Sub-indexes for bulls of Holstein breed in the Czech Republic

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ABSTRACT: Sub-indexes were constructed for bulls of the Holstein breed according to groups of production traits – production index for milk (IPH), sub-indexes for reproduction (IRH), longevity (IDH), health resistance (IOH) and fitness (IFH). Every index for selection for a group of traits applies all available information – breeding values for traits of milk performance, fertility and linear type trait classification. The sub-indexes were compared with the total index (SIH). The accuracy of total selection index (SIH) was 69.30%, the accuracies of the other indexes were as follows: IPH 83.32%, IRH 56.04%, IDH 9.80%, IOH 15.57% and IFH 9.86%. All of the indexes were standardised to have the mean 100 and standard deviation 12. Simplified index ZSIH was developed as a sum of IPH, IRH and IDH; its correlation with the total index is r = 0.992. If IPH is used, the values of secondary functional traits decrease. The use of IDH, IOH and IFH results in a decrease in milk performance. Selection differences, i.e. changes in breeding values at various intensities of selection according to some indexes and breeding values for kg of milk and kg of milk proteins, were tested on the basis of breeding values in a sample of the domestic population of bulls. The production index was compared with production indexes used in other countries. Correlations between production indexes were higher than r = 0.790.

Keywords: Holstein cattle; bulls; selection index; sub-indexes; production; reproduction; longevity; fitness; reliability; genetic gain

Přibyl et al. (2004) constructed the total index for selection of bulls of the Holstein breed (SIH). Sub-indexes can be used for potential intensive selection aimed at a group of desired traits. Total index can be expressed as a combination of sub-indexes. A change in the weights of sub-indexes in the total combination makes it possible to make up customised index according to economic conditions of the own herd. The construction of indexes is based on available sources of information – breeding values of all traits in animal recording.

Cunningham (1969, 1975) developed a method for the construction of selection indexes including relative importance of traits. Population genetic parameters and economic weights of traits are basic input data for index construction. The latest economic weights for cattle breeds in the Czech Republic were determined by Wolfová et al. (2001). Dědková and Wolf (2001) estimated genetic parameters for some traits. The influence of the use of economic weights of functional traits in selection programmes was studied by Groen et al. (1997). Weller et al. (1996) investigated the use of selection indexes in cattle breeding. The highest genetic progress is achieved when linear indexes and non-linear profit functions are used. Applying a simulation calculation the authors reported an increase in average profit by 0.4%. Methods to calculate linear selection indexes for non-linear profit functions were also investigated

Supported by the Ministry of Agriculture of the Czech Republic (Project No. QD 1234).

by Dekkers et al. (1996). Optimum selection index was derived on the basis of a modified theory of selection index construction when economic weights equalled the weighted average of partial derivatives of the profit function of trait averages in future generations.

Veerkamp (1998) published a review of measures taken to increase the economic efficiency of dairy cattle selection. Indexes containing traits of the linear type trait classification contribute to higher selection efficiency. Lindhe (1999) analysed selection indexes used in Sweden. The existing total merit index (TMI) was composed of 13 sub-indexes that were aimed at different groups of traits. The author examined genetic correlations between the particular sub-indexes. For the construction of new TMI sub-indexes were developed that were subsequently combined according to economic weights and mutual correlations.

In the area of development of selection sub-indexes in cattle breeding further traits, not used before now, have been included recently.

Amin et al. (1997) investigated correlations between milk yield and lactation persistency. They developed total and reduced selection indexes, sub-indexes and reduced selection sub-indexes. The expected genetic gain in daily milk yield by selection sub-indexes was similar to the corresponding value calculated by selection index, so the breeder can use a selection sub-index in the breeding program to improve daily milk yield. The contribution of persistency to improvement in daily milk yield was higher by sub-index than selection index application. The highest improvement of persistency was associated with the maximum improvement in daily milk yield per lactation and per calving interval and was achieved by a selection index which involved all these traits.

Boettcher et al. (1998) constructed a selection index for bull selection aimed at resistance to mastitis. A sub-index comprised milking speed, udder conformation and somatic cell score at first and subsequent lactations. The authors evaluated some variants of trait combinations and they concluded that the reliability of the index combining all traits increased by 15% compared to the index based on somatic cell score only. Similarly, De Jong and Lansbergen (1996) studied the influence of direct and indirect selection on the incidence of clinical mastitis. Resistance to mastitis was defined as a selection objective, and many combinations of traits of direct and indirect selection were examined. The selection index for direct and indirect selection provided a practically identical genetic response. The combination of direct and indirect selection resulted in an increase by 14%.

Veerkamp (1996) carried out a theoretical analysis of the construction of selection indexes for cattle aimed at feed intake and conversion. Besides the evaluation of sub-index variants he also studied the influence of traits of the linear type trait classification that were included in selection index.

An index for meat performance in dairy cattle based on carcass traits was constructed by Van der Werf et al. (1998). The index for meat performance was developed for slaughter calves, bull and cows. Standard deviation of the index was about 9% of the standard deviation of net merit index for milk performance traits.

A specific selection sub-index for fertility of daughters of bulls in the Netherlands (CI-index) was constructed by De Jong (1998). The sub-index was based on breeding values of two traits – non-return test at 56 days and post partum interval. These traits were combined in the index and compared with indexes in which also other traits were combined.

Pryce et al. (2002) analysed genetic relationships between calving interval and body condition score (BCS) by expressing the energy condition of a dairy cow. They investigated a possibility of BCS inclusion in selection index for fertility. Calving interval was used as a measure of reproductive performance. The use of this selection index increased milk performance.

The objective of the present paper is to construct sub-indexes for groups of traits in bulls of the Holstein breed: sub-indexes for milk production (IPH), reproduction (IRH), longevity (IDH), resistance (IOH) and fitness (IFH).

MATERIAL AND METHODS

To construct selection sub-indexes for Holstein bulls a methodical procedure similar to the construction of the total selection index was used (Přibyl et al., 2004). Economic weights of traits, genetic correlations and correlations between breeding values, genetic standard deviations and standard deviations of breeding values and reliabilities of estimations of breeding values for the particular traits were applied as input data to calculate weighting coefficients (b).

Total genetic gain of all traits in the genotype is calculated as the weighted sum of genetic gains for the particular traits multiplied by their economic weight.

The importance of a trait in total genotype (selection objective) is given by its ratio in total genetic gain. The importance of a trait (source of information) in selection index is determined as a percentage change in genetic gain if this trait is left off from the index.

The traits in total genotype (selection objective) in Table 1 can be included in several groups – milk, health, fertility, earliness/longevity, meat, adaptation to technologies. Economic weights were taken over from Wolfová et al. (2001) and complemented for other missing data on the basis of comparison with literature data and own study (Přibyl et al., 2004). They are overviewed in Table 1. Population genetic parameters were taken over from available sources (Šafus et al., 1998; Bouška et al., 1999; Dědková and Wolf, 2001).

Milk, fertility and linear type trait classification are traits under animal recording in Table 2 for which breeding values were determined. The table also shows standard deviations of breeding values that were calculated from the current national databank of Holstein bulls. Reliabilities of breeding value estimations in Table 2 were derived by the analysis of information volume available for individual bulls in the current national database.

Table 1. Breeding objective (total genotype)

Trait		Unit	Group of traits	EV	S_G
1	Milk plasma	kg	milk	–1.13⁺	501.00
2	Fat			13.12⁺	21.06
3	Protein			93.62⁺	15.61
4*	Milkability	kg/min	technology	700.00	0.20
5*	Mastitis	%	health	–19.00	7.50
6*	Metabolic disorders			–30.00	4.00
7	Calving interval – direct effect	day	reproduction	–39.00	7.00
8	Calving interval – maternal effect			–23.13⁺	7.00
9	Oestrus return in heifers – direct effect			–19.00⁺	5.50
10	Oestrus return in heifers – maternal effect			–17.86⁺	5.50
11	Calving – direct effect	0.01 class		–66.00	0.022
12	Calving – maternal effect			–33.00	0.013
13	Stillbirths – direct effect	%		–200.00	2.50
14	Stillbirths – maternal effect			–100.00	2.00
15	Age at 1st calving	day	earliness/longevity	–7.00⁺	30.00
16	Longevity	lactation		1000.00⁺	0.65
17	Weight of cows	kg	technology/nutrition	–10.00⁺	17.50
18*	Net gain	g/day	meat	9.76⁺	40.00
19*	Dressing classification	%		160.10⁺	0.20
20*	EUROP conformation	0.01 class		–5.19⁺	0.50
21*	Fattiness			–1.08⁺	0.30
22*	Nutrient consumption	MJ NE/kg gain		–163.40	1.50

*traits are not included in total selection index; EV = economic value; S_G = genetic standard deviations; ⁺economic weights taken over from Wolfová et al. (2001)

Table 2. Performance testing (source of information)

Trait		Unit	S_{BV}	r^2	S_G
1	Milk	kg	416.52	85	451.78
2	Fat content	%	0.21	83	0.23
3	Protein content		0.10	83	0.11
4	Own fertility	index	2.52	90	2.66
5	Fertility of daughters		1.52	53	2.09
6	Angularity	scores	1.13	60	1.45
7	Stature		1.18	60	1.53
8	Chest width		1.60	60	2.07
9	Body depth		1.50	60	1.93
10	Rump angle		1.46	60	1.89
11	Rump width		1.52	60	1.96
12	Rear legs		1.73	60	2.23
13	Foot angle		1.72	60	2.22
14	Fore udder attachment		1.45	60	1.87
15	Rear udder height		1.50	60	1.94
16	Central ligament		1.46	60	1.88
17	Udder depth		1.64	60	2.11
18	Front teat placement		1.62	60	2.09
19	Teat length		1.49	60	1.92

S_{BV} = standard deviations of breeding values; r^2 = reliabilities of breeding values; S_G = genetic standard deviations

Sub-indexes

Following the construction of the total index (SIH) for Holstein bulls (Přibyl et al., 2004) sub-indexes were developed for these groups of traits according to breeding objectives:

IPH – production index of milk performance (traits 1–3 from Table 1)
IRH – reproduction index (traits 7–14 from Table 1)
IDH – longevity index (trait 16 from Table 1)
IOH – resistance index (traits 5–6 from Table 1)
IFH – fitness index (jointly the traits IDH and IOH)

Breeding for a given objective is carried out through all traits examined in animal recording.

Standardised indexes

To make the animal selection easier indexes can be standardised to have the mean 100 and uniform variability. In accordance with the used expression of breeding values for milk performance we use standard deviation 12:

$$I_S = \frac{I - \bar{I}}{S_1} \times 12 + 100 \tag{1}$$

where: I_S = standardised index of evaluated bull
I = index for evaluated bull
$\bar{I}$ = the mean of indexes for all bulls
S_I = standard deviation of indexes

By summing the main sub-indexes we get a simplified index (ZSIH) that roughly corresponds to the total index (SIH). The simplified index does not include age at first calving and cow weight in the selection objective.

$$\text{ZSIH} = \text{IPH} + \text{IRH} + \text{IDH} \tag{2}$$

Simplified standardised index can be constructed by standardisation of the simplified index or as the sum of standardised sub-indexes multiplied (weighted) by coefficients (k) that express the ratio of standard deviations of the sub-index and simplified selection index plus constant Q = –48.3 (maintenance of the mean 100 and standard deviation 12).

$$ZSIH_S = k_P \times IPH_S + k_R \times IRH_S + k_D \times IDH_S + Q \quad (3)$$

$$Q = 100 \times (1 - k_P - k_R - k_D) \quad (4)$$

By the above procedure, approximately the total index can be calculated using the sub-indexes or the total index can be modified to customised index by the adjustment of weights of sub-indexes.

RESULTS AND DISCUSSION

Table 1 shows economic weights (EV) and genetic standard deviations (S_G) for traits in the selection objective (total genotype) belonging to the groups milk, technology, health, fertility, earliness/longevity, technology/nutrition and meat. The trait milkability and the groups health and meat performance are not included in the selection objective of indexes but we examine their changes as influenced by indirect selection.

Breeding values were combined into selection index. As Přibyl et al. (1997) reported, the weight of a trait in the index was related to the reliability of breeding value estimation. Table 2 illustrates genetic standard deviations, standard deviations of breeding values and ensuing reliabilities of breeding value estimations.

The importances of traits under animal recording are given in Table 3. The values in the table indicate that the importance of production traits and their groups markedly changes according to the objective of sub-indexes. In the total index SIH the importance of the groups of traits milk : fertility : linear type trait classification is at a ratio of 79.61 : 15.52 : 4.87. If IPH is used, the ratio is 98.05 : 0.47 : 1.48, for IRH the ratio is 11.50 : 76.71 : 11.79, for IDH 3.32 : 77.86 : 18.82, and for the indexes IOH and IFH 48.52 : 10.93 : 40.55 and 4.34 : 80.41 : 15.25, respec-

Table 3. Importance of traits in performance testing (%)

Trait		Unit	SIH		IPH		IRH		IDH		IOH		IFH	
1	Milk	kg	46.05		71.94		0.22		0.86		48.35		1.49	
2	Fat content	%	0.74	79.61	2.37	98.05	2.23	11.50	1.23	3.32	0.17	48.52	1.60	4.34
3	Protein content		32.82		23.74		9.05		1.23		0		1.25	
4	Own fertility	index	4.42	15.52	0.02	0.47	61.47	76.71	1.19	77.86	10.86	10.93	4.82	80.41
5	Fertility of daughters		11.10		0.45		15.24		76.67		0.07		75.59	
6	Angularity	scores	0.38	4.87	0.03	1.48	0.44	11.79	6.77	18.82	9.35	40.55	2.71	15.25
7	Stature		0.30		0.12		0.21		1.64		7.14		0.19	
8	Chest width		0.55		0.07		0.67		1.01		0.87		0.52	
9	Body depth		0.21		0.04		0.69		0.94		0.22		1.32	
10	Rump angle		0.59		0.32		0.30		0.07		4.64		0.94	
11	Rump width		0.16		0.14		0.33		0.38		1.05		0.93	
12	Rear legs		0.49		0		5.29		0.50		2.88		0.04	
14	Foot angle		0.47		0.03		1.00		0.77		0.71		0.39	
13	Fore udder attachment		1.06		0.24		0.93		0.05		4.97		0.90	
15	Rear udder height		0.09		0.22		0.01		0.56		1.24		0.16	
16	Central ligament		0.07		0.04		0		0		0.18		0.04	
17	Udder depth		0.39		0.22		1.19		5.34		0.30		6.47	
18	Front teat placement		0.09		0		0.34		0.01		3.56		0.55	
19	Teat length		0.02		0.01		0.39		0.78		3.44		0.09	

Table 4. Relative weights of breeding values (BV) on standard deviation included in the index

	Trait	Unit	SIH	IPH	IRH	IDH	IOH	IFH
1	Milk	kg	32.47	52.10	–3.15	6.77	–90.35	–10.51
2	Fat content	%	4.44	10.47	–9.86	7.99	5.47	10.77
3	Protein content		27.89	32.24	19.70	8.03	–0.70	9.54
4	Own fertility	index	9.50	–0.50	41.16	–6.95	–38.89	–16.43
5	Fertility of daughters		15.46	4.21	23.14	50.26	3.37	61.35
6	Angularity	scores	3.52	–1.20	4.89	20.77	–45.71	15.61
7	Stature		–3.27	–2.65	3.53	–10.68	41.45	–4.31
8	Chest width		–4.88	–2.25	–6.92	9.27	–16.13	7.85
9	Body depth		–3.15	–1.56	–7.24	9.22	8.42	12.87
10	Rump angle		3.58	3.43	3.25	–1.70	–26.15	–7.47
11	Rump width		1.96	2.44	3.66	–4.29	–13.29	–7.93
12	Rear legs		3.65	0.11	15.25	–5.16	23.08	–1.46
13	Foot angle		3.57	0.96	6.67	6.40	–11.49	5.35
13	Fore udder attachment		5.65	3.56	6.82	1.66	32.00	8.63
15	Rear udder height		1.59	3.22	0.70	–5.49	15.23	–3.47
16	Central ligament		1.26	1.31	–0.17	0.44	5.35	1.63
17	Udder depth		–3.93	–3.91	–8.73	20.06	8.94	26.06
18	Front teat placement		1.40	–0.02	3.57	–0.80	–23.36	–5.80
19	Teat length		–0.73	–1.94	3.74	–5.80	22.75	–2.30

tively. These data document the high importance of body conformation for the evaluation of functional traits, mainly longevity and resistance.

Table 4 shows relative weights of breeding values in the selection indexes converted to standard deviations. Milk amount in kg has the highest weight in IPH and SIH but its weight is negative in IOH, IFH and IRH.

Fitness index (IFH) combines the traits of IDH (longevity) and IOH (resistance) indexes.

Accuracy of indexes and selection effect for the groups of traits are given in Table 5. The accuracy of the total index is r^2 = 69.30. The highest accuracy of breeding solely for a group of traits was recorded in IPH with r^2 = 83.82, the lowest in IDH and IFH: 9.80 and 9.86, respectively. Even though selection

Table 5. Reliability of indexes and selection effect in groups of traits

Index	Accuracy r	Proportion in ΔG (%)			ΔG protein (kg)
		milk	meat	secondary traits	
SIH	69.30	77.66	8.48	13.85	11.87
IPH	83.82	97.31	9.67	–6.98	14.04
IRH	56.04	–35.94	7.68	128.27	–2.45
IDH	9.80	10.19	2.74	87.08	–0.37
IOH	15.57	–112.22	–1.44	13.66	–9.27
IFH	9.86	–109.11	4.26	204.85	–3.66
ZSIH		77.76	9.09	13.16	12.11

Table 6. Comparison of genetic gains at unit intensity of selection

	Trait	SIH		IPH		IRH		IDH		IOH		IFH	
		Δ_k	Prop	Δ_k	Prop	Δ_k	Prop	Δ_k	Prop	Δ_k	Prop	Δ_k	Prop
1	Milk plasma	254.97	–22	343.28	–33	–122.50	36	–45.82	13	–336.99	72	183.01	112
2	Fat	13.09	13	15.52	17	–3.56	–12	–1.78	5	–8.02	–20	–17.21	–11
3	Proteins	11.87	87	14.04	113	–2.45	–60	–0.37	–9	–9.27	–164	–343.18	–211
4	Milkability	0.06	3	0.06	4	0.01	2	0.02	4	–0.07	–9	–2.28	–1
5	Mastitis	0.22	0	0.65	–1	–0.23	1	–1.40	7	–2.89	10	43.41	27
6	Metabolic disorders	1.14	–3	1.03	–3	0.26	–2	0.52	–4	–0.92	5	–3.84	–2
7	Calving interval – direct effect	–1.24	4	0.67	–2	–5.86	59	1.10	–11	1.47	–11	–58.67	–36
8	Calving interval – maternal effect	–1.43	3	0.85	–2	–3.26	20	–4.74	28	–1.62	7	110.72	68
9	Oestrus return in heifers – direct effect	–0.71	1	0.52	–1	–3.74	19	0.73	–3	0.84	–3	–17.99	–11
10	Oestrus return in heifers – maternal effect	–1.12	2	0.67	–1	–2.56	12	–3.73	17	–1.27	4	67.17	41
11	Calving – direct effect	0.00	0	0.00	0	–0.00	0	0.00	0	0.00	0	–0.23	0
12	Calving – maternal effect	–0.00	0	–0.00	0	–0.00	0	–0.00	0	0.00	0	0.05	0
13	Stillbirths – direct effect	–0.05	1	0.04	–1	–0.21	11	0.18	–9	0.02	–1	–32.81	–20
14	Stillbirths – maternal effect	–0.23	2	–0.19	2	0.00	0	–0.27	7	0.01	0	23.68	14
15	Age at 1st calving	5.35	–3	4.63	–3	3.20	–6	–0.63	1	–3.89	5	13.72	8
16	Longevity	0.06	5	0.00	1	0.05	13	0.20	51	0.03	5	190.09	117
17	Weight of cows	–3.20	3	–0.60	0	–3.16	8	–0.24	1	0.13	0	1.72	1
18	Net gain	4.09	3	6.74	6	–0.23	–1	–0.52	–1	0.19	0	–3.85	–2
19	Dressing classification	0.01	0	0.01	0	–0.00	0	0.02	1	0.03	1	3.95	2
20	EUROP conformation	–0.02	0	–0.03	0	0.01	0	0.00	0	0.04	0	–0.10	0
21	Fattiness	–0.02	0	–0.00	0	–0.03	0	–0.04	0	0.02	0	0.03	0
22	Nutrient consumption	–0.21	3	–0.24	3	–0.00	0	–0.07	3	0.07	–2	5.16	3

Δ_k = expected values of genetic gain; Prop = proportions in total genetic gain in monetary terms

Table 7. Proportions of sub-indexes in simplified total index ($ZSIH_S$)

Index	Weight in index	Proportions of sub-indexes in simplified total index	Proportion of traits (in %) on ΔG
IPH_S	$k_P = 0.93$	0.832	88.00
IRH_S	$k_R = 0.38$	0.094	9.74
IDH_S	$k_D = 0.17$	0.074	2.26

is carried out solely for a group of traits, correlation response between all the other traits will occur. Therefore Table 5 shows percentage ratios of groups of traits in the achieved genetic gain. In SIH index the ratios for the effect of breeding in genetic gain are 78% milk : 8% meat : 14% secondary traits. In IPH production index milk shows the highest ratio in the achieved genetic gain (97%), the ratio of meat is 10% and the ratio of secondary traits has a negative value (–7%). In IRH sub-index the ratio in genetic

Table 8. Selective difference for various intensities of selection

		n	BVMK	BVPK	BVP (%)	BVOFE	BVDFE
SIH	100%	987	691.42	27.40	0.048	–0.098	–0.021
	20%	198	996.69	41.64	0.099	0.406	0.071
	10%	99	1059.57	44.58	0.108	0.299	0.258
	5%	49	1074.31	46.77	0.128	0.057	0.224
	2%	20	1125.90	49.35	0.137	0.355	0.265
	1%	10	1103.60	50.00	0.151	–0.220	0.690
BVMK	100%	987	691.42	27.40	0.048	–0.098	–0.021
	20%	198	1251.28	42.87	0.006	–0.554	–0.340
	10%	99	1388.60	46.73	–0.002	–0.934	–0.373
	5%	49	1518.90	50.00	–0.015	–0.775	–0.353
	2%	20	1637.15	52.15	–0.035	–0.980	–0.390
	1%	10	1725.80	53.90	–0.045	0.530	–0.500
BVPK	100%	987	691.42	27.40	0.048	–0.098	–0.021
	20%	198	1194.48	45.18	0.058	–0.764	–0.325
	10%	99	1305.25	49.52	0.064	–0.669	–0.403
	5%	49	1423.45	52.96	0.058	–0.543	–0.447
	2%	20	1532.80	56.30	0.052	–0.550	–0.655
	1%	10	1584.80	58.40	0.059	0.570	–1.140
IPH	100%	987	691.42	27.40	0.048	–0.098	–0.021
	20%	198	1091.33	44.08	0.089	–0.737	–0.219
	10%	99	1173.40	47.85	0.101	–0.695	–0.264
	5%	49	1275.71	51.14	0.010	–0.951	–0.245
	2%	20	1388.00	54.50	0.010	–0.485	–0.430
	1%	10	1374.60	56.20	0.117	–0.380	–0.190

BVMK = breeding value for milk amount; BVPK = breeding value for kg of milk proteins; BVP (%) = breeding value for % of milk proteins; BVOFE = breeding value for own fertility; BVDFE = breeding value for fertility of daughters

Table 9. Correlations between production indexes

Index	IPH	BVPK	Australia	Belgium	Estonia	France	Italy	Japan	Germany	Netherlands	Poland	Switzerland	G. Britain
IPH	1	0.943	0.796	0.853	0.880	0.997	0.723	0.822	0.880	0.775	0.854	0.841	0.791
BVPK		1	0.953	0.980	0.984	0.927	0.951	0.984	0.984	0.965	0.955	0.985	0.943
Australia			1	0.993	0.987	0.838	0.973	0.988	0.987	0.992	0.992	0.990	0.999
Belgium				1	0.998	0.890	0.969	0.995	0.999	0.989	0.993	0.998	0.990
Estonia					1	0.913	0.956	0.990	1	0.980	0.993	0.995	0.984
France						1	0.775	0.863	0.913	0.821	0.887	0.880	0.832
Italy							1	0.987	0.956	0.994	0.942	0.979	0.966
Japan								1	0.990	0.996	0.976	0.999	0.982
Germany									1	0.980	0.993	0.995	0.984
Netherlands										1	0.973	0.993	0.987
Poland											1	0.984	0.993
Switzerland												1	0.985
G. Britain													1

IPH = production index; BVPK = breeding value for kg of milk proteins

gain is –36 : 8 : 128. If IOH is used, the ratio of milk in genetic gain is negative (–112%).

A comparison of genetic gain at unit intensity of selection for kg of milk proteins shows the value +11.87kg achieved in SIH index and 14.04kg in IPH index; in the other indexes genetic gain is negative – even –9.27kg in IOH index. The ratio of meat in IOH index is also negative. On the contrary, the respective ratios of secondary traits in IDH and IFH indexes are 87% and 205%.

Table 6 shows a comparison of genetic gains at unit intensity of selection for the particular traits, achieved in total index and sub-indexes. Mainly in IRH, IFH and IOH genetic gain in secondary traits is accompanied by a large negative genetic gain in milk performance. Genetic gain in IOH has a higher absolute value with negative sign than the value with positive sign according to SIH index. A comparison with the importance of traits in information sources (Table 3) indicates that indirect selection according to milk performance is expressed particularly in IOH and IFH. If only IOH is used, it causes deterioration of sum of all traits although it improves health (the sum of the ratios in Table 5 is –100%).

Sub-indexes of major traits are combined in simplified total index. The correlation between SIH and ZSIH is high and positive: r = 0.992. Table 7 shows summary data – ratios of standardised sub-indexes in simplified total standardised index $ZSIH_S$. IPH_S has the highest weight in simplified total index (0.93) while the weights of IRH_S and IDH_S are lower (0.38 and 0.17, respectively). Based on the ratios in total variability the importance of standardised sub-indexes in total standardised index, as sources of information for total standardised index, is 83.2%, 9.4% and 7.4% for IPH_S, IRH_S and IDH_S, respectively. IPH_S shows the highest ratio in resultant genetic gain, 88%. The lowest proportion, 2.26%, was calculated for IDH_S index.

A data set from the national database of bulls was used for the testing of in-

Table 10. Correlations between selection indexes

Index	SIH	IPH	IRH	IDH	IOH	IFH	ZSIH
Total selection index SIH	1	0.885	0.330	0.286	–0.483	0.096	0.992
Production index IPH		1	–0.100	0.058	–0.513	–0.118	0.894
Reproduction index IRH			1	0.188	–0.076	0.143	0.324
Longevity index IDH				1	–0.117	0.936	0.294
Resistance index IOH					1	0.456	–0.483
Fitness index IFH						1	0.103
Simplified total index ZSIH							1

dexes. To evaluate selection gains in some production traits 987 bulls with breeding values for all traits were used. The rank of bulls was determined according to the values of indexes or breeding values for evaluated traits and a selection gain was evaluated for various intensities of selection (1, 2, 5, 10, 20 and 100%). Bull selection was carried out on the basis of total index (SIH), production index (IPH) and breeding values for milk amount (BVMK) and milk protein amount (BVPK). The results are shown in Table 8. We examined breeding values for kg of milk (BVMK), kg of milk proteins (BVPK), % of milk proteins (BVP%) and for own fertility (BVOFE) and fertility of daughters (BVDFE).

In the examined production traits an increase in selection intensity (a decrease in the number of the best bulls) leads to an increase in the mean of breeding values of the selected group of bulls. With selection of 1% of the best animals according to the index SIH 10 bulls were selected that achieved the average breeding value +1 103.60 kg milk (BVMK) and +50 kg proteins compared to +691.42 kg and 27.40 kg in the whole set. With selection of 1% of the best animals according to IPH the average breeding value was +1 374 kg milk and +56.20 kg milk proteins. The values of percentage content of proteins (BVP%) increase in both indexes – in IPH with random variation where the exceptional traits of some selected top individuals that cannot compare with the overall trend are likely expressed. If compared with selection according to the total index (SIH) higher selection gains for kg of milk and kg of milk proteins were recorded. The use of IPH increased the content of milk proteins but decreased the breeding value for reproduction traits (by contrast SIH slightly improved fertility). Fertility decreases with selection according to all criteria except for SIH.

As for the milk amount and milk protein amount the results of bull selection according to IPH are

Table 11. Correlations between breeding values for milk and fertility and selection indexes

	BVMK	BVPK	BVF (%)	BVP (%)	BVOFE	BVDFE
Total selection index SIH	0.555	0.777	0.163	0.473	0.062	0.124
Production index IPH	0.744	0.943	0.152	0.424	–0.194	–0.209
Reproduction index IRH	–0.234	–0.167	0.000	0.144	0.771	0.415
Longevity index IDH	–0.138	–0.068	0.164	0.150	–0.164	0.782
Resistance index IOH	–0.714	–0.630	0.265	0.187	–0.211	0.177
Fitness index IFH	–0.378	–0.267	0.249	0.221	–0.222	0.757
Simplified total index ZSIH	0.573	0.795	0.167	0.472	0.090	0.098

BVMK = breeding value for milk amount; BVPK = breeding value for kg of milk proteins; BVF (%) = breeding value for % of milk fat; BVP (%) = breeding value for % of milk proteins; BVOFE = breeding value for own fertility; BVDFE = breeding value for fertility of daughters similar to the results of direct selection according to breeding values for kg of milk and kg of milk proteins. With selection according to the production index breeding values for protein content oscillate and tend to increase. If selection is carried out according to the breeding value for milk amount or protein amount, a higher increase in milk performance is achieved but protein content and fertility, especially fertility of daughters, decrease.

Table 9 shows correlations between production index for milk (IPH), breeding value for protein amount in kg (BVPK) and production indexes used in several countries. The correlations were calculated in a set of bulls whose breeding values for all traits were known. The values of the correlations between production indexes were high (> 0.790) except the indexes used in Italy and in the Netherlands. The correlations approach the value one in many cases, which documents marked similarity of the used production indexes. Very high correlations were found out between breeding value for protein amount and examined production indexes.

Table 10 illustrates correlations between total selection indexes SIH and ZSIH and sub-indexes IPH, IRH, IDH, IOH and IFH in the evaluated set of 987 bulls. The correlations are influenced by the set in question. The highest correlation was found out between SIH and ZSIH (0.992). The correlation between total and production index was 0.885.

Table 11 documents correlations between breeding values for milk performance and fertility and selection indexes. Both SIH and IPH show favourable correlations with breeding values for milk performance. SIH is in positive correlation with all examined indexes and breeding values. Sub-indexes for reproduction, longevity and fitness are in negative correlations with breeding values for milk and protein amount. The correlations of production index for milk with breeding values for fertility are negative.

Significant changes in the use of selection indexes occurred recently: since 1996 the ratio of production in the "world index" decreased from 79% to 57% in 2004, and the ratio of longevity, health and management in the "world index" is 27% and body conformation accounts for 16% (Wesseldijk, 2004). Greater attention is paid to longevity and health, mostly contrary to production and body conformation. Most countries adopted a Scandinavian model – total index comprising traits of health and management. Body conformation traits are taken into account for prediction of longevity and health traits in many currently used indexes.

CONCLUSION

Production index for milk (IPH) and sub-indexes for reproduction (IRH) and longevity (IDH) were constructed for practical application. We do not recommend using IOH and IFH because direct indicators for health are not available in animal recording and this trait is selected mainly indirectly through its negative correlation to milk performance.

The constructed indexes are substantially influenced by population genetic and economic parameters.

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Received: 04–10–26
Accepted after corrections: 05–02–04

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