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Heterosis Evaluation of Some Local and Imported Hybrids of Silkworm, *Bombyx mori* L.

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**ABSTRACT**  
Five local and two imported hybrids were used. The hybrids were evaluated according to heterosis over mid, better and check parent value. As well as evaluation index and subordinate function value for cocoon weight (CW), cocoon shell weight (CSW), pupal weight (PW), cocoon shell ratio (CSR), silk productivity (SP) for females and males. Fifth instar duration (Fd), total larval duration (LD), mortality percentage (MP), number of cocoon per liter (C/L), cocooning percentage (CP), puation ratio (PR), cocoon crop by number (crop/No) and weight (Crop/W), fecundity (Fecund) and fertility (Fertil).

There isn’t any hybrid earned the best heterosis over mid parent and better parent value for all traits together. HY A hybrid has the best heterosis for most characters understudy over mid and better parent values. Generally, HY A exhibited hybrid vigour over check parent value of G1 and G2 of most characters under study. Hybrid HY A has the best results for most traits under investigation. About the mean of evaluation index for hybrids understudy, best data registered for HY A, HY B, G2 and G1. Also, hybrid HY A registered the highest value of the subordinate function for most traits. Cumulative subordinate function raveled that G2, HY A, G1 and HY B hybrids acquired the highest results, respectively.

**INTRODUCTION**

Natural silk has a unique location in the world. Mulberry silkworm, *Bombyx mori* L., is a very important economic insect. It produces silk fiber which reckons a queen of textiles.

Many breeders practice breeding programs through hybridization and selection which considered an important tool to improve the economic characters of silkworm breeds. Regarding Egypt, recently the silkworm breeding scenario was initiated by Ghazy (1999 & 2005), the concept of breeding program mono and bivoltine breeds.

The major aims of the breeding program are bespoke hybrids of mulberry silkworm to rearers which produce higher and sustain crops in different climate conditions. Moreover, silkworm breeds/hybrids which perform consistently good under adverse climatic conditions are considered as stable. In order to introduce bivoltine races in a temperate country, it is necessary to have stability in cocoon crop under high-temperature environments. The prerequisite of summer hybrid is healthiness and adaptability to adverse conditions of high...
temperature, low food quality, relatively higher economic traits, with the potential for increased cocoon production (Suresh Kumar et al., 2011).

A significant impact of silkworm hybrids through the exploitation of hybrid vigour where introduce through several scientists across the sericulture countries to increased quantitative and qualitative silk productivity besides crop stability on a commercial scale and succeeded in the development bivoltine silkworm hybrids (Harada, 1961; Mano et al. 1982; He et al. 1991; Chen et al., 1994; Basavaraja et al. 1995; Rajalakshmi et al. 1998; Datta et al. 2000; Sudhakara Rao et al. 2001; Suresh Kumar et al. 2004, Jalali et al. 2011; Khan, 2015 and Ghazy et al. 2017).

Heterosis estimation for mulberry silkworm, Bombyx mori L., of some local hybrids will be adopted. Evaluate the hybrid vigour over two imported hybrids. Also, this study aims to develop hybrids in Egypt.

MATERIALS AND METHODS

Six silkworm races Bombyx mori L. were used for hybridization. It is obtained from the Sericulture Research Department – Plant Protection Research Institute – Agricultural Research Center. The races are RBPJ3, RBPch 4, L 252, O 111, I 214 and G 155. The hybridization made as follows (Table 1):

| No. | hybrid               | Code |
|-----|----------------------|------|
| 1   | L 252 X RBPch 4      | HY A |
| 2   | RBPch 4 X L 252      | HY B |
| 3   | G 155 X O 111        | HY X |
| 4   | O 111 X G 155        | HY D |
| 5   | I 214 X RBPI 3       | HY F |

In addition two imported hybrids from Bulgaria are G2XK2XH1XKK and H1XkkXXV2XG2 which coded as G1 and G2, respectively.

Three replicates of each hybrid were reared. Each replicate contained 500 larvae. Mulberry leaves of Morus alba var Kokoso-27 were used for feeding larvae of a silkworm. Chopped leaves were offered during young instars. Whole leaves and shoots used for feeding fourth and fifth instar, respectively. Collapsible frames applied for mountage. During young silkworm wet foam used for adjusted the humidity and polythene sheets for bottom and cover of rearing trays (Ghazy, 2008). Temperature and humidity inside rearing room recorded. Average of temperature was 28.2 ± 2 and 66.5 ± 2 %for humidity percentage.

Data were registered for the following characters: cocoon weight (CW), cocoon shell weight (CSW), pupal weight (PW), cocoon shell ratio (CSR), silk productivity (SP) for females and males. fifth instar duration (Fd), total larval duration (LD), mortality percentage (MP), number of cocoon per liter (C/L), cocooning percentage (CP), pupation ratio (PR), cocoon crop by number (Crop/No) and weight (Crop/W), fecundity (Fecund) and fertility (Fertili).

Cocoon shell ratio for each entry was calculated according to Tanaka (1964) as follows:

\[
\text{Cocoon shell ratio} \, (\%) = \frac{\text{cocoon shell weight}}{\text{fresh cocoon weight}} \times 100
\]

Silk productivity was estimated by using formula of Iyengar et al. (1983):

\[
\text{Silk productivity} \, \text{(cg/day)} = \frac{\text{Cocoon shell weight (cg)}}{\text{fifth instar duration (day)}}
\]
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Pupation ratio was calculated according to the following formulae of LEA (1996):

\[
\text{Pupation ratio (\%) = \frac{\text{Number of health pupae}}{\text{Corrected basic number of examined}}} \times 100
\]

The formulae of estimating heterosis over better and mid parent values:

Heterosis was estimated by using the following formulae of (Rao et al. 2002):

1. **Heterosis over better parent value (BPV)**

\[
\text{BPV} = \frac{\bar{F}_1 - \text{BPV}}{\text{BPV}} \times 100
\]

Where: \( \bar{F}_1 \) : Mean of hybrid

2. **Heterosis over mid parent value (MPV)**

\[
\text{MPV} = \frac{\bar{F}_1 - \text{MPV}}{\text{MPV}} \times 100
\]

BPV: The best value of the parents involved in the hybridization.

MPV: The average value of the parents involved in the hybridization.

3. The formula of heterosis over check parent value:

Heterosis was calculated according to the formula of Singh et al. (2002) as follows:

\[
\text{Heterosis over CPV} = \frac{\bar{F}_1 - \text{CPV}}{\text{CPV}} \times 100
\]

Where CPV: Check Parent Value

Modified of evaluation index and Subordinate function were calculated According to Ghazy (2014) as follow:

Evaluation index (EI) = \((A - B) / C \times 10\) + 50 for Positive traits

Evaluation index (EI) = 50 - \((A - B) / C \times 10\) for negative traits

\(X_U = (X_i - X_{\text{worst}}) / (X_{\text{best}} - X_{\text{worst}})\)

Where \(X_U = \) Subordinate Function, \(X_i = \) Measurement of the character of a tested genotype, \(X_{\text{worst}} = \) the worst value of this character among all the tested genotypes, \(X_{\text{best}} = \) the best value of this character among all the tested genotypes.

**RESULTS AND DISCUSSION**

**Performance of Parental Races, Local and Imported Hybrids:**

Mean performance of five local hybrids and two imported hybrids and six local races of silkworm *Bombyx mori* L. found in Table 2. The performance of hybrids HY A, HY B and HY X are better than the parental races for CW, CSW, PW, SP for females and males. Also the previous hybrids are the best results for MP, C/L, fecund characters. The performance of hybrid HY A is best than the imported hybrid G1 for CW, CSW, PW, CSR, SP for females and males. In addition, FD, LD, C/L, CP, Crop/No, Crop/W, Fecund and fertili were superior. Moreover, the same local hybrid is better than the imported hybrid G2 for CW, CSW, PW, CSR, C/L, CP, PR, Crop/No, Crop/W, fecund and fertili characters.
Table 2. Performance of some local hybrids and two imported hybrids and six of local races of silkworm *Bombyx mori* L.

| Character                                         | CW (g) | CSW (g) | PW (g) | CSR (%) | SP (cg/day) |
|--------------------------------------------------|--------|---------|--------|---------|-------------|
| HY A                                             | 2.211  | 2.012   | 0.418  | 0.409   | 1.723       |
| HY B                                             | 2.188  | 2.037   | 0.418  | 0.411   | 1.708       |
| HY X                                             | 1.967  | 1.775   | 0.369  | 0.351   | 1.537       |
| HY D                                             | 1.713  | 1.705   | 0.324  | 0.329   | 1.325       |
| HY F                                             | 1.700  | 1.500   | 0.297  | 0.285   | 1.331       |
| G1                                               | 2.132  | 1.995   | 0.392  | 0.414   | 1.671       |
| G2                                               | 2.164  | 2.010   | 0.411  | 0.396   | 1.683       |
| RBPj1                                            | 1.733  | 1.473   | 0.314  | 0.342   | 1.358       |
| RBPch1                                           | 1.705  | 1.335   | 0.309  | 0.256   | 1.334       |
| L 252                                            | 1.367  | 1.117   | 0.227  | 0.214   | 1.077       |
| O111                                             | 1.310  | 1.092   | 0.214  | 0.202   | 1.034       |
| I 211                                            | 1.452  | 1.229   | 0.248  | 0.256   | 1.143       |
| G251                                             | 1.247  | 1.081   | 0.206  | 0.214   | 0.979       |
| SD                                               | 0.348  | 0.378   | 0.078  | 0.080   | 0.268       |

Table 2. (Continued)

| Character                                         | Fd     | LD     | MP     | C/L    | CP     | PR     | Crop/No | Crop/w | Fecund | Fertili |
|--------------------------------------------------|--------|--------|--------|--------|--------|--------|---------|--------|--------|---------|
| HY A                                             | 8.000  | 28.000 | 15.000 | 105.040 | 93.000 | 99.000 | 9300.000 | 19637.384 | 498.200 | 97.593  |
| HY B                                             | 9.000  | 29.000 | 16.000 | 105.000 | 94.761 | 100.000 | 9476.130 | 19853.377 | 497.200 | 98.487  |
| HY X                                             | 10.000 | 28.000 | 16.000 | 128.800 | 71.428 | 98.000 | 7140.000 | 13622.010 | 416.600 | 90.284  |
| HY D                                             | 8.000  | 27.000 | 14.000 | 119.940 | 73.000 | 98.000 | 7300.000 | 12474.459 | 525.600 | 80.531  |
| HY F                                             | 9.000  | 28.000 | 19.000 | 114.240 | 75.400 | 97.000 | 7540.000 | 12062.975 | 452.200 | 94.604  |
| G1                                               | 8.000  | 28.000 | 13.000 | 120.400 | 89.000 | 100.000 | 8900.000 | 18365.862 | 413.600 | 95.393  |
| G2                                               | 7.000  | 27.000 | 11.000 | 105.280 | 75.400 | 97.000 | 7540.000 | 15736.534 | 435.333 | 97.631  |
| RBPj1                                            | 8.800  | 30.000 | 18.000 | 150.267 | 82.979 | 100.000 | 8297.900 | 12730.389 | 392.333 | 97.429  |
| RBPch1                                           | 8.800  | 29.800 | 16.800 | 154.933 | 86.420 | 88.000 | 8641.900 | 13575.215 | 451.000 | 97.080  |
| L 252                                            | 9.000  | 29.000 | 20.571 | 173.600 | 88.571 | 98.000 | 8857.100 | 10634.897 | 430.000 | 95.581  |
| O111                                             | 9.800  | 29.000 | 24.000 | 211.867 | 75.800 | 98.000 | 7580.000 | 9102.595  | 406.667 | 92.176  |
| I 211                                            | 9.000  | 30.000 | 29.474 | 166.133 | 70.526 | 99.000 | 7052.600 | 9456.267  | 405.000 | 87.901  |
| G251                                             | 9.000  | 31.000 | 20.000 | 174.440 | 80.000 | 96.000 | 8000.000 | 9312.960  | 436.000 | 97.477  |
| SD                                               | 0.802  | 1.200  | 4.898  | 33.808  | 8.383  | 3.796  | 838.543  | 3784.006  | 41.800  | 5.163   |

Evaluation of Heterosis:

For cocoon weight (CW), cocoon shell weight (CSW), pupal weight (PW), cocoon shell ratio (CSR), silk productivity (SP) for females and males. Pupation ratio (PR), cocooning percentage (CP), Fecundity (Fecund), Fertility (Fertili), cocoon crop by number (Crop/No) and weight (Crop/W) positive hybrid vigour is desirable. While negative hybrid vigour is required for mortality percentage (MP), fifth instar duration (Fd), total larval duration (LD), number of cocoons per liter (C/L).

1-Heterosis Over Mid Parent Value:

Figures 1- 3 illustrated the hybrid vigour over mid parent value for the fifteen characters under investigation.

CW, CSW, PW, CSR and SP showed positive heterosis over mid parent value for females and males except female CSR and male of CSW& CSR for hybrid HY F (Figs 1&2).

C/L, LD and MP represented negative hybrid vigour for all hybrids under study. Hybrids of HY B, HY X and HY F acquired undesirable positive hybrid vigour for Fd trait. All hybrids have positive heterosis of pupation ratio except that of HY F. Regarding to cocoon percentage and cocoon crop by number hybrids of HY A and B have positive hybrid vigour. Only hybrid HY X has negative heterosis for fecundity percentage trait, while HY X and HY D for fertility percentage character. All hybrids have positive heterosis for cocoon crop by weight traits (Fig.3).
There isn’t any hybrid earned best hybrid vigour over mid parent value for all traits together. HY A hybrid has the best heterosis for most characters under study.

The same results were obtained by Sharma and Bali (2019) evaluated six parents and thirty-one hybrid combinations. Different hybrids combinations exhibited significant and desirable heterotic estimates at egg, larval, cocoon and post cocoon stage. No single hybrid is better for all characters together over mid parent value.

Fig.1. Heterosis over mid parent value of female hybrids for five characters.

Fig.2. Heterosis over mid parent value of male hybrids for five characters.
2-Hybrid Vigour Over Better Parent Value:

Heterosis over better parent value clarified in Figures 4-6 for previous traits. Females and males of all hybrids except HY F have the best hybrid vigour over better parent value for characters of cocoon weight, cocoon shell weight, pupal weight, cocoon shell ratio and silk productivity (Figs. 4&5).

Best hybrid vigour over better parent value was detected for C/L, LD and MP for all hybrids except HY F for MP character. Only HY A and D have better heterosis for Fd traits. Only one hybrid (HY F) has the worst hybrid vigour for PR and Crop/W traits. About CP and Crop/No all hybrids have negative hybrid vigour over better parent value except those of HY A and HY B. Hybrids of HY A and HY D acquired the best heterosis for Fd trait. All hybrids have the best heterosis for fecundity character. Hybrids of HY A and B earned the best hybrid vigour for fertility character (Fig. 6).

From the previous results, it appears that there are no hybrid has better hybrid vigour over better parent value for all characters together. Generally, Hybrid of HY A is better than others.

These results are coincidence with those found by Ghazy and Fouda (2006) they evaluated four simple hybrids. Heterosis over better parent value was registered for six characters. There is no superior hybrid in all traits together.
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Fig. 4. Heterosis over better parent value of female hybrids for five traits.

Fig. 5. Heterosis over better parent value of male hybrids for five traits.
3-Hybrid Vigor Over Check Parent Value:

Two imported hybrids from Bulgaria G₁ and G₂ used as check parents.

3-1 Check parent G1:

Hybrid vigour over check parent G₁ is founded in Figures 7-9. Fig. 7 explained the hybrid vigour over check parent G₁ of five traits for females. Positive heterosis was detected for the female of HY A and HY B except for SP of HY B. Males of HY A showed hybrid vigour for CW, PW and CSR (Fig. 8).

There isn't any hybrid represent heterosis for Fd, LD and MP except HY D for larvae duration. Hybrid vigour over check parent value (G₁) appeared for all hybrids of C/L and PR except HY X for C/L and HY B for PR. Hybrids of HYA and HY B exhibit heterosis for CP, Crop/No, Crop/W and Fertili characters. All hybrids exposed hybrid vigour for Fecund trait.

Generally, HY A exhibited hybrid vigour over check parent value (G₁) of most characters understudy, this hybrid is promising and can be used for commercial production.

These results are in agreement with those found by Ghazy (2007) and who manifested hybrid vigour over check parent value. Some hybrids are promising which can be used for commercial production.
Fig. 7. Heterosis over check parent (G₁) value of female hybrids for five traits.

Fig. 8. Heterosis over check parent (G₁) value of male hybrids for five traits.
3-2 Check parent \( G_2 \):

Data in Figures 10-12 displayed the heterosis over check parent \( G_2 \) for all characters under investigation. Female of HY B has hybrid vigour for four characters and HY A for three traits. About male HY B submitted hybrid vigour for the same character as a female. And HY A male has heterosis for three characters (Figs. 10&11).

No hybrid showed hybrid vigour of Fd, LD and MP over check parent value \( G_2 \). HY A and HY B represent hybrid vigour for C/L, CP, Crop/No and Crop/W characters. Heterosis was observed for four hybrids of PR, three hybrids for a fecund trait. Only a hybrid of HY B showed hybrid vigour for Fertili character. Hybrids of HY A and HY B represent hybrid vigour over check parent \( G_2 \) for most characters. There are promising hybrids that can be exploited commercially.

These results are contributed to the findings of Ghazy (2012) who estimation the hybrid vigour over check parent value for fourteen local hybrids. Only, one hybrid is promising for most characters.
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Fig. 10. Heterosis over check parent (G2) value of female hybrids for five traits.

Fig. 11. Heterosis over check parent (G2) value of male hybrids for five traits.
4-Evaluation Index Value:

Evaluation index values were found in Figures 13-16 for all traits under investigation. Values of evaluation index of female and male for cocoon weight (CW), cocoon shell weight (CSW), pupal weight (PW), cocoon shell ratio (CSR), silk productivity (SP) represented in Figures 13 & 14. HY A and G₂ have valued over 50 for all previous characters. And HY B and G₁ have higher values than 50 for all traits except those of SP for HY B and CSR for G₁.

Values of pupation ratio (PR), cocooning percentage (CP), Fecundity (Fecund), Fertility (Fertility), cocoon crop by number (Crop/No) and weight (Crop/W) positive hybrid vigour is desirable. While negative hybrid vigour is required for mortality percentage (MP), fifth instar duration (Fd), total larval duration (LD), number of cocoons per liter (C/L) for evaluation index were illustrated in Fig 15.

Where, hybrid HY A has the best results for the fifth duration, No of cocoon/liter, cocooning percentage, pupation ratio, crop/number, crop/weight, fecundity and fertility. And hybrid HY B showed better results for a number of cocoon/liter, cocooning percentage, pupation ratio, crop/number, crop/weight, fecundity and fertility. Imported hybrid G₁ demonstrated good results for the fifth duration, mortality percentage, cocooning percentage, pupation ratio, crop/number, crop/weight and fertility. And hybrid G₂ revealed best values for the fifth duration, larvae duration, mortality percentage, number of cocoon/liter, crop/weight and fertility.

Figure 16 containing data of the evaluation index mean for hybrids under study. Best data registered for HY A, HY B, G₂ and G₁, respectively. So, two hybrids are superior comparing to the imported hybrids.

These results are advocated with the findings of Seshagiri et al. (2013) who evaluated Twenty-four hybrid combinations used evaluation index value. They stated that, hybrid MSO₃ x APS₄₅ with the highest evaluation index over multiple traits excelled over other combinations. Further, the combination recorded higher percent improvement over its control for all the 8 traits studied with the highest improvement was recorded for the trait shell weight.
Also, Ghazy and Mahmoud (2013) estimate the evaluation index value of thirteen single hybrids, hybrids for Giza of C, H, L, P and V have better values of the average of evaluation index.

**Fig.13.** Evaluation index value for female of five local and two imported hybrids for five characters.

**Fig.14.** Evaluation index value for male of five local and two imported hybrids.
5-Subordinate Function:

Subordinate function values were recorded in Figures 17-20. Data of CW, CSW, PW, CSR and SP for subordinate function were constituted in Figures. 17&18 for females and males. Hybrids of HY A, HY B, G2 and G1 got the best data for both females and males.
Higher data were documented of HY A for Fd, LD, MP, CP, Crop/No, Crop/W, Fecund and fertili characters. And hybrid G₁ for Fd, LD, MP, CP, PR, Crop/No, Crop/W and fertili traits. Also for hybrid G₂ of Fd, LD, MP, C/L, Crop/W and fertili characters (Fig. 19).

The cumulative subordinate function was settled in Fig. 20 for all hybrids under examination. Data raveled that G₂, HY A, G₁ and HY B hybrids acquired the highest results, respectively.

These results are accordance with those found by Ghazy (2014) who studied the subordinate function of thirteen single hybrids for nineteen characters. The highest value of the subordinate function was recorded for ten hybrids.
6-Ranking of Local and Imported Hybrids:

Table 3. showed the ranking of the local and imported hybrids. Data of average of evaluation index and cumulative of subordinate function were descending order. HY A and HY B hybrids ranking first and second order in the mean of evaluation index while it ranking second and four of cumulative and subordinate function. G₁ and G₂
ranking third and four for the average of evaluation index and first and third for cumulative and subordinate function.

Table 3. Ranking of some local and imported hybrids

| Hybrids | Mean  | Serial number | Cumulative | Serial number |
|---------|-------|---------------|------------|---------------|
| HY A    | 59.422| 1             | 15.615     | 2             |
| HY B    | 57.178| 2             | 11.528     | 4             |
| G2      | 56.991| 3             | 15.759     | 1             |
| G1      | 55.889| 4             | 15.236     | 3             |
| HY D    | 46.412| 5             | 7.227      | 5             |
| HY F    | 40.709| 6             | 3.095      | 7             |
| HY X    | 40.657| 7             | 6.324      | 6             |

CONCLUSION

Five local and two imported hybrids used in evaluated the heterosis over better, mid and check parent values. As well as the evaluation index value and subordinate function exploited to determine the best hybrids. The results revealed that, there aren’t any hybrid earned best hybrid vigour over mid parent and better parent values for all traits together. HY A hybrid has the best heterosis for most characters understudy for mid and better parent values.

Generally, HY A exhibited hybrid vigour over check parent value (G1) of most characters understudies, this hybrid is promising and can be used for commercial production. Also, hybrids of HY A and HY B represent hybrid vigour over check parent (G2) for most characters. There are promising hybrids that can be exploited commercially. Best data registered for HY A, HY B, G2 and G1, respectively. So, two local hybrids are superior to the imported hybrids. G2, HY A, G1 and HY B hybrids acquired the highest results, respectively for cumulative subordinate function.

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ARABIC SUMMARY

Bombyx mori L. تقدير قوة الهجين في بعض الهجن المحلية والمستوردة من ديدان الحرير. قمن بحث الحير معهد بحوث وقاية النباتات. جيزة. مصر.

تم استخدام خمس هجين محلية وأثنان من الهجن المستوردة في هذه الدراسة، تم تقييم قوة الهجين في تلك الهجن
على حسب اختلاف عن قيم متوسط الأباء وأفضل الأباء وأب الاختياري. وبالمثل تم تقييم قيمة دليل التقييم
لصفاته وزن الشرفة، وزن غلاف الشرفة، ونسبة المحتوى الحيوي، نسبة التثبيت، نسبة التشبيت، نسبة المشحور، نسبت العد والوزن، عدد البيض الكلي/انثى
و نسبة الخصوبة.

وبالنسبة لقياس متوسط الأباء وأفضل الأباء أظهر الهجين HY A قوة هجين في كل الصفات معا، بالنسبة لقياس متوسط الأباء وأفضل الأباء HY A أظهر قوة هجين في معظم الصفات تحت الدراسة من حيث تقييم متوسط الأباء وأفضل الأباء وعامة الهجن HY A لمعظم الصفات تحت الدراسة. الهجين HY A هو أظهر قوة هجين من حيث تقييم على أساس الأداء الاختياري الأول G1 و G2، منＬمعظم الصفات تحت الدراسة. نسبة التثبيت HY A ، HY B، HY A، HY B، HY A، و G2، وكذلك الهجين HY A، HY B، HY A لأظهرت أن G1. الضروري والقدرة للفئات التراكمية للـ Subordinate function.

Evaluation index