that in terms of dynamics of development, crossbreds of European dark bees and Norwegian bees stood out, while the Carniolan bee was slightly inferior. On the other hand, the native Dobra line of Carniolan honey bee stayed longer in the winter cluster than other Carniolan bees, and thus began egg laying later in the spring and dynamic development only after the weather had stabilized [13]. Olszewski [15] showed that Buckfast bees do not develop as well in the spring as Caucasian and Carniolan crossbreds. Gontarz reported that Carniolan honey bees develop in the spring and become strong much faster than Caucasian honey bees.

Swarming tendency is treated as an additional performance parameter. In modern beekeeping it is an undesirable phenomenon because it markedly reduces the honey yield of bee colonies and of the apiary as a whole. Our research showed that the mean score for swarming tendency during the entire study period in both breeding lines was 2.96 points (Table 4). This parameter was also high in each year, oscillating near 3.00 points. Only in 2009 did the bee colonies of both lines have a greater swarming tendency than in other years, as the Ca line received 2.85 points and the Cb line 2.79 points. Apart from the hereditary tendency of bees to swarm, unfavourable weather conditions and nectar flow patterns also contribute to manifestation of this trait. According to a study by Roman and Bursy, Carniolan honey bees of the Ca line were less susceptible to the swarming impulse (3.71 points on a 4-point scale) than the Cb line (3.64 points on a 4-point scale). Likewise, honey bees of the Car Dobra line exhibit little swarming tendency [13]. On the other hand, in a study conducted at the Regional Animal Breeding Station (OSHZ) in Szczecin [14], all evaluated groups of Carniolan honey bee colonies, both crossbred and of pure lines, exhibited a stronger tendency to swarm. Olszewski [15] also reported a greater swarming tendency in colonies of Caucasian bees crossbred with Carniolan honey bees in comparison with Buckfast bees. On the other hand, Gontarz [7] found that

Carniolan honey bees exhibited a significantly lower swarming tendency than Caucasian bees. According to Bratkowski and Wilde [4], swarming tendency does not always have a negative impact on the honey yield of bee colonies.

Winter hardiness is a feature that expresses the adaptation of honey bees to local climatic conditions, the length of winter, and the difficult transition period from winter to spring. In the climatic conditions of southwestern Poland, surviving the winter is not a significant problem for honey bees. However, the end of winter and early spring are the periods when the most honey bee colonies die. In terms of winter hardiness, the Cb line earned a better average score from the four years (2.89 points) than the Ca line (2.75 points) line (Table 4). Roman and Bursy [18] have reported similar results, with the Ca line receiving a lower score (3.00 points on a 4-point scale) than the Cb line (3.44 points on a 4-point scale). These data are corroborated by our own research, in which the assessment of winter hardiness in the 4-year period varied greatly, ranging from 2.5 to 2.9 points. On the other hand, a study conducted at OSHZ in Szczecin [14] showed no clear differences in winter hardiness between crossbreds of Carniolan honey bees with European dark bees and Carniolan purebred honey bees. Kareta [13], describing the Carniolan honey bee of the Dobra line, found good overwintering to be a distinctive feature, even on stores with an admixture of honeydew. Olszewski [15] also reported that in the conditions of south-eastern Poland Caucasian-Carniolan crossbreds survive winter better than Buckfast bees. Surprisingly, a study by Gontarz [7] found Carniolan honey bees to be in much poorer condition after the winter than Caucasian bees. Hońko and Jasiński [11], on the other hand, reported no significant differences in overwintering of Carniolan, Caucasian and European dark bees in the conditions of Finland. Similarly, Villa et al. [23], in their research on African, European and Africanized bees, showed no significant differences between them in terms of winter hardiness, which would mean that preparation of bees for overwintering has a more significant influence than their genotype. Genç and Kaftanoğlu [5] and Yeninar et al. [25] have demonstrated that the type of hive also has an enormous impact on overwintering of bee colonies. According to these authors, the lowest food consumption and lowest mortality are observed in wooden hives.

Gentleness is one of the most important biological characteristics that should be taken into account when selecting honey bee colonies. The tendency of bees to aggression depends on the genetic properties of a given colony, as well as on many external factors, especially weather, time of day, nectar flow conditions, and the manner in which the beekeeper works. Our study showed that the two breeding lines were equally gentle, attaining scores close to the maximum: Ca line – 2.98 points, Cb line – 2.96 points (Table 4). There were no significant differences in the assessment of gentleness between breeding lines, within a given line, or between the years of research. Viciousness in bees largely depends on the breed, as it is a hereditary trait passed on from generation to generation by queens from vicious colonies [19]. Roman and Bursy [18] rated bees of the Cb line (3.03 points on a 4-point scale) as gentler than the Ca line (2.84 points on a 4-point scale). In a study by Prabucki and Chuda-Mickiewicz [17], the Carniolan breed was assessed as gentle. Colonies from mating of lines of the European dark bee were found to be the most vicious (2.5 points). In tests conducted at OSHZ in Szczecin [14], the Carniolan honey bee was also classified as gentle. Similarly, in a study by Kareta [13], Carniolan honey bees of the Dobra line have been described as very gentle and calm.

Gregorc and Lokar [8] assessed the Carniolan honey bee as a characterized by good honey yield, rapid development, little tendency to swarm, and gentleness, as confirmed in our study. Gontarz [7] showed no significant differences between different breeding lines (J, L, N, Si, Sk and T) of Carniolan honey bees in terms of honey yield and biological characteristics, including swarming tendency and spring development.

Table 5
Value of correlation coefficient between traits

Traits	Breeding line	
	Ca	Cb
Honey yield – spring development	0.700**	–0.044
Honey yield – dynamics of development	0.591**	–0.053
Honey yield – swarming	–0.036	–0.037
Honey yield – defensive behaviour	–0.023	0.054
Honey yield – winter hardiness	0.495**	0.546**
Spring development – dynamics of development	0.740**	0.449*
Spring development – defensive behaviour	–0.019	0.008
Spring development – swarming	–0.030	0.072
Spring development – winter hardiness	0.612**	0.479**
Defensive behaviour – swarming	–0.026	–0.036
Defensive behaviour – dynamics of development	–0.022	–0.006
Defensive behaviour – winter hardiness	0.126	0.161
Swarming – dynamics of development	–0.035	–0.035
Swarming – winter hardiness	0.228	0.163
Dynamics of development – winter hardiness	0.672**	0.707**

*Correlations statistically significant at $p \leq 0.05$
**Correlations statistically significant at $p \leq 0.01$

In both lines in our study, statistically highly significant positive correlations were found between early development and both winter hardiness and dynamics of development; between honey yield and winter hardiness; and between dynamics of development and winter hardiness (Table 5). Although the positive correlations between early development and honey yield and between dynamics of development and honey yield appear to be obvious, they were only found for the Ca line. In the Cb line, no correlation was found between these characteristics, which is difficult to explain. There were also no statistically significant interactions between the effect of the breeding line and the effect of time (year).

In conclusion, the breeding material studied received high marks for honey yield and selected biological characteristics. The results of the study suggest that the introduction of the Carniolan breed for large-scale use should continue. In terms of gentleness, the two breeding lines of Carniolan honey bees were similar. The Carniolan bees of the Ca line were rated higher than the Cb line in terms of honey yield, swarming tendency, early development and dynamics of development. The Cb line received the highest scores for swarming tendency and the lowest for honey yield and dynamics of development. Taking into account all these characteristics, it can be concluded that the Ca line was assessed as superior to the Cb line. It was demonstrated that the choice of bee breed for a given apiary should be based on local weather and nectar flow conditions and the type of beekeeping, with Ca proving to be the more useful line. The study showed that the Ca and Cb lines of Carniolan honey bees are well adapted to the climatic and nectar flow conditions in south-western Poland.

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