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Expected genetic response to selection from Multi-trait selection Indices incorporating unconventional layer traits

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Abstract
Due to progressive reduction in genetic gains by traditional layer traits, a study was conducted to evaluate the genetic gains expected from oviposition and clutch traits as direct and correlated response in Egg number (EN-1). Five single trait Osborne indices were prepared using EN-1, EN-2, MOT40, MOI40 and ACL as primary trait. Six layer traits (EW40, EN-1, EN-2, MOT40, MOI40 and ACL) in all possible combinations were used as selection criterion to construct two types of multi-trait selection index (type A and B). The indices were evaluated on the basis ΔH, R_{IH}, expected genetic gain in EN-1and EW40. These indices were compared with the Osborne indices for their efficiency by comparing the responses in individual traits.The five desirable indices from 'A' type were I_{A1}, I_{A7}, I_{A9}, I_{A29}, and I_{A44}, while I_{B1}, I_{B3}, I_{B8}, I_{B23} and I_{B44} were the five desirable type 'B' in six, five, four, three and two trait combinations respectively. EN-1 received highest weight in 'A' type indices, whereas, EN-2 followed by EN-1 received highest weight in 'B' type indices. Inclusions of BW16 into different multi-trait indices led to positive gain in EW40, whereas, inclusion of oviposition and clutch traits resulted enhanced efficiency of the index. Osborne indices showed greater efficiency than multi-trait indices for improvement in single trait. Among multi-trait indices, I_{B17} (EN-2, MOT40, MOI40, ACL) was found to be the best index for net improvement in genetic worth of the layer population.

Key words: *Multi-trait selection Index, Oviposition Time, Oviposition Interval, Clutch length*

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I. Introduction

It has been reported by various authors that many generations of single trait selection for part record egg production has shown undesirable changes in other traditional correlated traits like egg weight, body weight at 40 week of age and age at sexual maturity apart from the gradual decline of genetic response in primary trait and reduction in persistency of production (Muir, 1990; Sharma *et al.* 1998; Kataria *et al.* 2000 and Mallik *et al.* 2007). Unless a multiple trait selection is performed, simultaneous improvement in different economic traits of the layer hen is not feasible (Gowe and Fairfull, 1985). The primary trait (egg number or rate of lay) is showing reduced additive variability in most of the long term selected commercial layer populations, therefore it becomes important to investigate other traits which may be combined with traditional economic traits in an index to maximize the total genetic gain from layer breeding.

Various authors have reported construction of multi- trait general indices (Hazel, 1943) for simultaneous improvement of several traditional layer traits (Singh *et al.* 1986; Chatterjee *et al.* 1998; Ahmad *et al.* 2000; Kumar *et al.* 2001; Sharma *et al.* 2001; Dhankhar *et al.* 2004 and Santhosh *et al.* 2007), particularly for improving the aggregate genotypic value.

Present study was aimed to estimate the potentiality of other layer traits (egg number of early layers, mean oviposition time and average clutch length) being used in comparison to traditional selection traits (egg number) either by Osborne Indices or by Multi-trait selection indices and to observe the efficiency of these indices in improving the expected genetic gain by one generation of family selection on a long term selected layer population.

In view of above, this paper reports the construction of different Multi-trait selection Indices and comparison of their efficiency with Osborne Indices.

II. Material And Method

Details on experimental stock, management practices, sample size and recording of traits along with descriptive statistics of population means for various traits have been reported earlier by Roy *et al.* (2014). Estimates of genetic parameters, correlation coefficients, effective population size, expected selection differential, expected directed and correlated response from different Osborne selection indices have also been reported by Roy *et al* (2020). The definition of traits selected for making of selection indices have been given in table 8.

Multi-trait selection indices

Two types of multi-trait selection indices were constructed as per Hazel (1943).

(I) Multi-trait selection indices with the objective to improve EN-1 only = **'A' type**.

(II) Multi- trait selection indices with the objective to improve all traits = **'B' type**.

The sire plus dam component of genetic and phenotypic variances and co-variances among traits were used to construct both types of selection indices. A total of 57 selection indices of type 'A' were constructed using six traits in all possible combinations by MIX 2.0 software (Nath and Singh, 2002).

BW16, EN-1, EN-2, MOT 40, MOI 40 and ACL were included in the index as primary trait (selection criteria) whereas, EW 40 and ASM as secondary trait.

The general form of the selection index (I) was as follows:

$I = b_1X_1 + b_2X_2 + \ldots\ldots\ldots\ldots + b_nX_n$ where,

b_1 to b_n are the weighting coefficients for the trait 1 to n and X_1 to X_n are the phenotypic values of a pullet for the trait 1 to n respectively.

The aggregate breeding value (H) or, genetic economic value of the index was estimated as:

$H = a_1g_1 + a_2g_2 + \ldots\ldots\ldots\ldots + a_ng_n$ Where, a_1 to a_n are the relative economic value and g_1 to g_n are the breeding value or genetic value of 1 to n traits respectively.

The b values (bi's) were estimated in such a way that the correlation between I and H is maximized and were calculated as under **for 'A' type indices**

[P] [b] = [G] [a]

$[b] = [P]^{-1}[G]$ [a] where,

[P] = Phenotypic variance-covariance matrix of order n x n, where n is the number of traits in selection criteria.

[b] = A column vector of unknown weighting coefficients of order n x 1.

[G] = A column vector of genetic variance-covariance matrix of EN-1 (the trait in selection objective) with all other traits included in selection criteria (n x1).

[a] = A scalar (1 x 1) of relative economic value of the trait in selection objective (EN-1) assuming one.

Although, the selection criteria were the multi- traits, the selection objective was to improve the 40 week egg production (EN-1) only which constituted the aggregate genotype (ΔH) and hence, the relative economic value was assumed one while computing the weighting coefficients for construction of different selection indices (Dhankhar *et al.* 2004 and Santhosh *et al.* 2007).

For 'B' type indices the b values were calculated in such a way that the correlation between I and H is maximized and were calculated as under:

[P] [b] = [G] [a]

$[b] = [P]^{-1}[G]$ [a] where,

[P] = Phenotypic variance-covariance matrix of order n x n, where n is the number of traits in selection criteria.

[b] = A column vector of unknown weighting coefficients of order n x 1.

[G] = A column vector of genetic variance-covariance matrix of order n x n.

[a] = A column vector of relative economic value of order (n x 1).

The relative economic weights for all the traits were kept 1.00. It has been reported that efficiency of index selection does not changes much with changes in economic weights (Pease *et al.* 1967, Smith, 1983, Ahmad and Singh., 2001 and Sharma *et al.* 2003). Negative signs were assigned to EW 40, ASM, MOT 40 and MOI 40 whereas; positive signs were accorded to EN-1, EN-2, ACL and BW 16 respectively. The signs of economic weights were determined from the sign of regression coefficients, obtained for each index trait on 40 week egg production (EN-1).

The two types of multi- trait indices were compared on the basis of expected response in aggregate genotype (ΔH) and accuracy or efficiency of the index (R_{IH}). The accuracy of the index, gain in aggregate genotype and gain in individual traits were calculated using following formulae

Variance of the index (σ^2_I) = $b' Pb$

Variance of aggregate genotype (σ^2_H) = $a' G$

Accuracy or efficiency of index (R_{IH}) = σ_I / σ_H

Response in aggregate genotype (ΔH) = $i\,\sigma_I = i\,R_{IH}\,\sigma_H$

Response in i_{th} trait of the index (ΔG_i) = $g_i\, b\, (i/\sigma_I)$

Where, g_i is the i^{th} row vector of genetic variance-covariance matrix and i is the selection intensity of combined sex assuming 20 % selection (i = 1.40)

Response in the j^{th} trait not included in the selection criteria

Correlated response (ΔG_j) = $g_j\, b\, (i/\sigma_I)$ where, g_j is the row vector of additive genetic covariance of j^{th} trait with the traits included in index.

The relative importance of the trait was measured by reduction in expected genetic gain in aggregate genotype (ΔH) which would result from dropping that trait from the index and was calculated as per Cunningham *et al.* (1970).

Percent reduction in genetic gain = 100 {1-√[(b′ Pb – b_i^2) / (w_{ii}) / b′ Pb)] where,

b_i = weighting coefficient of the i^{th} trait.

w_{ii} = corresponding diagonal element of P^{-1}.

b′ Pb = variance of the index.

The relative efficiency (RE) of ‘A‘type indices were measured as the ratio of expected genetic gain from an index to the standard index. The relative efficiency (RE) of ‘B’ type indices were calculated as the ratio of efficiency from the application of an index to the efficiency from a standard index.

III. Results And Discussion

Multi-trait general selection indices for improvement in part period egg production (EN-1) only (‘A’ type)

Egg number and egg weight are the two most important traits in determining the profit from a layer enterprise. Selection based on part record egg production using Osborne index is effective in improving the egg number, but a consistent decline in egg weight has been reported. In the present investigation, six economically important layer traits were used to construct various (57) multi-trait general selection indices with the aim to improve egg production up to 40 weeks of age along with improvement in egg weight (EW40) as a correlated trait.

The traits included in selection criteria were BW16, EW40, EN-1, EN-2, MOT40, MOI40 and ACL recorded up to 40 weeks of age (Roy *et al* 2014). Expected correlated response was observed for EW40 and ASM. EW40 and ASM were not included in the selection criteria, because the response observed in EN-1 and EW 40 after inclusion of these two traits (EW40 and ASM) in any possible combination, were not better than the response observed after inclusion of six selected traits as mentioned above. In addition, with the purpose to minimize the number of traits entering in to selection criteria, only the correlated response was estimated for these two traits. The phenotypic and genotypic variances and covariances used in constructing different indices have been presented in table 1 and 2 respectively.

However, the selection criteria were the multi-traits, the selection objective was to improve the egg number up to 40 week of age (EN-1) only, which constituted the aggregate genotype (ΔH) in ‘A’ type indices. EN-1 was given a value of ‘1.00’, while other index traits were assigned ‘0.00’ relative economic value. The different multi-trait selection indices were evaluated on the basis of expected genetic gain in aggregate genotype (ΔH), accuracy of the index (R_{IH}) and expected correlated response in egg weight (EW40).The results of ‘A’ type indices have been presented in table 3.

The index I_{A1} showed highest gain in ΔH (3.6892) and R_{IH} value (0.3891) among all the ‘A’ type indices constructed. Irrespective of negative correlated response in egg weight, this index was considered as standard. It was given relative efficiency of 100 percent. This Index is expected to bring the genetic gain in individual traits as 13.4689 g, 3.6892 eggs, 7.4224 eggs, -0.1897 h, -0.0687 h and 1.0132 days for BW16, EN-1, EN-2, MOT40, MOI40 and ACL respectively. The correlated response observed in EW40 and ASM were -0.0264 g and -0.0357 days respectively.

The indices numbering I_{A2} to I_{A7}, incorporating five traits, revealed that their accuracies (R_{IH}) varied from 0.3650 (I_{A5}) to 0.3888 (I_{A2}), whereas, the response in aggregate genotype (ΔH) varied from 3.4607 (I_{A5}) to 3.6866 units (I_{A2}) respectively. Among the indices involving five traits, maximum improvement in EN-1 (3.6866 eggs) was expected from index number I_{A2}, but there would be reduction in egg weight by 0.0287g. In comparison to index number I_{A2}, the index numbering I_{A7} (BW16, EN-1, EN-2, MOI40, ACL) showed positive gain in egg weight (0.0227 g) with marginal reduction in ΔH and R_{IH} .The aggregate genotype (ΔH) and R_{IH} due to index I_{A7} were 3.5190, and 0.3711 respectively. The expected genetic changes (Δgi) were estimated as 14.3326 g, 3.5190 eggs, 6.4310 eggs, -0.0708 h and 0.9318 days, respectively for BW16, EN1, EN2, MOI40, and ACL. The relative efficiency of index I_{A7} (95.39%) was slightly less than index I_{A2} (99.93%), however, due to positive gain in egg weight, I_{A7} was adjudged the best in all five trait indices.

The indices constructed with 05 traits were compared on the basis of reduction in ΔH values and reduction or gain in egg weight. Dropping BW16 from an index ($I_{A\ 4}$) resulted in more decline in egg weight, whereas dropping EN-1 from an index (I_{A5}) resulted more decline in ΔH. Reductions in ΔH by dropping EN-1(I_{A5}), BW16 (I_{A4}), MOT40 (I_{A7}), MOI40 (I_{A3}), EN-2 (I_{A6}) and ACL (I_{A2}) from the indices (written in parentheses) were important in the respective order. The order of importance for gain in egg weight was as MOT40 (I_{A7}), EN-1 (I_{A5}), EN-2 (I_{A6}), MOI40 (I_{A3}), ACL (I_{A2}) and BW16 (I_{A4}) by dropping traits from their respective indices.

The aggregate genotype (ΔH) ranged from 3.1280 (I_{A17}) to 3.6352 (I_{A10}) units and R_{IH} from 0.3299 (I_{A17}) to 0.3834 (I_{A10}) in 15 indices (I_{A8} to I_{A22}) constructed by incorporating four traits at a time. The maximum improvement in EN-1 (3.6352 eggs) was expected through index I_{A10} (BW16, EN1, MOT40, MOI40) but with a reduction in egg weight (-0.0117 g). The index with maximum expected improvement in EN-1 along with improvement in egg weight was observed from index number I_{A9} with ΔH and R_{IH} as 3.5147 and 0.3707 respectively. The ΔH and R_{IH} estimates of four-trait index number I_{A9} were almost similar to the estimates of five-trait index number I_{A7}. Among four trait indices, index number I_{A9} was the most desirable with relative efficiency of 95.27%. The expected genetic gain in individual traits were observed as 14.1399 g, 3.5147 eggs, 6.4402 eggs and -0.0717h for BW16, EN-1, EN-2 and MOI40 respectively. The correlated response in EW40 and ASM were 0.0201 g and -0.1210 days respectively. Index number I_{A12} was the second most desirable index with ΔH and R_{IH} as 3.4985 and 0.3690. The relative efficiency and expected genetic gain in EW40 for index I_{A12} were 94.83 percent and 0.0101 g respectively. Maximum reduction in ΔH was observed after dropping BW16 and EN-1 from the index (I_{A17}) along with greater reduction in egg weight. Similar to five trait indices, more reduction in egg weight was expected after dropping BW16 from the four trait indices.

The ΔH in three trait indices (I_{A23} to I_{A42}) varied from 2.8274 (I_{A39}) to 3.4978 (I_{A25}) with lowest (76.64%) and highest (94.81%) relative efficiency respectively. The index number I_{A25} (BW16, EN-1 and MOT40) was observed to be the most desirable with expected improvement in EN-1 by 3.4978 eggs and 0.0114 g expected gain in egg weight 40. The expected gain in BW16 and MOT40 were observed as 14.9635 g and -0.2172 h respectively. The other desirable index observed was I_{A29} with 3.4514 eggs and 0.0085 g expected gain in EN-1 and egg weight 40 respectively. The relative efficiency of index number I_{A29} (BW16, EN-2 and MOI40) was 93.55 percent in comparison to index number I_{A1}. Among three trait indices, the maximum reduction in ΔH were expected to occur by dropping BW16, EN-1 and MOI40 from the index (I_{A39}), whereas, maximum reduction in egg weight 40 was expected to occur by dropping BW16, EN-1 and EN-2 (I_{A42}).

For two trait indices (I_{A43} to I_{A57}) ΔH varied from 2.5132 (I_{A56}) to 3.2384 (I_{A49}) and the relative efficiency varied from 68.12 (I_{A56}) to 87.78 percent (I_{A49}). Index number I_{A49} (EN-1 and MOT40) seemed to be the most desirable for maximum improvement in egg production (3.2384 eggs) but with reduction in egg weight (-0.0879 g). Index number I_{A44} was observed to be the most desirable index for improvement in egg production (EN-1) along with improvement in egg weight (EW40). Selection based on index 44 (BW16, EN-2) was expected to improve EN-1 by 3.2014 eggs and EW40 by 0.0524 g with a relative efficiency of 86.78 percent as compared to index I_{A1}. Responses in all other traits were in desirable direction. Other desirable two trait indices were I_{A46} (BW16 and MOI40), I_{A43} (BW16 and EN-1) and I_{A45} (BW16 and MOT40) with expected genetic change (ΔH) of 3.0970, 3.0571 and 2.9301 units and relative efficiency of 83.95, 82.87 and 79.42 percent respectively, with positive gain in egg weight.

A lot of literature is available on use of different combinations of multi-trait selection indices in poultry (Singh *et al.* 1986; Ahmad *et al.* 2000; Kumar *et al.* 2001, Sharma *et al.* 2003 and Ahmad and Singh., 2006) mainly for improving the aggregate economic value. However, little information is available on the use of selection indices incorporating multi-traits as the selection criteria with the aim to improve egg production alone as a selection objective.

Literature support on use of oviposition and clutch traits in multi-trait selection index are limited. Luc *et al.* (1997) reported that incorporation of oviposition interval into selection indices improved the selection response in egg production and total genetic merit; although some decrease in egg weight still occurred. Similar results were observed in present investigation, although decrease in egg weight was not observed from the five desirable indices.

A trait was dropped out from the standard index (I_{A1}) to know the genetic cost of restriction. The costs of restriction were observed as 5.79, 6.19, 1.26, 4.61, 3.49 and 0.07 percent for BW16, EN-1, EN-2, MOT40, MOI40 and ACL respectively. The contribution of EN-1 was found to be the highest, followed by BW16, MOT40, MOI40, EN-2 and ACL. The contribution of traits from the present investigation differed from the results of Dhankhar *et al.* (2004), which might be attributed to the differences in trait combinations. The partial regression coefficients (bi's) for different selection indices also revealed that egg production (EN-1 and EN-2) received highest positive weights.

Multi-trait general selection indices for improvement of all index traits ('B' type)

The overall productivity and net profit from layer birds are determined by several traits exhibited during the lifetime. Many generations of selective breeding for egg production has resulted gradual decline in additive genetic variability for egg number, thus use of other important layer traits becomes important in determining the overall productivity and net profit from layer enterprise.

Part period or Annual egg production intended for genetic gain in egg number as primary trait has resulted in reduction in body weight, egg weight and age at sexual maturity (Sharma *et al.* 1998 and Johari *et al.* 1988). Selection based on other promising layer traits like oviposition time, clutch length, body weight at 16 week may improve the total genetic merit of the layer birds. The genetic gain from index selection is a function of heritability, genetic correlations and relative economic values of the index traits (Saini *et al.* 1990).

Various (57) multi-trait general selection indices ('B' type) were constructed by incorporating six important traits (BW16, EN-1, EN-2, MOT40, MOI40 and ACL) in selection criteria with equal economic weight. The relative economic weights for all the traits were assigned +1.00 or -1.00 values depending on the sign of regression obtained for each trait with egg production up to 40 weeks of age (EN-1). EN-1, EN-2, ACL and BW16 were assigned positive signs, whereas MOT40, MOI40, EW40 and ASM were assigned negative signs respectively. EW40 and ASM were not included in the selection criteria, only the correlated response was estimated for these two traits. The phenotypic and genetic variances and covariances used for construction of indices have been presented in table 1 and 2 respectively. The responses in aggregate genotype (ΔH) were the sum of expected genetic gain in individual traits (Δg_i) as the purpose was to improve all the index traits.

The expected genetic gain in individual traits, aggregate genetic gain from an index and efficiency of the Index from 'B' type indices have been presented in table 4.

The different multi-trait selection indices were evaluated on the basis of expected genetic gain in aggregate genotype (ΔH), accuracy of the index (R_{IH}), expected genetic gain in egg production up to 40 weeks of age (EN-1) and expected correlated response in egg weight (EW40). Relative efficiency of the indices were analyzed in comparison to ΔH ($RE_{\Delta H}$) and R_{IH} (RE_{IH}) of the standard index.

The index $\mathbf{I}_{B1}$ showed highest gain in ΔH (31.0013) and R_{IH} values (0.4384) among all the indices constructed with positive correlated response in egg weight and age at sexual maturity. This index was considered as the standard. It was given relative efficiency of 100 percent. This Index is expected to bring the genetic gain in individual traits as 21.4527g, 3.0764 eggs, 5.8666 eggs, -0.1535 h, -0.2950 h and 0.4226 days for BW16, EN-1, EN-2, MOT40, MOI40 and ACL respectively. The correlated response observed in EW40 and ASM were 0.1218 g and 0.2665 days respectively. The responses in all the traits were in the desirable direction.

Among five trait indices (I_{B2} to I_{B7}), the response in aggregate genotype (ΔH) varied from 15.2878 (I_{B4}) to 30.9714 (I_{B3}) units, whereas the accuracies (R_{IH}) varied from 0.4266 (I_{B6}) to 0.5365 (I_{B4}) respectively. Dropping of body weight (BW16) from an index I_{B4} resulted in highest accuracy (0.5365) but lowest response in aggregate genotype (15.2878) and negative correlated response in egg weight (-0.1597g). Significant reduction in ΔH by dropping body weights from the index has also been reported by Sharma *et al*. (2003). It was observed that indices with higher ΔH values were not necessarily having the highest R_{IH} values, which is similar to the results of Sharma *et al.* (2003). The $RE_{\Delta H}$ varied from 49.31 to 99.90 percent and RE_{IH} varied from 97.31 to 122.38 percent respectively.

Out of the five trait indices, the maximum improvement in EN-1 (3.0653 eggs), ΔH (30.9714) and accuracy (0.4384) equivalent to the standard index (100 %) was observed for index number I_{B3} with positive response in EW40 and ASM. This was observed to be the most desirable index among five trait indices. The expected genetic changes (Δgi) from selection on index I_{B3} were estimated as 21.4918 g, 3.0653 eggs, 5.8474 eggs, -0.1530 h and 0.4139 days, respectively for BW16, EN-1, EN-2, MOT40, and ACL. The other important five trait indices observed were index number I_{B2} and I_{B7} with 30.3299, 30.4180 genetic response in aggregate genotype and 98.81, 98.45 percent relative efficiency (RE_{IH}) respectively. The observed expected change in EN-1 was higher than the results of Ahmad and Singh (2001) and Sharma *et al.* (2003), which might be due to favorable genetic association of EN-1 with other traits, as the correlated response in EN-1 was approximately closer to the direct response (index I_{B5} versus Index I_{B4}) when it was dropped from the index. This also indicates that the traits incorporated in index were important for improvement in EN-1.

The five trait indices were compared based on reduction in ΔH values and reduction or gain in egg weight. Dropping BW16 from an index (I_{B4}) resulted in more decline in ΔH and egg weight, whereas, dropping EN-2 from an index (I_{B6}) resulted more decline in ΔH. Reduction in ΔH by dropping BW16 (I_{B4}), EN-2 (I_{B6}), EN-1 (I_{B5}), ACL (I_{B2}), MOT40 (I_{B7}), and MOI40 (I_{B3}) from the respective indices (written in parentheses) were important in the respective order, whereas the order of importance for gain in egg weight was as follows : EN-2 (I_{B6}), MOT40 (I_{B7}), EN-1 (I_{B5}), ACL (I_{B2}), MOI40 (I_{B3}) and BW16 (I_{B4}) by dropping traits from their respective indices. This order indicated that ΔH was favorably affected more by BW16, EN-2 and EN-1, whereas Δgi in EW40 was favorably affected more by BW16 than by other traits.

Among four trait indices (I_{B8} to I_{B22}), the ΔH varied from 5.0845 (I_{B19}) to 30.3647 (I_{B10}) and R_{IH} varied from 0.4177 (I_{B18}) to 0.5775 (I_{B17}) respectively. The Δgi in EN-1 varied from 1.9984 (I_{B18}) to 3.3076 eggs (I_{B19}), whereas the RE_{IH} varied from 95.28 (I_{B18}) to 131.73 (I_{B17}) percent respectively. Out of all the four trait indices, index number I_{B8} was observed to be the best with Δgi in EN-1, ΔH and R_{IH} as 3.0602 eggs, 30.2481 and 0.4324 respectively. It showed positive correlated response in EW40 (0.1246) and ASM (0.2079) along with 98.63 percent relative efficiency (RE_{IH}). Index number I_{B10} was comparable to index I_{B8} with higher ΔH (30.3647) but response in EN-1 (2.8733 eggs) and R_{IH} estimate was lower than I_{B8}. Other desirable four trait indices were I_{B14}, I_{B9}, I_{B22} and I_{B13} with relative efficiency ranging from 99.43 to 98.18 from $RE_{IH.}$ Index numbering I_{B15}, I_{B16}, I_{B17}, I_{B19} and I_{B20} showed consistent expected reduction in egg weight after dropping BW16 from these indices. Index number I_{B17} revealed highest relative efficiency (131.73 %), highest R_{IH} (0.5775) but low ΔH (12.4854) and negative response in egg weight (-0.1652 g). The increase in R_{IH} might be due to better genetic association between traits.

Among three trait indices (I_{B23} to I_{B42}) the ΔH varied from 1.9445 (I_{B42}) to 29.7535 (I_{B23}), whereas the R_{IH} varied from 0.3721 (I_{B33}) to 0.5792 (I_{B40}) respectively. The RE_{IH} varied from 84.88 (I_{B33}) to 132.12 percent (I_{B40}). Index number I_{B23} was found to be the most desirable among three trait indices, with ΔH, R_{IH} and Δgi in EN-1 observed to be 29.7535, 0.4267 and 2.882 eggs with positive gain in EW40 (0.1559 g). The efficiency of index I_{B23} was 97.33 percent in comparison to the standard index. The other desirable three trait indices were I_{B24} to I_{B29} with relative efficiency varying from 96.19 to 98.68 percent. Indices numbering from I_{B33} to I_{B42} were not considered desirable because of their negative correlated response in egg weight.

The ΔH in two trait indices (I_{B43} to I_{B57}) ranged from 0.4080 to 26.9125 and R_{IH} ranged from 0.3042 (I_{B51}) to 0.5792 (I_{B52}). The RE_{IH} ranged from 69.39 to 132.12 percent whereas, the Δgi for EN-1 ranged from 1.8623 (I_{B46}) to 3.2314 eggs (I_{B49}). Among two trait indices, the index I_{B44} was observed to be the most desirable with ΔH, $R_{IH,}$ Δgi for EN-1 and RE_{IH} were 26.9125, 0.4261, 2.7996 eggs and 97.19 percent respectively. Other two trait desirable indices were I_{B43}, I_{B45}, I_{B46} and I_{B47} with RE_{IH} varied from 95.16 to 96.19 percent along with positive gain in EW40. Indices numbering I_{B48} to I_{B57} were not considered desirable because of their negative correlated response in egg weight.

Several reports are available on use of different traditional traits in various combinations for constructing multi-trait indices (Chatterjee *et al.* 1988; Ahmad *et al.* 2000; Kumar *et al.* 2001, Sharma *et al.* 2003; Mallik *et al.* 2005 and Santhosh *et al.* 2007). However, information on use of oviposition and clutch traits in combination with BW16 are limited, therefore, comparison of result from the present investigation with the reported literature is not possible.

Noda *et al.* (2002) used 06-11.00 h egg production along with ASM and egg weight in a multi-trait selection index for desired gain, for a period of six generation and reported that long term egg production improved by 1.2 times than by using part period egg production; without affecting the ASM and egg weight. Luc *et al.* (1997) and Pukhrambha *et al.* (2001) reported increase in efficiency of selection indices by incorporating mean oviposition interval and average clutch length, respectively.

The partial regression coefficients (bi's) for different selection indices revealed that EN-2 followed by EN-1 and BW16 received highest weightage. Maximum weightage to egg production was also reported by Chtterjee *et al.* (1998).

Indices with greater than 100 percent RE_{IH} revealed low ΔH and negative expected response in egg weight. These were also the indices from which BW16 was dropped. The cause of low ΔH might be the low Δgi in terms of numerical units in traits having low standard deviation (MOT40, MOI40 and ACL), while synergistic effects among oviposition traits (EN-2, MOT40 and MOI40) might be the reason for greater than 100 percent $RE_{IH.}$ Smith (1983) has reported that the efficiency of the index is sensitive to the dominance of one or few traits, which is measured by the product of economic weight and heritability for the trait. In present investigation, since the economic weights were equal to all traits, it appears that the efficiencies of the indices were mainly determined by the heritability of the trait combination in an index. Traits with higher heritability (MOT40, EN-2, MOI40 and BW16) revealed greater accuracy than traits with lower heritability (EN-1 and ACL), especially in two and three trait indices, while increase in efficiency was evident by dropping BW16 from five trait indices.

Desirable indices

The most desirable indices were selected from the 57 multi-trait indices of type 'A' and 'B'. The criteria of selection were the ΔH and expected positive response in EW40 for 'A' type indices, whereas for 'B' type indices the criteria of selection were ΔH, RE_{IH}, expected response in EN-1 and positive response in EW40. The selected five indices from each class of trait combination for 'A' and 'B' type indices have been shown in table 5 and 6. The five desirable indices from 'A' type were I_{A1}, I_{A7}, I_{A9}, I_{A29}, and I_{A44}, while $I_{B1,}$ $I_{B3,}$ $I_{B8,}$ I_{B23} and I_{B44} were the five desirable from type 'B' in six, five, four, three and two trait combinations respectively.

On the basis of efficiency, I_{B17} (EN-2, MOT40, MOI40, ACL) was adjudged to be the best index with R_{IH} equal to 0.5775. The negative response in EW40 might be overcome by fixing mild culling level for EW40 before selecting parents.

Comparison of efficiency between Osborne (Combined) indices and Multi-trait indices

The Five different Osborne indices and the best judged multi-trait indices of 'A', and 'B' types were compared based on the expected response in individual traits. To compare the Osborne indices with multi-trait indices, the expected genetic response from Osborne indices were calculated assuming the average intensity of 1.40. Table 8 shows that the expected genetic response in a single trait was more from Osborne indices (represented by the trait) than from multi-trait indices. However, improvement in more than one trait is not possible with Osborne indices. To improve more than one trait, the 'B' type multi-trait indices selected based on efficiency alone ('B'**) would be more reliable and efficient than Osborne and other types of multi-trait ('A' and 'B') indices.

IV. Conclusion

Six traits (EW40, EN-1, EN-2, MOT40, MOI 40 and ACL) in all possible combination were included in selection criterion to construct two types of multi-trait selection indices. EW40 and ASM were taken as correlated trait. When improvement was sought in EN-1 only, it was designated as 'A' type and when improvement in all traits was sought, it was designated as 'B' type index. I_{A1} and I_{B1} were the standard index with ΔH and R_{IH} values as 3.6892 eggs, 0.3891 and 31.0013, 0.4384 respectively. The indices were evaluated on the basis ΔH, R_{IH}, expected genetic gain in EN-1and EW40. One index in each class of trait combination was chosen desirable and from the five desirable indices, one was selected to be the most desirable among both types of indices. The five desirable indices from 'A' type were I_{A1}, I_{A7}, I_{A9}, I_{A29}, and I_{A44}, while $I_{B1,}$ $I_{B3,}$ $I_{B8,}$ I_{B23} and I_{B44} were the five desirable from type 'B' in six, five, four, three and two trait combinations respectively. EN-1 received highest weightage in 'A' type indices, whereas, EN-2 followed by EN-1 received highest weight in 'B' type indices.

The 'A' type index with maximum expected improvement in EN-1 along with improvement in egg weight was I_{A9} with ΔH and R_{IH} as 3.5147 eggs and 0.3707 respectively. The most desirable 'B' type index was I_{B8} with Δgi in EN-1, ΔH and R_{IH} as 3.0602 eggs, 30.2481 and 0.4324 respectively. It showed positive correlated response in EW40 (0.1246) along with 98.63 percent relative efficiency (RE_{IH}). However, both types of desirable indices showed less than 50 percent efficiency, therefore 'B' type indices were further selected on the basis of efficiency alone and I_{B17} (EN-2, MOT40, MOI40, ACL) was adjudged to be the best index with R_{IH} equal to 0.5775. The negative response in EW40 might be overcome by fixing mild culling level for EW40 before selecting parents. The five Osborne indices and the desired multi-trait indices were compared for efficiency by comparing the responses in individual traits. Osborne indices showed greater efficiency than multi-trait indices for improvement in single trait, whereas, multi-trait index I_{B17} (EN-2, MOT40, MOI40, ACL) was adjudged to be the best index with R_{IH} equal to 0.5775 for net improvement in genetic worth of the layer population.

From the present study, it may be concluded that EN-2, MOT40, MOI40 and ACL should be considered in selection programme of Layer hens as secondary traits for the genetic gain in egg number as primary trait and for the net improvement of the breeding flock, either by Osborne Index or by multi-trait selection Index. Usefulness of these traits in selection programme would be more, if the traits are recorded up to 64 weeks of age. Automated, precise and full proof method of trap nesting would further add information on utility of these traits in Layer Breeding.

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CONFLICT OF INTEREST

The authors declare that there being no conflict of interest.

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Table 1. Phenotypic variance and covariance matrix for Multi-trait selection index

Traits	BW 16	EW40	ASM	EN1	EN2	MOT40	MOI40	ACL
BW16	9496.386	62.4133	-350.772	538.9985	535.0644	-10.894	-4.6875	46.5424
EW28	62.4133	6.8469	0.9406	-3.6439	-6.8765	0.1378	0.0759	-2.2884
ASM	-350.772	0.9406	120.8292	-101.572	-72.9938	0.5426	0.2232	-1.8150
EN1	538.9985	-3.6439	-101.572	583.8475	462.0467	-3.6945	-3.3942	71.1940
EN2	535.0644	-6.8765	-72.9938	462.0467	758.1548	-16.123	-4.6151	96.7279
MOT40	-10.894	0.1378	0.5426	-3.6945	-16.123	0.5748	0.1056	-1.8445
MOI40	-4.6875	0.0759	0.2232	-3.3942	-4.6151	0.1056	0.1164	-1.0928
ACL	46.5424	-2.2884	-1.815	71.194	96.7279	-1.8445	-1.0928	42.8119

Diagonal: variance; above and below diagonal: covariance

Table 2. Genetic variance and covariance matrix for Multi-trait selection index

Traits	BW 16	EW 40	ASM	EN1	EN2	MOT40	MOI40	ACL
BW16	1648.372	15.4598	22.8614	144.7304	106.4842	-1.0194	-0.2686	-7.994
EW28	15.4598	0.9722	2.9912	0.1114	-1.4578	0.08578	0.029	-0.5346
ASM	22.8614	2.9912	16.0014	-19.2146	-5.2592	-0.30242	-0.0802	-2.925
EN1	144.7304	0.1114	-19.2146	45.8678	55.0698	-1.2718	-0.6252	7.9632
EN2	106.4842	-1.4578	-5.2592	55.0698	173.8866	-5.7736	-1.2282	21.628
MOT40	-1.0194	0.08578	-0.30242	-1.2718	-5.7736	0.184	0.0329	-0.6902
MOI40	-0.2686	0.029	-0.0802	-0.6252	-1.2282	0.0329	0.0242	-0.3104
ACL	-7.994	-0.5346	-2.925	7.9632	21.628	-0.6902	-0.3104	5.0634

Diagonal: variance; above and below diagonal: covariance

Table 3. Expected genetic gain in individual traits (ΔG_i) from selection of pullets on multi-trait indices along with response in aggregate genotype (ΔH), accuracy (R_{IH}) and Relative Efficiency (RE); when objective was to improve only egg production (EN1) (Type A)

Index*	BW16	EN1	EN2	MOT 40	MOI 40	ACL	EW 40**	ASM**	ΔH	R_{IH}	RE
1	13.4689	3.6892	7.4224	-0.1897	-0.0687	1.0132	-0.0264	-0.0357	3.6892	0.3891	1.0000
	0.0094	0.0803	-0.0485	-2.4799	-2.5002	-0.0189					
2	13.3196	3.6866	7.4339	-0.1902	-0.0694	1.0283	-0.0287	-0.0580	3.6866	0.3888	0.9993
	0.0095	0.0799	-0.0503	-2.4902	-2.3932	(-)					
3	14.4318	3.5604	7.6025	-0.1982	-0.0523	0.8717	-0.0116	-0.2431	3.5604	0.3755	0.9651
	0.0097	0.0920	-0.0547	-2.9057	(-)	0.0209					
4	6.4298	3.4754	7.9695	-0.2119	-0.0764	1.1967	-0.1170	-0.2041	3.4754	0.3665	0.9420
	(-)	0.0938	-0.0560	-2.8014	-2.6034	-0.0304					
5	13.4931	3.4607	7.7636	-0.2266	-0.0769	1.0920	-0.0006	0.2452	3.4607	0.3650	0.9381
	0.0111	(-)	0.0397	-0.3467	-3.1360	-0.0108					
6	13.7691	3.6425	7.5229	-0.2055	-0.0705	1.0160	-0.0090	-0.0162	3.6425	0.3842	0.9873
	0.0098	0.0498	(-)	-1.3277	-2.6171	-0.0314					
7	14.3326	3.5190	6.4310	-0.1770	-0.0708	0.9318	0.0227	-0.0909	3.5190	0.3711	0.9539
	0.0104	0.0285	0.0323	(-)	-3.0644	-0.0239					
8	14.6722	3.5568	7.5975	-0.1980	-0.0506	0.8450	-0.0079	-0.2259	3.5568	0.3751	0.9641
	0.0096	0.0931	-0.0529	-2.9154	(-)	(-)					
9	14.1399	3.5147	6.4402	-0.1776	-0.0717	0.9515	0.0201	-0.1210	3.5147	0.3707	0.9527
	0.0105	0.0277	0.0305	(-)	-2.9313	(-)					
10	13.5308	3.6352	7.5494	-0.2074	-0.0718	1.0424	-0.0117	-0.0535	3.6352	0.3834	0.9854
	0.0099	0.0472	(-)	-1.2732	-2.4420	(-)					
11	15.9625	3.3054	6.4107	-0.1856	-0.0490	0.7171	0.0577	-0.3923	3.3054	0.3486	0.8960
	0.0109	0.0320	0.0422	(-)	(-)	0.0257					
12	14.8641	3.4985	7.7388	-0.2176	-0.0532	0.8656	0.0101	-0.2349	3.4985	0.3690	0.9483
	0.0100	0.0579	(-)	-1.6212	(-)	0.0089					
13	13.4022	3.4598	7.7699	-0.2268	-0.0773	1.1010	-0.0020	0.2309	3.4598	0.3649	0.9378
	0.0111	(-)	0.0384	-0.3586	-3.0729	(-)					
14	14.9511	3.2330	8.1537	-0.2498	-0.0558	0.9159	0.0276	0.0243	3.2330	0.3410	0.8763
	0.0117	(-)	0.0483	-0.4977	(-)	0.0426					
15	6.0724	3.4683	7.9980	-0.2131	-0.0777	1.2255	-0.1221	-0.2450	3.4683	0.3658	0.9401
	(-)	0.0933	-0.0590	-2.8221	-2.4311	(-)					
16	7.0332	3.3265	8.2302	-0.2235	-0.0588	1.0549	-0.1070	-0.4477	3.3265	0.3508	0.9017
	(-)	0.1063	-0.0627	-3.2537	(-)	0.0107					
17	4.1167	3.1280	8.6781	-0.2703	-0.0905	1.3745	-0.1145	0.1107	3.1280	0.3299	0.8479
	(-)	(-)	0.0593	0.0021	0.0961	0.0015					
18	12.6605	3.3517	7.8451	-0.2208	-0.0806	1.1692	-0.0231	0.4912	3.3514	0.3535	0.9084
	0.0119	(-)	(-)	-1.2509	-3.4680	0.0306					
19	14.6368	3.4221	4.6900	-0.1091	-0.0682	0.8060	0.0387	-0.2381	3.4221	0.3609	0.9276
	0.0108	0.0476	(-)	(-)	-3.4934	0.0060					
20	6.1598	3.2392	6.8826	-0.2015	-0.0808	1.1373	-0.0741	-0.3067	3.2392	0.3416	0.8780
	(-)	0.0360	0.0357	(-)	-3.2617	-0.0376					
21	6.0724	3.4683	7.9980	-0.2131	-0.0777	1.2255	-0.1221	-0.2450	3.4683	0.3658	0.9401
	(-)	0.0933	-0.0590	-2.8221	-2.4311	(-)					
22	13.7677	3.4529	7.3787	-0.2152	-0.0759	1.0503	0.0100	0.1710	3.4529	0.3642	0.9359
	0.0111	(-)	0.0472	(-)	-3.1843	-0.0140					
23	16.2912	3.2995	6.3981	-0.1853	-0.0467	0.6810	0.0629	-0.3705	3.2995	0.3480	0.8944
	0.0108	0.0331	0.0448	(-)	(-)	(-)					
24	14.6950	3.4217	4.6605	-0.1079	-0.0679	0.7986	0.0397	-0.2256	3.4217	0.3609	0.9275
	0.0108	0.0481	(-)	(-)	-3.5360	(-)					
25	14.9635	3.4978	7.7347	-0.2172	-0.0525	0.8539	0.0114	-0.2275	3.4978	0.3689	0.9481
	0.0100	0.0589	(-)	-1.6442	(-)	(-)					
26	16.9034	3.1195	3.8332	-0.0872	-0.0398	0.4770	0.0907	-0.6818	3.1195	0.3290	0.8456
	0.0115	0.0586	(-)	(-)	0.0759	(-)					
27	15.4221	3.2156	7.5695	-0.2327	-0.0538	0.8466	0.0448	-0.0970	3.2156	0.3391	0.8716
	0.0117	(-)	0.0594	(-)	(-)	0.0391					
28	15.5193	3.2163	8.1617	-0.2510	-0.0520	0.8568	0.0371	0.0713	3.2163	0.3392	0.8718
	0.0116	(-)	0.0547	-0.4584	(-)	(-)					
29	13.6606	3.4514	7.3693	-0.2149	-0.0764	1.0603	0.0085	0.1487	3.4514	0.3640	0.9355
	0.0111	(-)	0.0459	(-)	-3.1036	(-)					
30	12.8767	3.3431	7.8329	-0.2195	-0.0797	1.1471	-0.0207	0.5655	3.3431	0.3526	0.9062
	0.0119	(-)	(-)	-1.3058	-3.7067	(-)					
31	14.1606	3.0538	8.3763	-0.2474	-0.0571	0.9912	0.0023	0.3179	3.0538	0.3221	0.8278
	0.0129	(-)	(-)	-1.6442	(-)	0.1012					
32	13.6052	3.1380	4.9765	-0.1230	-0.0788	0.9621	0.0256	0.2809	3.1380	0.3310	0.8506

	0.0128	(-)	(-)	(-)	-4.2601	0.0633					
33	5.896	3.1098	4.8224	-0.1215	-0.0787	1.0046	-0.0627	-0.4967	3.1098	0.3280	0.8429
	(-)	0.0574	(-)	(-)	-3.7445	-0.0050					
34	7.1932	3.3255	8.2254	-0.2233	-0.0578	1.0396	-0.1046	-0.4375	3.3255	0.3507	0.9014
	(-)	-0.1068	-0.0617	-3.2573	(-)	(-)					
35	7.0042	2.9723	6.9767	-0.2166	-0.0570	0.9201	-0.0467	-0.6972	2.9723	0.3135	0.8057
	(-)	0.0401	0.0463	(-)	(-)	0.0146					
36	5.6821	3.2274	6.9083	-0.2030	-0.0826	1.1752	-0.0805	-0.3626	3.2274	0.3404	0.8748
	(-)	0.0348	0.0328	(-)	-3.0543	(-)					
37	5.8292	3.3921	8.1954	-0.2368	-0.0814	1.2592	-0.1076	-0.2530	3.3921	0.3578	0.9195
	(-)	0.0552	(-)	-1.4001	-2.4907	(-)					
38	7.0500	3.2385	8.4603	-0.2498	-0.0606	1.0624	-0.0871	-0.4532	3.2385	0.3416	0.8778
	(-)	0.0677	(-)	-1.7892	(-)	-0.0036					
39	4.4515	2.8274	9.4119	-0.3094	-0.0677	1.2176	-0.0993	-0.1843	2.8274	0.2982	0.7664
	(-)	(-)	0.0584	-0.4653	(-)	0.0340					
40	3.8207	3.1234	8.7018	-0.2712	-0.0916	1.3986	-0.1189	0.0752	3.1234	0.3294	0.8466
	(-)	(-)	0.0458	-0.3294	-3.2559	(-)					
41	4.3911	3.1214	8.3059	-0.2593	-0.0896	1.3341	-0.1042	0.0388	3.1214	0.3292	0.8461
	(-)	(-)	0.0551	(-)	-3.4322	-0.0260					
42	1.5069	2.9424	8.9923	-0.2707	-0.0985	1.5365	-0.1648	0.4384	2.9424	0.3103	0.7976
	(-)	(-)	(-)	-1.4229	-3.8265	0.0270					
43	18.3393	3.0571	3.1796	-0.0629	-0.0292	0.2891	0.1176	-0.6716	3.0571	0.3224	0.8287
	0.0114	0.0681	(-)	(-)	(-)	(-)					
44	15.9714	3.2014	7.6174	-0.2350	-0.0504	0.7965	0.0524	-0.0450	3.2014	0.3376	0.8678
	0.0116	(-)	0.0644	(-)	(-)	(-)					
45	15.6583	2.9301	8.5197	-0.2509	-0.0456	0.8385	0.0214	0.5964	2.9301	0.3090	0.7942
	0.0130	(-)	(-)	-1.9665	(-)	(-)					
46	14.2246	3.0970	4.6384	-0.1094	-0.0765	0.8885	0.0366	0.4322	3.0970	0.3266	0.8395
	0.0128	(-)	(-)	(-)	-4.8539	(-)					
47	16.8928	2.5972	3.9380	-0.0998	-0.0428	0.5640	0.0993	-0.1275	2.5972	0.2739	0.7040
	0.0144	(-)	(-)	(-)	(-)	0.1703					
48	7.2489	2.9702	6.9671	-0.2164	-0.0556	0.8965	-0.0430	-0.6822	2.9702	0.3133	0.8051
	(-)	0.0573	0.1053	(-)	(-)	(-)					
49	6.9932	3.2384	8.4632	-0.2500	-0.0609	1.0679	-0.0879	-0.4568	3.2384	0.3415	0.8778
	(-)	0.0673	(-)	-1.7800	(-)	(-)					
50	5.8277	3.1095	4.8499	-0.1226	-0.0790	1.0118	-0.0638	-0.5028	3.1095	0.3280	0.8429
	(-)	0.0570	(-)	(-)	-3.7091	(-)					
51	6.9162	2.7176	3.8672	-0.0989	-0.0472	0.6562	-0.0211	-1.1179	2.7176	0.2866	0.7366
	(-)	0.0701	(-)	(-)	(-)	0.0694					
52	5.0086	2.8153	9.4207	-0.3105	-0.0642	1.1633	-0.0903	-0.1408	2.8153	0.2969	0.7631
	(-)	(-)	0.0634	-0.4341	(-)	(-)					
53	4.0818	3.1155	8.2966	-0.2592	-0.0907	1.3576	-0.1082	-0.0085	3.1155	0.3286	0.8445
	(-)	(-)	0.0526	(-)	-3.2837	(-)					
54	4.9319	2.8101	8.7976	-0.2915	-0.0655	1.1452	-0.0813	-0.3148	2.8101	0.2964	0.7617
	(-)	(-)	0.0687	(-)	(-)	0.0308					
55	1.7256	2.9348	8.9830	-0.2695	-0.0976	1.5148	-0.1624	0.5133	2.9348	0.3095	0.7955
	(-)	(-)	(-)	-1.4710	-4.0366	(-)					
56	0.8346	2.5132	10.2173	-0.3257	-0.0736	1.4248	-0.1693	0.2022	2.5132	0.2651	0.6812
	(-)	(-)	(-)	-1.8749	(-)	0.1052					
57	0.5741	2.6164	5.4283	-0.1507	-0.1014	1.3525	-0.1293	0.1455	2.6164	0.2759	0.7092
	(-)	(-)	(-)	(-)	-4.7673	0.0643					

* The numbers in second row within each index are the partial regression coefficients (b_i's)
** Correlated response for traits not included in index

Table 4.Expected genetic gain in individual traits (ΔG_i) from selection of pullets on multi-trait indices along with response in aggregate genotype (ΔH), accuracy (R_{IH}) and Relative Efficiency (RE); when objective was to improve all traits included in index (Type B)

Index	BW16	EN1	EN2	MOT 40	MOI 40	ACL	EW 40**	ASM**	ΔH	RIH	REΔH	REIH
1	21.4527	3.0764	5.8666	-0.1535	-0.2950	0.4226	0.1218	0.2665	31.0013	0.4384	1.0000	1.0000
	0.1729	0.2461	0.0226	-11.669	-0.6661	-0.5218						
2	21.6079	3.0023	5.5488	-0.1435	-0.0273	0.3995*	0.1285	0.1724	30.3299	0.4332	0.9783	0.9881
	0.1777	0.2360	-0.0265	-11.056	4.2951	(-)						
3	21.4918	3.0653	5.8474	-0.1530	-0.028*	0.4139	0.1229	0.2610	30.9714	0.4384	0.9990	1.0000
	0.1731	0.2490	0.0209	-11.742	(-)	-0.5164						
4	3.1792*	2.9394	10.5465	-0.3240	-0.0758	1.4022	-0.1597	0.3226	15.2878	0.5365	0.4931	1.2238

	(-)	0.1054	-0.0472	-13.338	-5.2574	0.0553						
5	21.8549	2.8123*	5.5042	-0.1519	-0.0246	0.3389	0.1460	0.3737	27.8746	0.4359	0.8991	0.9943
	0.1670	(-)	0.2531	-4.7875	0.5223	-0.4863						
6	24.1322	2.5527	2.5033*	-0.0411	-0.0076	-0.0440	0.2060	0.1351	26.6895	0.4266	0.8609	0.9731
	0.1747	0.2332	(-)	-2.5277	0.2238	-0.5400						
7	21.9840	2.9252	5.1341	-0.140*	-0.0286	0.3460	0.1530	0.2377	30.4180	0.4316	0.9812	0.9845
	0.1777	0.0094	0.3911	(-)	-3.3005	-0.5467						
8	21.4807	3.0602	5.5642	-0.1430	-0.031*	0.4444*	0.1246	0.2079	30.2481	0.4324	0.9757	0.9863
	0.1776	0.2118	-0.0224	-10.250	(-)	(-)						
9	22.0893	2.8510	4.8258	-0.130*	-0.0265	0.3263*	0.1586	0.1389	29.7926	0.4269	0.9610	0.9738
	0.1823	0.0113	0.3203	(-)	1.9317	(-)						
10	22.1083	2.8733	5.0720	-0.139*	-0.025*	0.3111	0.1576	0.2042	30.3647	0.4313	0.9795	0.9838
	0.1783	0.0138	0.4003	(-)	(-)	-0.4985						
11	24.1377	2.5497	2.4793*	-0.0403	-0.007*	-0.0460	0.2064	0.1383	26.6817	0.4267	0.8607	0.9733
	0.1748	0.2322	(-)	-2.4624	(-)	-0.5486						
12	23.9903	2.4000	2.0170*	-0.0282	-0.0047	-0.079*	0.2148	0.0194	26.4232	0.4231	0.8523	0.9651
	0.1800	0.1896	(-)	-0.6961	5.2389	(-)						
13	22.0132	2.7219*	5.1237	-0.1398	-0.0218	0.3064*	0.1537	0.2718	27.2984	0.4304	0.8806	0.9818
	0.1714	(-)	0.1970	-4.4051	5.3615	(-)						
14	21.8698	2.8176*	5.4877	-0.1511	-0.024*	0.3402	0.1461	0.3792	27.8488	0.4359	0.8983	0.9943
	0.1669	(-)	0.2514	-4.2784	(-)	-0.5004						
15	3.5368*	2.9326	10.5745	-0.3248	-0.0723	1.3631*	-0.1550	0.3051	13.9043	0.5324	0.4485	1.2144
	(-)	0.1111	-0.0442	-12.500	-3.5821	(-)						
16	3.3594*	2.8304	10.6000	-0.3278	-0.067*	1.3268	-0.1543	0.2234	15.0850	0.5323	0.4866	1.2142
	(-)	0.1306	-0.0607	-14.214	(-)	0.1332						
17	2.0087*	2.6089*	10.6897	-0.3388	-0.0717	1.3852	-0.1652	0.4623	12.4854	0.5775	0.4027	1.3173
	(-)	(-)	0.0218	-10.226	-2.7519	0.0867						
18	23.8590	1.9984*	1.4904*	-0.0133	0.0003	-0.1718	0.2264	0.4199	23.7003	0.4177	0.7645	0.9528
	0.1730	(-)	(-)	-0.9169	-0.2952	-0.2802						
19	4.2629*	3.3076	9.1013*	-0.2696	-0.0894	1.4180	-0.1373	0.0481	5.0845	0.4253	0.1640	0.9701
	(-)	0.0507	(-)	-2.5753	-4.5650	0.0159						
20	3.3594*	2.8304	10.6000	-0.3278	-0.067*	1.3268	-0.1543	0.2234	15.0850	0.5323	0.4866	1.2142
	(-)	0.1306	-0.0607	-14.214	(-)	0.1332						
21	24.2460	2.4385	1.6670*	-0.013*	-0.0018	-0.0028	0.2197	0.0843	26.5697	0.4253	0.8571	0.9701
	0.1767	0.2293	(-)	(-)	-1.2652	-0.4809						
22	22.5054	2.7906*	4.7765	-0.129*	-0.0222	0.2545	0.1671	0.2518	27.5585	0.4325	0.8889	0.9865
	0.1668	(-)	0.3488	(-)	-0.1558	-0.5295						
23	22.0252	2.882	4.8461	-0.130*	-0.028*	0.3486*	0.1559	0.1570	29.7535	0.4267	0.9598	0.9733
	0.1822	0.0081	0.3089	(-)	(-)	(-)						
24	24.0338	2.3574	1.7545*	-0.019*	-0.0012	-0.108*	0.2194	0.0070	26.3948	0.4231	0.8514	0.9651
	0.1805	0.1894	(-)	(-)	4.9056	(-)						
25	23.8181	2.4817	2.0303*	-0.0270	-0.010*	-0.017*	0.2093	0.0686	26.3268	0.4217	0.8492	0.9619
	0.1798	0.1636	(-)	0.1533	(-)	(-)						
26	24.2937	2.4076	1.6000*	-0.011*	-0.003*	-0.1403	0.2221	0.0680	26.5610	0.4254	0.8568	0.9703
	0.1770	0.2331	(-)	(-)	(-)	-0.4625						
27	22.5285	2.7837*	4.7583	-0.129*	-0.021*	0.2496	0.1678	0.2519	27.5365	0.4326	0.8882	0.9868
	0.1669	(-)	0.3484	(-)	(-)	-0.5319						
28	22.5750	2.6963*	4.4224	-0.118*	-0.0196	0.2291*	0.1731	0.1484	27.0170	0.4274	0.8715	0.9749
	0.1715	(-)	0.2806	(-)	4.9648	(-)						
29	21.8794	2.8320*	5.1619	-0.1381	-0.028*	0.3722*	0.1466	0.3094	27.1794	0.4289	0.8767	0.9783
	0.1706	(-)	0.1676	-4.2019	(-)	(-)						
30	23.7986	1.8515*	0.9271*	0.0029	0.0051	-0.242*	0.2370	0.2944	23.7906	0.4182	0.7674	0.9539
	0.1762	(-)	(-)	0.4785	3.8623	(-)						
31	23.8679	1.9841*	1.4591*	-0.0125	0.0009*	-0.1797	0.2273	0.4178	23.7007	0.4179	0.7645	0.9532
	0.1732	(-)	(-)	-0.9102	(-)	-0.2798						
32	23.8936	1.9407*	1.1227*	-0.001*	0.0016	-0.2092	0.2325	0.3982	23.6827	0.4179	0.7639	0.9532
	0.1737	(-)	(-)	(-)	-0.7018	-0.2680						
33	3.6676*	3.0186	5.3594*	-0.142*	-0.0916	1.2097	-0.0962	-0.2988	4.3198	0.3721	0.1393	0.8488
	(-)	0.0486	(-)	(-)	-6.1327	0.0742						
34	2.9440*	2.4346	9.6121	-0.331*	-0.066*	1.2229	-0.1011	0.0507	13.2696	0.4774	0.4280	1.0890
	(-)	-0.1510	0.4036	(-)	(-)	0.1488						
35	3.8570*	2.8448	10.5921	-0.3270	-0.064*	1.2861*	-0.1479	0.2432	13.7638	0.5299	0.4440	1.2087
	(-)	0.1306	-0.0486	-13.101	(-)	(-)						
36	2.9634*	2.6617	9.6503	-0.324*	-0.0784	1.3332*	-0.1123	0.2148	12.3904	0.4845	0.3997	1.1052
	(-)	0.0553	(-)	-1.7447	-2.6674	(-)						
37	5.5301*	3.3841	8.6391*	-0.2525	-0.0825	1.3029*	-0.1164	-0.1688	3.7191	0.3759	0.1200	0.8574
	(-)	0.0553	(-)	-1.7447	-2.6674	(-)						
38	4.9742*	3.1378	9.5879*	-0.2924	-0.069*	1.2667	-0.1243	-0.2354	4.6969	0.3983	0.1515	0.9085
	(-)	0.0653	(-)	-3.0567	(-)	0.0802						

39	2.0054*	2.4999*	10.6972	-0.3420	-0.0659*	1.3329	-0.1580	0.4107	12.3722	0.5761	0.3991	1.3141
	(-)	(-)	0.0296	-10.323	(-)	0.1278						
40	2.3706*	2.5454*	10.7151	-0.3415	0.0665	1.3238*	-0.1547	0.4764	11.1230	0.5792	0.3588	1.3212
	(-)	(-)	0.0350	-9.2010	-1.3090	(-)						
41	5.0576*	2.9920*	8.8507	-0.287*	-0.0748	1.2248	-0.0888	-0.1702	10.1504	0.4830	0.3274	1.1017
	(-)	(-)	0.2349	(-)	-4.1732	-0.0066						
42	1.7161*	2.8837*	9.6268*	-0.2963	-0.0935	1.5546	-0.1722	0.3212	1.9445	0.5127	0.0627	1.1695
	(-)	(-)	(-)	-1.1063	-1.6719	0.0513						
43	23.8100	2.4874	2.0852*	-0.028*	-0.011*	-0.011*	0.2084	0.0763	26.2974	0.4217	0.8483	0.9619
	0.1797	0.1605	(-)	(-)	(-)	(-)						
44	22.4311	2.7996*	4.4813	-0.117*	-0.025*	0.2933*	0.1658	0.1888	26.9125	0.4261	0.8681	0.9719
	0.1707	(-)	0.2493	(-)	(-)	(-)						
45	23.7346	1.9643*	0.9558*	0.0039	-0.000*	-0.185*	0.2322	0.3000	23.7307	0.4172	0.7655	0.9516
	0.1751	(-)	(-)	1.2249	(-)	(-)						
46	23.7885	1.8623*	1.0810*	-0.002*	0.0052	-0.232*	0.2350	0.3011	23.7833	0.4184	0.7672	0.9544
	0.1759	(-)	(-)	(-)	4.5666	(-)						
47	23.9067	1.9143*	1.0723*	-0.000*	-0.002*	-0.2231	0.2340	0.3916	23.6836	0.4181	0.7640	0.9537
	0.1740	(-)	(-)	(-)	(-)	-0.2576						
48	3.5727*	2.4496	9.5994	-0.330*	-0.062*	1.1708*	-0.0924	0.0742	12.0491	0.4738	0.3887	1.0807
	(-)	-0.1277	0.3798	(-)	(-)	(-)						
49	6.6732*	3.2314	8.8773*	-0.2646	-0.062*	1.1134*	-0.0967	-0.3708	3.4960	0.3582	0.1128	0.8171
	(-)	0.0675	(-)	-2.0991	(-)	(-)						
50	5.7026*	3.1090	4.8838*	-0.123*	-0.0802	1.0263*	-0.0660	-0.4778	3.1892	0.3318	0.1029	0.7568
	(-)	0.0568	(-)	(-)	-3.9218	(-)						
51	4.7780*	2.6329	4.4472*	-0.123*	-0.057*	0.8494	-0.0526	-1.0592	3.4823	0.3042	0.1123	0.6939
	(-)	0.0691	(-)	(-)	(-)	0.1893						
52	2.4416*	2.4799*	10.7042	-0.3458	-0.062*	1.2857*	-0.1508	0.4561	11.0470	0.5792	0.3563	1.3212
	(-)	(-)	0.0410	-9.2138	(-)	(-)						
53	3.2125*	2.9206*	8.8771	-0.291*	-0.0699	1.1770	-0.0831	-0.2142	8.9469	0.4812	0.2886	1.0976
	(-)	(-)	0.2181	(-)	-2.111	(-)						
54	5.1651*	2.8078*	8.8262	-0.292*	-0.064*	1.1246	-0.0780	-0.2926	9.9508	0.4768	0.3210	1.0876
	(-)	(-)	0.2506	(-)	(-)	0.0573						
55	1.9176*	2.6402*	10.6102*	-0.3328	-0.0752	1.4082*	-0.1668	0.5693	0.4080	0.5567	0.0132	1.2698
	(-)	(-)	(-)	-0.3447	-0.1779	(-)						
56	0.7575*	2.5117*	10.1036*	-0.3221	-0.074*	1.4294	-0.1692	0.1663	1.7515	0.4860	0.0565	1.1086
	(-)	(-)	(-)	-1.2644	(-)	0.0799						
57	0.0675	2.5732	5.5992	-0.1601	-0.0998	1.3785	-0.1344	-0.0288	1.4783	0.4419	0.0477	1.0080
	(-)	(-)	(-)	(-)	-2.2307	0.0686						

* Correlated response in individual traits when not included in selection criteria
** Correlated response in traits not included in index
*** The numbers in second row within each index are the partial regression coefficients (b_i's

Table 5. Desirable multi-trait indices with the objective to improve EN-1 only ('A' type)

Index No.	No. of Traits	Traits	Δg_i in EW40	ΔH	R_{IH}	RE
I_{A1}	6	BW16, EN1, EN2, MOT40, MOI40, ACL	-0.0264	3.6892	0.3891	1.0000
I_{A7}	5	BW16, EN1, EN2, MOI40, ACL	0.0227	3.5190	0.3711	0.9539
I_{A9}	4	BW16, EN1, EN2, MOI40	0.0201	3.5147	0.3707	0.9527
I_{A29}	3	BW16, EN2, MOI40	0.0085	3.4514	0.3640	0.9355
I_{A44}	2	BW16, EN2	0.0524	3.2014	0.3376	0.8678

Table 6. Desirable multi-trait indices with objective to improve all the index traits ('B' type)

Index No.	No. of Traits	Traits	Δg_i		ΔH	R_{IH}	RE
			EN-1 (eggs)	EW40 (g)			
I_{B1}	6	BW16, EN-1, EN-2, MOT40, MOI40, ACL	3.0764	0.1218	31.0013	0.4384	1.000
I_{B4}	5	EN-1, EN-2, MOT40, MOI40, ACL	2.9394	-0.1597	15.2878	0.5365	1.2238
I_{B17}	4	EN-2, MOT40, MOI40, ACL	2.6089	-0.1652	12.4854	0.5775	1.3173
I_{B40}	3	EN-2, MOT40, MOI40	2.5454	-0.1547	11.1230	0.5792	1.3212
I_{B44}	2	EN-2, MOT40	2.4799	-0.1508	11.0470	0.5792	1.3212

Table7. Expected genetic response in index traits from Osborne (I_A = 1.40) and Multi-trait indices with correlated response in EW40

Traits	Osborne index	'A' (Multi-trait)	'B' (Multi-trait)	'B' ** (Multi-trait)	EW40# (g)
EN-1 (eggs)	3.73	3.51	3.06	2.61	0.002
EN-2 (eggs)	11.37	6.44	5.56	10.67	-0.053
MOT40 (h)	-0.42	-0.18	-0.14	-0.34	0.121
MOI40 (h)	-0.13	-0.07	-0.03	-0.07	0.052
ACL (days)	1.50	0.95	0.34	1.38	-0.076
EW40* (g)	-	0.02	0.12	-0.16	-

* correlated response in EW40 from multi-trait indices
# correlated response in EW40 from Osborne indices
** 'B' type multi-trait indices chosen on the basis of efficiency only.

Table 8. Definition of selected traits

Traits	:	Definition
BW16	:	Body weight at the age of 16 week
EW40	:	Egg weight at the age of 28 week
ASM	:	Age at sexual maturity
EN-1	:	Egg number in 24 h period up to the age of 40 week
EN-2	:	Egg number in 06.00-11.00 h period up to the age of 40 week
MOT40	:	Mean oviposition time up to the age of 40 week
MOI40	:	Mean oviposition interval up to the age of 40 week
ACL	:	Average clutch length