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**Research Paper**

# Selection indices for high seed yield in *desi* chickpea (*Cicer arietinum* L.) genotypes under terminal heat stress

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## ABSTRACT

**Seventy-one genotypes of *desi* chickpea including released varieties were evaluated over two years under normal and late conditions. The selection index based on discriminant function analysis was used to determine the phenotypic value of different characters in selection. Seed yield and its five contributing traits were used to construct the index under normal and late-sown conditions. The results indicated that the efficiency of the index increased with the inclusion of a greater number of traits. The best selection index for the normal sown condition was observed for three characters including date of maturity, reproductive phase duration, and number of pods per plant in $E_1$ as well as with days to 50% flowering, days to maturity, and number of pods per plant in $E_3$. On the other hand, under late sown conditions ($E_2$ and $E_4$), four characters seed yield per plant, reproductive phase duration, number of pods per plant, and 100-seed weight had the best selection index. This study showed that the selection of these characters may be considered for better genetic gain for higher seed yield under any of these conditions.**

***Key words***: Discriminant function, Dates of sowing, Genetic advance, Heat stress, Selection index

## INTRODUCTION

Chickpea (*Cicer arientinum* L.) is an important pulse crop. Its area under cultivation is also slowly increasing especially in the irrigated, rice fellow and late sown conditions due to the government's recent increase in crop MSP and farmers' realization regarding crop potential in conservation agriculture (Kumar *et al*. 2023). India is the largest producer of chickpea and the country has many region-specific high-yielding varieties accounting for 50% (13.5 mt) of the nation's pulse production (Jayalakshmi and Kumar 2023). However, the productivity of chickpea is a constraint in the country may be due to various abiotic and biotic stresses (IPCC 2014). Therefore, it becomes important to breed cultivars or donors that can grow under late-sown conditions without yield penalty. The progress in the genetic enhancement of this crop is slow due to the narrow genetic base. Limited variability is available for improving the market and farmer-oriented economic traits. Therefore sincere breeding efforts are needed to generate new combinations of genes to boost the speed, efficiency, and accuracy of selection (Viola and Daniel 2018).

Seed yield is a complex trait associated with many contributing traits, which are interrelated among themselves (Prasanthi *et al*. 2023). The interdependency of contributing traits affects the selection criteria. Selection based on the selection index has been found important to directional selection for seed yield. Smith (1936) developed a selection index in the form of a discriminant function that can be useful in identifying important combinations of yield components for their selection criteria for chickpea breeders. To have a perfect picture of selection criteria especially when the crop is under terminal stress is important in the changing environment scenario. Therefore present study aimed to identify important yield contributing characters for selection under stress conditions.

## MATERIALS AND METHODS

In the present study, a set of seventy-one genotypes of *desi* chickpea (*Cicer arietinum* L.) were evaluated in Randomized Block Design with three replications under normal (5$^{th}$ and 1$^{st}$ November) and late (3$^{rd}$ and 2$^{nd}$ December) sown conditions at Pulses Research Station, Junagadh Agricultural University, Junagadh during *Rabi* 2017-18 (Y-I) and 2018-19 (Y-II) to estimate best selection indices. Delayed sowing exposed genotypes to heat stress due to terminal higher temperatures (Fig. 1). Each

genotype was grown in a single row of 4 meters in length. The line-to-line distance was 45 cm and plant to plant distance was 10 cm. The data was recorded on five randomly selected plants of each genotype for the ten characters listed in Table 1. The six characters were used (coded S.N. 1 to 7) to construct selection indices as they have moderate to high direct effect on SYP are presented below for both the sowing conditions and in both the years;

**Table 1.** List of characters studied in the present investigation

| S.N. | Characters | Trait Code |
|---|---|---|
| 1 | SYP= seed yield per plant (g) | A |
| 2 | DFF= days to 50 per cent flowering | B |
| 3 | DM= days to maturity | C |
| 4 | RPPD= reproductive phase duration | D |
| 5 | NPP= number of pods per plant, | E |
| 6 | HSW= 100-seed weight (g)) | F |
| 7 | SPAD= SPAD value (chlorophyll content index) | G |
| 8 | RPPD= reproductive phase duration | H |
| 9 | PH= plant height (cm) | I |
| 10 | NPBP= number of primary branches per plant | J |

The selection indices were created by addressing the equations proposed by Robinson *et al*. (1951). The individual indices were formulated for each component character, as well as SYP in combination with two or more characters along with SYP. The expected genetic advance of these indices was expressed as the percent of genetic advance achieved through the sole selection of yield.

## RESULTS AND DISCUSSION

The yield is a polygenic character and hence interdependent on many other associated traits (Chetariya *et al*. 2022). As a breeder while selecting for yield improvement in any environment, these interdependencies of yield contributing traits should not be neglected as it may directly affect selection criteria. Deciding selection criteria in stress breeding is difficult with the highest efficiency and efficacy. Discriminant function-based analysis is an efficient tool for breeders to find worthy individuals and groups of phenotypic characters for greater yield improvement. In the present study, selection indices were separately formulated for normal and late-sown conditions to establish the selection criterion (Table 1-4).

Sixty-three selection indices were created by considering all possible combinations of five characters contributing to genetic gain in yield. The genetic advances were estimated for each selected character as well as relative efficiency of various discriminant functions was assessed concerning the direct selection for the seed yield. The selected characters by using different selection indices for normal ($E_1$ and $E_3$) and late sown conditions ($E_2$ and $E_4$) in both years are given in Tables 1 to 4 assuming that the efficiency of straight selection for seed yield is 100 %.

The overall results indicated that the selection efficiency was greater when selection was based on component chracters (NPP and DFF) as compared to the straight selection, which was further enhanced with the addition of two or more characters. The highest efficiency was observed when all five or six characters were taken into consideration collectively.

### *Selection indices of normal sown conditions*

Under the normal sown condition of the first year ($E_1$), all the single character indices showed higher relative efficiency when compared with seed yield alone (Table 1 & 3). Among 15 various indices having two characters, the index consisted of DM and NPP exhibited the highest relative efficiency (668.90%). In most of the cases, it was observed that the addition of one more yield attribute in the preceding index resulted in increased efficiency of the succeeding index. There was an increase of about 140% in the relative efficiency of the index having a combination of three characters (DM, RPPD, and NPP) over the best selection index of two characters. Among 15 selection indexes of four characters combination, inclusions of SYP, DM, RPPD, and NPP (A+C+D+E) showed the maximum 848.90% relative efficiency. In the case of a combination of five characters including SYP, DM, RPPD, NPP, and HSW registered the maximum relative efficiency (886.44%). When all six *viz*., DFF, DM, RPPD, NPP, and HSW were included in a selection index, relative efficiency was 832.95%.

Under normal sown condition ($E_1$), the index comprising only three characters *viz*., DM, RPPD, and NPP emerged as the best index because it had a relative efficiency of 808.52% with 21.33 genetic gain which was quite higher in comparison to single character index. The sacrifice in efficiency was also not too much when more characters (four or five) were included. The next best index had a combination of four characters *viz*., SYP, DM, RPPD, and NPP as it had 22.40 genetic gains and 848.90% relative efficiency.

Under normal sown conditions of the second year ($E_3$), all the single character indices showed

**Table 1.** The results of selected traits from the use of different selection indices in chickpea under normal sown conditions ($E_1$) during *Rabi* 2017-18 (Y-I)

| Sr. No. | Selection index | Discriminant function | Expected genetic advance | Relative efficiency (%) | Relative efficiency per character (%) |
|---|---|---|---|---|---|
| 1 | A | 0.9294 A | 2.64 | 100.00 | 100.00 |
| 2 | B | 0.9176 B | 8.77 | 332.21 | 332.21 |
| 3 | C | 0.8935 C | 8.84 | 334.87 | 334.87 |
| 4 | D | 0.8653 D | 9.66 | 365.93 | 365.93 |
| 5 | **E** | 0.9482 E | **14.77** | **559.72** | 559.72 |
| 6 | F | 0.9819 F | 8.49 | 321.86 | 321.86 |
| 7 | A+B | 0.7999 A + 0.8948 B | 7.91 | 299.94 | 149.97 |
| 8 | A+C | 0.8446 A + 0.8841 C | 8.56 | 324.28 | 162.14 |
| 9 | A+D | 1.0005A + 0.8645 D | 10.47 | 396.74 | 198.37 |
| 10 | A+E | 0.7874A + 0.9615 E | 16.35 | 619.56 | 309.78 |
| 11 | A+F | 0.9243A + 0.9929F | 10.19 | 386.18 | 193.09 |
| 12 | B+C | 0.9445B + 0.9059C | 14.73 | 558.14 | 279.07 |
| 13 | B+D | 0.9173B + 0.8818D | 8.84 | 335.09 | 167.55 |
| 14 | B+E | 0.9076B + 0.9429E | 16.53 | 626.31 | 313.16 |
| 15 | B+F | 0.8936B + 0.9342F | 9.01 | 341.51 | 170.75 |
| 16 | C+D | 0.3929C + 0.5601D | 9.11 | 345.27 | 172.64 |
| 17 | **C+E** | 0.9954C + 0.9896E | **17.65** | **668.90** | 334.45 |
| 18 | C+F | 0.8860C + 0.9584F | 11.03 | 417.85 | 208.92 |
| 19 | D+E | 0.8624D + 0.9463E | 17.54 | 664.88 | 332.44 |
| 20 | D+F | 0.8609D + 1.0163F | 14.30 | 542.13 | 271.07 |
| 21 | E+F | 0.9387E + 0.9475F | 15.11 | 572.64 | 286.32 |
| 22 | A+B+C | 0.7596A + 0.9192B + 0.8997C | 13.81 | 523.55 | 174.52 |
| 23 | A+B+D | 0.8705A + 0.9007B + 0.8783D | 8.56 | 324.36 | 108.12 |
| 24 | A+B+E | 0.5610A + 0.8602B + 0.9776E | 17.36 | 658.03 | 219.34 |
| 25 | A+B+F | 0.8387A + 0.8833B + 0.9549F | 9.57 | 362.78 | 120.93 |
| 26 | A+C+D | 0.9351A + 0.8935C + 0.8441D | 16.44 | 623.17 | 207.72 |
| 27 | A+C+E | 0.6813A + 0.8635C + 0.9634E | 17.56 | 665.44 | 221.81 |
| 28 | A+C+F | 0.8575A + 0.8804C + 0.9797F | 11.89 | 450.64 | 150.21 |
| 29 | A+D+E | 0.8999A + 0.8656D + 0.9480E | 17.38 | 658.66 | 219.55 |
| 30 | A+D+F | 0.9504A + 0.8611D + 1.0229F | 15.68 | 594.11 | 198.04 |
| 31 | A+E+F | 0.8477A + 0.9492E + 0.9757F | 15.68 | 594.11 | 198.04 |
| 32 | B+C+D | 0.0000B + 1.8346C + -0.0709D | 17.68 | 670.18 | 223.39 |
| 33 | B+C+E | 0.9379B + 0.8943C + 0.9366E | 19.69 | 746.23 | 248.74 |
| 34 | B+C+F | 0.9185B + 0.9022C + 0.9251F | 13.88 | 525.94 | 175.31 |
| 35 | B+D+E | 0.8997B + 0.8706D + 0.9407E | 16.46 | 623.75 | 207.92 |
| 36 | B+D+F | 0.9045B + 0.8791D + 0.9687F | 11.03 | 417.92 | 139.31 |
| 37 | B+E+F | 0.4469B + 0.7759E +-0.1830F | 13.17 | 499.28 | 166.43 |
| 38 | **C+D+E** | 0.8834C + 0.8447D + 0.9381E | **21.33** | **808.52** | 269.51 |

Contd….

Table 1. Contd...

| Sr. No. | Selection index | Discriminant function | Expected genetic advance | Relative efficiency (%) | Relative efficiency per character (%) |
|---|---|---|---|---|---|
| 39 | C+D+F | 0.9017C + 0.8359D + 1.0025F | 18.67 | 707.60 | 235.87 |
| 40 | C+E+F | 0.8646C + 0.9257E + 0.9149F | 15.89 | 602.31 | 200.77 |
| 41 | D+E+F | 0.8635D + 0.9410E + 0.9822F | 18.90 | 716.15 | 238.72 |
| 42 | A+B+C+D | 0.8242A + 0.0000B + 1.8117C -0.0527D | 17.20 | 651.94 | 162.98 |
| 43 | A+B+C+E | 0.5280A + 0.8900B + 0.8857C + 0.9743E | 20.11 | 761.99 | 190.50 |
| 44 | A+B+C+F | 0.3801A + 0.3164B + 1.0419C + 0.7798F | 12.49 | 473.19 | 118.30 |
| 45 | A+B+D+E | 0.6756A + 0.8607B + 0.8644D + 0.9639E | 17.56 | 665.44 | 166.36 |
| 46 | A+B+D+F | 0.8706A + 0.8942B + 0.8760D + 0.9849F | 11.89 | 450.67 | 112.67 |
| 47 | A+B+E+F | 0.7633A + 0.8515B + 0.9435E + 0.9208F | 16.38 | 620.92 | 155.23 |
| 48 | **A+C+D+E** | 0.7886A + 0.8578C + 0.8659D + 0.9501E | **22.40** | **848.90** | 212.23 |
| 49 | A+C+D+F | 0.8968A + 0.8936C + 0.8415D + 1.0152F | 19.44 | 736.64 | 184.16 |
| 50 | A+C+E+F | 0.8137A + 0.8600C + 0.9403E + 0.9495F | 17.73 | 672.02 | 168.01 |
| 51 | A+D+E+F | 0.8882A + 0.8642D + 0.9462E + 1.0012F | 20.98 | 795.16 | 198.79 |
| 52 | B+C+D+E | 0.0000B + 1.8158C + -0.0640D + 0.9340E | 21.91 | 830.32 | 207.58 |
| 53 | B+C+D+F | 0.0411B + 1.7769C -0.0162D + 0.9589F | 18.09 | 685.79 | 171.45 |
| 54 | B+C+E+F | 0.8879B + 0.8871C + 0.9145E + 0.8643F | 17.38 | 658.63 | 164.66 |
| 55 | B+D+E+F | 0.8630B + 0.8652D + 0.9255E + 0.9139F | 15.89 | 602.31 | 150.58 |
| 56 | C+D+E+F | 0.8611C + 0.8628D + 0.9278E + 0.9490F | 21.81 | 826.71 | 206.68 |
| 57 | A+B+C+D+E | 0.6410A + 0.0000B + 1.7727C -0.0277D + 0.9605E | 22.48 | 852.16 | 170.43 |
| 58 | A+B+C+D+F | 0.8295A + 0.0192B + 1.7851C -0.0284D + 0.9808F | 18.31 | 694.02 | 138.80 |
| 59 | A+B+C+E+F | 0.7747A + 0.8802B + 0.8839C + 0.9334E + 0.9040F | 18.51 | 701.44 | 140.29 |
| 60 | A+B+D+E+F | 0.8061A + 0.8532B + 0.8622D + 0.9405E + 0.9471F | 17.73 | 672.03 | 134.41 |
| 61 | **A+C+D+E+F** | 0.8478A + 0.8527C + 0.8686D + 0.9374E + 0.9736F | **23.39** | **886.44** | 177.29 |
| 62 | B+C+D+E+F | 0.1006B + 1.6725C + 0.0734D + 0.9167E + 0.8994F | 20.81 | 788.73 | 157.75 |
| 63 | **A+B+C+D+E+F** | 0.8165A + 0.0695B + 1.6941C + 0.0489D + 0.9304E + 0.9305F | **21.98** | **832.95** | 138.83 |

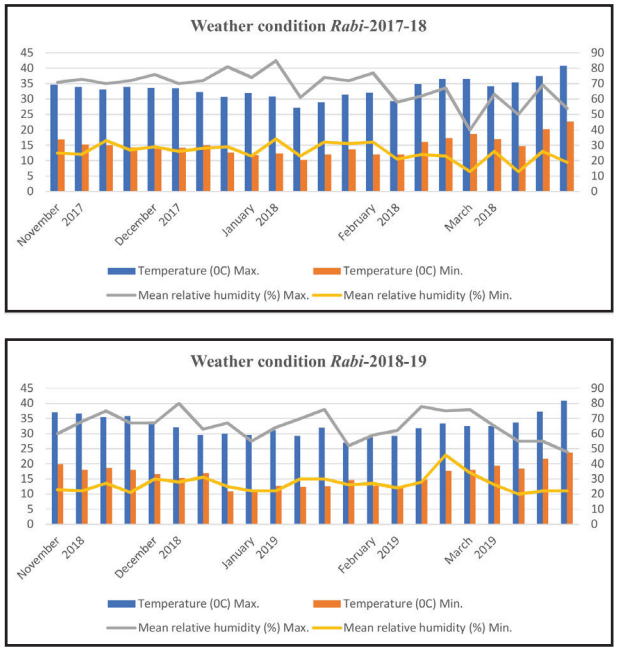


**Fig.** 1. Weather conditions of *Rabi* season 2017-18 and 2018-19

higher relative efficiency when compared with seed yield alone. Among the 15 various indices having two characters, the index consisting of DFF and NPP (B+E) exhibited a maximum relative efficiency of 612.16%. The relative efficiency of the index having a combination of three characters (DFF, DM, and NPP) was found 703.34%. Among the 15 selection indexes of four character combinations including SYP, DFF, DM, and NPP (A+B+C+E) showed the maximum 718.17% relative efficiency. In the case of five five-character (SYP, DFF, DM, NPP, and HSW) combinations registered the maximum relative efficiency (648.79%). When all six characters (A to F) were included in a selection index, relative efficiency was found 594.35%.

Under normal sown condition ($E_3$), among all the 63 selection indices the best index based on three characters *viz*., DFF, DM, and NPP identified as the best selection index. This index had 31.15 genetic gain and 703.34% relative efficiency. The next best index had a combination of four characters *viz*., SYP, DFF, DM, and NPP having 31.81 genetic advance and 718.17% relative efficiency. The third-best index comprised only two characters DFF and RPPD. This index had comparatively little less genetic gain (27.13) and relative efficiency (612.16), but the figures were quite higher than the gain obtained by individual component character.

Even under the same sowing condition i.e. normal sown condition in different years, the ideal selection indices were not found same. In the first year, it was with three characters DM, RPPD and NPP (C+D+E). While in the second year, the best index comprised DFF, DM, and NPP (B+C+E). Of course, two characters were common (DM and NPP) in both above mentioned best indices. Therefore emphasis must be paid to these indices while making selection in material sown under normal sown condition.

### *Selection indices of late sown conditions*

Under the late sown condition of the fist year ($E_2$), when the characters under study were considered individually the maximum genetic advance was observed in the case of NPP under late sowing (Table 2 & 4). The gain over selection based on seed yield itself was 14.00%. When two characters were included in the index, the selection index based on NPP and HSW (E+F) showed a relative efficiency of 541.06%. Further progress in expected genetic advance and relative efficiency was noticed in several selection indices having a combination of three characters. However, the maximum gain was shown by the selection index involving SYP, NPP, and HSW (633.63%). Genetic advance and relative efficiency were increased up to 21.57% and 688.69 %, respectively in the case of selection index having four characters *viz*., SYP, RPPD, NPP, and HSW. An increase of 23.42% in genetic gain and 747.69% in relative efficiency was found in the selection index involving five characters like SYP, DM, RPPD, NPP and HSW. When all the six characters *viz*., SYP, DFF, DM, RPPD, NPP and HSW are included in the selection index, maximum relative efficiency (744.68%) was observed.

Among all the 63 selection indices the best index is based on four characters like SYP, RPPD, NPP, and 100-seed weight (A+D+E+F). This index had 21.57 genetic gain and 688.69% relative efficiency which was slightly lower than the six characters index and quite higher than other indices. The next best index comprises three characters *viz*., SYP, RPPD, and HSW (A+D+F) with 19.85 genetic gains and 633.63% relative efficiency.

Under the late sown condition of the second year ($E_4$), when only one character under study was considered individually the maximum genetic advance was observed in the case of NPP under late sowing. The gain over selection based on seed yield itself was 17.69%. When two characters were included in the index, the selection index based on DFF and RPPD (B+E) exhibited a maximum relative

**Table 2.** The results of selected traits from the use of different selection indices in chickpea under late sown condition ($E_2$) during *Rabi* 2017-18 (Y-I)

| Sr. No. | Selection index | Discriminant function | Expected genetic advance | Relative efficiency (%) | Relative efficiency per character (%) |
|---|---|---|---|---|---|
| 1 | A | 0.9580 A | 3.13 | 100.00 | 100.00 |
| 2 | B | 0.8603 B | 6.76 | 215.75 | 215.75 |
| 3 | C | 0.8487 C | 7.38 | 235.73 | 235.73 |
| 4 | D | 0.7451 D | 6.01 | 192.01 | 192.01 |
| 5 | **E** | 0.9492 E | **14.00** | **446.88** | 446.88 |
| 6 | F | 0.9835 F | 8.12 | 259.23 | 259.23 |
| 7 | A+B | 0.8814A + 0.8500B | 6.65 | 212.18 | 106.09 |
| 8 | A+C | 0.9602A + 0.8514C | 7.87 | 251.39 | 125.69 |
| 9 | A+D | 1.0781A + 0.7434D | 7.42 | 236.97 | 118.49 |
| 10 | A+E | 1.0130A + 0.9400E | 16.45 | 525.14 | 262.57 |
| 11 | A+F | 0.9723A + 0.9899F | 10.38 | 331.41 | 165.71 |
| 12 | B+C | 0.9087B + 0.8694C | 12.85 | 410.37 | 205.19 |
| 13 | B+D | 0.8926B + 0.8086D | 7.41 | 236.40 | 118.20 |
| 14 | B+E | 0.8804B + 0.9540E | 15.53 | 495.85 | 247.93 |
| 15 | B+F | 0.8333B + 0.9311F | 8.46 | 270.08 | 135.04 |
| 16 | C+D | 0.6788C + 0.3451D | 7.82 | 249.71 | 124.86 |
| 17 | C+E | 0.8760C + 0.9587E | 16.07 | 512.87 | 256.44 |
| 18 | C+F | 0.8439C + 0.9629F | 10.14 | 323.64 | 161.82 |
| 19 | D+E | 0.7377D + 0.9496E | 15.34 | 489.85 | 244.92 |
| 20 | D+F | 0.7448D + 1.0279F | 11.16 | 356.40 | 178.20 |
| 21 | **E+F** | 0.9496E + 0.9930F | **16.95** | **541.06** | 270.53 |
| 22 | A+B+C | 0.9132A + 0.8972B + 0.8765C | 12.70 | 405.53 | 135.18 |
| 23 | A+B+D | 0.9990A + 0.8952B + 0.8130D | 7.89 | 251.97 | 83.99 |
| 24 | A+B+E | 0.8327A + 0.8664B + 0.9740E | 17.45 | 557.14 | 185.71 |
| 25 | A+B+F | 0.9616A + 0.8334B + 0.9400F | 10.10 | 322.38 | 107.46 |
| 26 | A+C+D | 1.1284A + 0.9127C + 0.6440D | 12.36 | 394.68 | 131.56 |
| 27 | A+C+E | 0.9963A + 0.8620C + 0.9462E | 18.04 | 576.04 | 192.01 |
| 28 | A+C+F | 1.0215A + 0.8474C + 0.9581F | 11.93 | 380.79 | 126.93 |
| 29 | A+D+E | 1.2847A + 0.7251D + 0.8964E | 17.88 | 570.66 | 190.22 |
| 30 | A+D+F | 1.0536A + 0.7469D + 1.0149F | 13.25 | 422.98 | 140.99 |
| 31 | **A+E+F** | 1.0671A + 0.9324E + 0.9803F | **19.85** | **633.63** | 211.21 |
| 32 | B+C+D | 1.7852B + 0.0000C + 1.6172D | 14.81 | 472.81 | 157.60 |
| 33 | B+C+E | 0.9289B + 0.8696C + 0.9581E | 19.07 | 608.88 | 202.96 |
| 34 | B+C+F | 0.8767B + 0.8757C + 0.9270F | 13.17 | 420.36 | 140.12 |
| 35 | B+D+E | 0.9129B + 0.8090D + 0.9539E | 15.93 | 508.54 | 169.51 |
| 36 | B+D+F | 0.8823B + 0.8124D + 0.9789F | 10.15 | 323.95 | 107.98 |
| 37 | B+E+F | 0.5965B + 1.0022E + 0.1143F | 15.44 | 492.81 | 164.27 |
| 38 | C+D+E | 0.9200C + 0.6369D + 0.9544E | 18.40 | 587.26 | 195.75 |

Contd….

Table 2. Contd...

| Sr. No. | Selection index | Discriminant function | Expected genetic advance | Relative efficiency (%) | Relative efficiency per character (%) |
|---|---|---|---|---|---|
| 39 | C+D+F | 0.9045C + 0.6533D + 1.0295F | 14.38 | 459.09 | 153.03 |
| 40 | C+E+F | 0.8550C + 0.9542E + 0.9729F | 18.08 | 577.16 | 192.39 |
| 41 | D+E+F | 0.7356D + 0.9474E + 1.0392F | 18.69 | 596.67 | 198.89 |
| 42 | A+B+C+D | 1.1675A + 0.2180B + 1.7145C -0.2180D | 15.05 | 480.34 | 120.08 |
| 43 | A+B+C+E | 0.8730A + 0.9136B + 0.8776C + 0.9715E | 20.61 | 657.92 | 164.48 |
| 44 | A+B+C+F | 0.7608A -0.3874B + 1.4501C + 0.6945F | 12.51 | 399.36 | 99.84 |
| 45 | A+B+D+E | 1.1017A + 0.9231B +0.8108 D + 0.9304E | 18.06 | 576.49 | 144.12 |
| 46 | A+B+D+F | 1.0357A + 0.8855B + 0.8161D + 0.9707F | 11.94 | 381.06 | 95.26 |
| 47 | A+B+E+F | 0.9290A + 0.8577B + 0.9604E + 0.9620F | 19.69 | 628.54 | 157.13 |
| 48 | A+C+D+E | 1.3941A + 0.9523C + 0.5984D + 0.8836E | 20.50 | 654.60 | 163.65 |
| 49 | A+C+D+F | 1.1217A + 0.9088C + 0.6509D + 1.0017F | 15.98 | 510.25 | 127.56 |
| 50 | A+C+E+F | 1.1590A + 0.8584C + 0.9231E + 0.9416F | 20.77 | 662.96 | 165.74 |
| 51 | **A+D+E+F** | 1.3930A + 0.7298D + 0.8810E + 0.9599F | **21.57** | **688.69** | 172.17 |
| 52 | B+C+D+E | 1.8056B + 0.0000C + 1.6175D + 0.9585E | 20.52 | 655.19 | 163.80 |
| 53 | B+C+D+F | -0.2031B + 1.9776C -0.3565D + 0.9776F | 15.80 | 504.44 | 126.11 |
| 54 | B+C+E+F | 0.9021B + 0.8752C + 0.9611E + 0.9415F | 19.93 | 636.21 | 159.05 |
| 55 | B+D+E+F | 0.9073B + 0.8120D + 0.9542E + 0.9947F | 18.09 | 577.49 | 144.37 |
| 56 | C+D+E+F | 0.9295C + 0.6279D + 0.9518E + 1.0458F | 20.84 | 665.44 | 166.36 |
| 57 | A+B+C+D+E | 1.1655A + 0.9365B + 0.8842C + 0.7334D + 0.9246E | 21.36 | 681.90 | 136.38 |
| 58 | A+B+C+D+F | 1.0825A + 1.8953B - 0.1141C + 1.7374D + 0.9684F | 16.95 | 541.27 | 108.25 |
| 59 | A+B+C+E+F | 1.0490A + 0.9021B + 0.8788C + 0.9466E + 0.9330F | 22.14 | 706.72 | 141.34 |
| 60 | A+B+D+E+F | 1.2310A + 0.9141B + 0.8125D + 0.9122E + 0.9499F | 20.78 | 663.27 | 132.65 |
| 61 | **A+C+D+E+F** | 1.5679A + 0.9420C + 0.6099D + 0.8590E + 0.9338F | **23.42** | **747.69** | 149.54 |
| 62 | B+C+D+E+F | -0.1931B + 1.9926C - 0.3720D + 0.9588E + 0.9926F | 21.84 | 697.14 | 139.43 |
| 63 | **A+B+C+D+E+F** | 1.3864A + 0.9240B + 0.8848C + 0.7334D + 0.8934E + 0.9168F | **23.33** | **744.68** | 124.11 |

**Table 3.** The results of selected traits from of different selection indices in chickpea under normal sown conditions ($E_3$) during *Rabi* 2018-19 (Y-II)

| Sr. No. | Selection index | Discriminant function | Expected genetic advance | Relative efficiency (%) | Relative efficiency per character (%) |
|---|---|---|---|---|---|
| 1 | A | 0.9629 A | 4.43 | 100.00 | 100.00 |
| 2 | B | 0.9445 B | 14.36 | 324.26 | 324.26 |
| 3 | C | 0.8209 C | 6.47 | 145.97 | 145.97 |
| 4 | D | 0.8638 D | 10.68 | 241.13 | 241.13 |
| 5 | **E** | 0.9707 E | **21.49** | **485.12** | 485.12 |
| 6 | F | 0.9975 F | 9.16 | 206.87 | 206.87 |
| 7 | A+B | 0.8711A + 0.9294B | 13.14 | 296.73 | 148.37 |
| 8 | A+C | 0.8303A + 0.7845C | 6.09 | 137.41 | 68.70 |
| 9 | A+D | 1.0539A + 0.8578D | 12.74 | 287.56 | 143.78 |
| 10 | A+E | 0.9163A + 0.9751E | 24.07 | 543.50 | 271.75 |
| 11 | A+F | 0.9513A + 1.0115F | 12.30 | 277.61 | 138.80 |
| 12 | B+C | 0.9996B + 0.7961C | 19.55 | 441.33 | 220.66 |
| 13 | B+D | 0.8113B + 0.7388D | 6.53 | 147.35 | 73.68 |
| 14 | **B+E** | 0.9512B + 0.9755E | **27.13** | **612.61** | 306.30 |
| 15 | B+F | 0.9223B + 0.9300F | 11.88 | 268.19 | 134.09 |
| 16 | C+D | 1.4414C + 1.1321D | 17.27 | 389.83 | 194.91 |
| 17 | C+E | 0.3076C + 0.9436E | 21.43 | 483.80 | 241.90 |
| 18 | C+F | 0.7451C + 0.8804F | 7.04 | 159.04 | 79.52 |
| 19 | D+E | 0.8582D + 0.9682E | 23.79 | 537.16 | 268.58 |
| 20 | D+F | 0.8476D + 1.0608F | 16.45 | 371.48 | 185.74 |
| 21 | E+F | 0.9694E + 0.9826F | 21.32 | 481.29 | 240.64 |
| 22 | A+B+C | 0.7994A + 0.9836B + 0.7718C | 18.00 | 406.45 | 135.48 |
| 23 | A+B+D | 0.8735A + 0.7847B + 0.7218D | 6.13 | 138.45 | 46.15 |
| 24 | A+B+E | 0.7448A + 0.9180B + 1.0009E | 28.31 | 639.07 | 213.02 |
| 25 | A+B+F | 0.9137A + 0.9192B + 0.9518F | 12.45 | 281.07 | 93.69 |
| 26 | A+C+D | 0.8669A + 0.6104C + 0.7923D | 11.59 | 261.57 | 87.19 |
| 27 | A+C+E | 0.6413A + 0.7381C + 1.0208E | 25.61 | 578.25 | 192.75 |
| 28 | A+C+F | 0.9161A + 0.7383C + 0.9013F | 9.60 | 216.63 | 72.21 |
| 29 | A+D+E | 1.0571A + 0.8517D + 0.9571E | 26.69 | 602.57 | 200.86 |
| 30 | A+D+F | 0.9909A + 0.8468D + 1.0640F | 19.14 | 432.19 | 144.06 |
| 31 | A+E+F | 0.8588A + 0.9846E + 1.0309F | 24.90 | 562.10 | 187.37 |
| 32 | B+C+D | 0.8353B + 0.6153C + 0.6153D | 12.47 | 281.56 | 93.85 |
| 33 | **B+C+E** | 1.0045B + 0.7983C + 0.9840E | **31.15** | **703.34** | 234.45 |
| 34 | B+C+F | 0.9703B + 0.7354C + 0.8511F | 15.52 | 350.39 | 116.80 |
| 35 | B+D+E | 0.8198B + 0.7425D + 0.9809E | 23.72 | 535.54 | 178.51 |
| 36 | B+D+F | 0.7556B + 0.7002D + 0.9092F | 7.07 | 159.71 | 53.24 |
| 37 | B+E+F | 0.5967B + 0.8935E - 0.1312F | 23.07 | 520.92 | 173.64 |
| 38 | C+D+E | 0.6430C + 0.7772D + 0.9889E | 24.92 | 562.51 | 187.50 |

Contd….

Table 3. Contd...

| Sr. No. | Selection index | Discriminant function | Expected genetic advance | Relative efficiency (%) | Relative efficiency per character (%) |
|---|---|---|---|---|---|
| 39 | C+D+F | 0.5658C + 0.8051D + 0.8808F | 13.81 | 311.90 | 103.97 |
| 40 | C+E+F | 0.7517C + 0.9737E + 0.8709F | 21.87 | 493.83 | 164.61 |
| 41 | D+E+F | 0.8450D + 0.9730E + 1.0490F | 25.13 | 567.30 | 189.10 |
| 42 | A+B+C+D | 0.7381A + 0.8000B + 0.6027C + 0.6027D | 11.26 | 254.13 | 63.53 |
| 43 | **A+B+C+E** | 0.5564A + 0.9679B + 0.7262C + 1.0345E | **31.81** | **718.17** | 179.54 |
| 44 | A+B+C+F | 0.5631A - 0.1160B + 1.5988C + 0.4011F | 9.46 | 213.51 | 53.38 |
| 45 | A+B+D+E | 0.7011A + 0.7462B + 0.6932D + 1.0134E | 25.62 | 578.42 | 144.60 |
| 46 | A+B+D+F | 0.9327A + 0.7491B + 0.6951D + 0.9249F | 9.62 | 217.09 | 54.27 |
| 47 | A+B+E+F | 0.7437A + 0.9190B + 1.0014E + 1.0020F | 26.31 | 593.97 | 148.49 |
| 48 | A+C+D+E | 0.6439A + 0.5555C + 0.8063D + 1.0285E | 27.27 | 615.58 | 153.89 |
| 49 | A+C+D+F | 0.9515A + 0.5599C + 0.8059D + 0.8918F | 16.18 | 365.32 | 91.33 |
| 50 | A+C+E+F | 0.6902A + 0.7310C + 1.0135E + 0.9706F | 24.89 | 561.86 | 140.47 |
| 51 | A+D+E+F | 0.9276A + 0.8454D + 0.9784E + 1.0724F | 28.73 | 648.57 | 162.14 |
| 52 | B+C+D+E | 0.9815B + 0.6445C + 0.8315D + 0.9920E | 25.76 | 581.51 | 145.38 |
| 53 | B+C+D+F | 0.7412B + 0.5750C + 0.5750D + 0.7566F | 9.43 | 212.89 | 53.22 |
| 54 | B+C+E+F | 0.9737B + 0.7390C + 0.9752E + 0.8441F | 27.17 | 613.36 | 153.34 |
| 55 | B+D+E+F | 0.7625B + 0.7038D + 0.9756E + 0.9023F | 21.88 | 494.08 | 123.52 |
| 56 | C+D+E+F | 0.5716C + 0.8010D + 0.9821E + 0.8773F | 24.69 | 557.52 | 139.38 |
| 57 | A+B+C+D+E | 0.4992A + 0.9400B + 0.5634C + 0.8315D + 1.0496E | 27.09 | 611.61 | 122.32 |
| 58 | A+B+C+D+F | 0.9150A + 0.7362B + 0.5726C + 0.5726D + 0.7753F | 10.32 | 233.03 | 46.61 |
| 59 | **A+B+C+E+F** | 0.6114A + 0.9674B + 0.7190C + 1.0262E + 0.9668F | **28.74** | **648.79** | 129.76 |
| 60 | A+B+D+E+F | 0.7161A + 0.7424B + 0.6882D + 1.0115E + 0.9910F | 24.89 | 562.04 | 112.41 |
| 61 | A+C+D+E+F | 0.6818A + 0.5494C + 0.8061D + 1.0229E + 0.9771F | 27.92 | 630.25 | 126.05 |
| 62 | B+C+D+E+F | 0.9455B + 0.5764C + 0.8315D + 0.9818E + 0.8190F | 22.45 | 506.81 | 101.36 |
| 63 | **A+B+C+D+E+F** | 0.4953A + 0.7265B + 0.5650C + 0.5649D + 1.0549E+ 0.9174F | **26.33** | **594.35** | 99.06 |

**Table 4.** The results of selected traits from the use of different selection indices in chickpea under late sown condition ($E_4$) during *Rabi* 2018-19 (Y-II)

| Sr. No. | Selection index | Discriminant function | Expected genetic advance | Relative efficiency (%) | Relative efficiency per character (%) |
|---|---|---|---|---|---|
| 1 | A | 0.9723 A | 4.52 | 100.00 | 100.00 |
| 2 | B | 0.9813 B | 13.33 | 295.27 | 295.27 |
| 3 | C | 0.8477 C | 4.27 | 94.56 | 94.56 |
| 4 | D | 0.9392 D | 9.77 | 216.39 | 216.39 |
| 5 | **E** | 0.9580 E | **17.69** | **391.88** | 391.88 |
| 6 | F | 0.9958 F | 9.04 | 200.22 | 200.22 |
| 7 | A+B | 0.9343A + 0.9710B | 11.80 | 261.30 | 130.65 |
| 8 | A+C | 0.8459A + 0.7729C | 3.98 | 88.08 | 44.04 |
| 9 | A+D | 1.0188A + 0.9341D | 12.31 | 272.71 | 136.36 |
| 10 | A+E | 0.9965A + 0.9525E | 20.86 | 461.91 | 230.95 |
| 11 | A+F | 0.9555A + 1.0120F | 12.73 | 281.99 | 140.99 |
| 12 | B+C | 1.0564B + 0.7202C | 17.22 | 381.39 | 190.70 |
| 13 | B+D | 0.7580B + 0.6687D | 4.35 | 96.26 | 48.13 |
| 14 | **B+E** | 0.9802B + 0.9574E | **22.19** | **491.39** | 245.70 |
| 15 | B+F | 0.9687B + 0.9682F | 10.36 | 229.46 | 114.73 |
| 16 | C+D | 2.0728C + 1.3877D | 13.07 | 289.36 | 144.68 |
| 17 | C+E | 0.7661C + 0.9502E | 17.83 | 394.90 | 197.45 |
| 18 | C+F | 0.7777C + 0.9263F | 6.91 | 153.01 | 76.50 |
| 19 | D+E | 0.9307D + 0.9550E | 19.92 | 441.15 | 220.58 |
| 20 | D+F | 0.9189D + 1.0456F | 16.64 | 368.61 | 184.31 |
| 21 | E+F | 0.9576E + 0.9995F | 20.38 | 451.46 | 225.73 |
| 22 | A+B+C | 0.8589A + 1.0489B + 0.6661C | 15.33 | 339.60 | 113.20 |
| 23 | A+B+D | 0.8809A + 0.7043B + 0.6206D | 4.05 | 89.62 | 29.87 |
| 24 | A+B+E | 0.9313A + 0.9694B + 0.9624E | 23.56 | 521.87 | 173.96 |
| 25 | A+B+F | 0.9501A + 0.9683B + 0.9859F | 11.35 | 251.29 | 83.76 |
| 26 | A+C+D | 0.8240A + 0.4231C + 0.7988D | 9.34 | 206.82 | 68.94 |
| 27 | A+C+E | 0.7270A + 0.6810C + 0.9899E | 20.51 | 454.22 | 151.41 |
| 28 | A+C+F | 0.8976A + 0.7584C + 0.9573F | 10.25 | 226.99 | 75.66 |
| 29 | A+D+E | 1.1304A + 0.9057D + 0.9276E | 23.55 | 521.58 | 173.86 |
| 30 | A+D+F | 0.9357A + 0.9165D + 1.0705F | 19.83 | 439.17 | 146.39 |
| 31 | A+E+F | 0.9904A + 0.9529E + 1.0035F | 24.44 | 541.33 | 180.44 |
| 32 | B+C+D | 0.6395B + 0.2059C + 0.2059D | 7.84 | 173.69 | 57.90 |
| 33 | **B+C+E** | 1.0813B + 0.6261C + 0.9506E | **24.52** | **543.10** | 181.03 |
| 34 | B+C+F | 1.0355B + 0.7024C + 0.9362F | 13.18 | 291.93 | 97.31 |
| 35 | B+D+E | 0.6888B + 0.5746D + 0.9507E | 17.95 | 397.62 | 132.54 |
| 36 | B+D+F | 0.7358B + 0.6614D + 0.9577F | 6.94 | 153.65 | 51.22 |
| 37 | B+E+F | 0.5430B + 0.9916E - 0.0586F | 19.87 | 440.16 | 146.72 |
| 38 | C+D+E | 0.4267C + 0.7629D + 0.9443E | 18.60 | 411.92 | 137.31 |

Contd….

Table 4. Contd...

| Sr. No. | Selection index | Discriminant function | Expected genetic advance | Relative efficiency (%) | Relative efficiency per character (%) |
|---|---|---|---|---|---|
| 39 | C+D+F | 0.4627C + 0.8079D + 0.9414F | 13.51 | 299.17 | 99.72 |
| 40 | C+E+F | 0.7183C + 0.9548E + 0.9111F | 19.28 | 426.92 | 142.31 |
| 41 | D+E+F | 0.9043D + 0.9524E + 1.0588F | 24.48 | 542.10 | 180.70 |
| 42 | A+B+C+D | 0.6354A + 0.5733B + 0.1881C + 0.1880D | 6.18 | 136.83 | 34.21 |
| 43 | A+B+C+E | 0.7819A + 1.0647B + 0.5598C + 0.9789E | 25.33 | 560.96 | 140.24 |
| 44 | A+B+C+F | 0.8918A + 1.0405B + 0.6746C + 0.9713F | 13.12 | 290.55 | 72.64 |
| 45 | A+B+D+E | 0.8290A + 0.6212B + 0.5189D + 0.9715E | 20.53 | 454.64 | 113.66 |
| 46 | A+B+D+F | 0.8922A + 0.7131B + 0.6336D + 0.9926F | 10.27 | 227.49 | 56.87 |
| 47 | A+B+E+F | 0.9680A + 0.9694B + 0.9565E + 0.9843F | 23.78 | 526.66 | 131.67 |
| 48 | A+C+D+E | 0.7519A + 0.3341C + 0.7825D + 0.9775E | 21.94 | 485.81 | 121.45 |
| 49 | A+C+D+F | 0.8307A + 0.4337C + 0.8022D + 0.9970F | 16.61 | 367.89 | 91.97 |
| 50 | A+C+E+F | 0.7958A + 0.6891C + 0.9793E + 0.9728F | 23.03 | 510.09 | 127.52 |
| 51 | **A+D+E+F** | 1.0116A + 0.9006D + 0.9444E + 1.0578F | **28.58** | **632.97** | 158.24 |
| 52 | B+C+D+E | 1.1537B + 0.2916C + 0.9495D + 0.9443E | 16.39 | 363.01 | 90.75 |
| 53 | B+C+D+F | 0.5600B + 0.1943C + 0.1943D + 0.8188F | 6.28 | 139.11 | 34.78 |
| 54 | B+C+E+F | 1.0589B + 0.6064C + 0.9522E + 0.9313F | 22.34 | 494.85 | 123.71 |
| 55 | B+D+E+F | 0.6631B + 0.5652D + 0.9517E + 0.9528F | 19.29 | 427.32 | 106.83 |
| 56 | C+D+E+F | 0.3895C + 0.7835D + 0.9458E + 0.9376F | 22.26 | 493.02 | 123.26 |
| 57 | A+B+C+D+E | 0.4419A + 0.5322B + 0.1687C + 0.1687D + 1.0184E | 20.87 | 462.30 | 92.46 |
| 58 | A+B+C+D+F | 0.7306A + 0.5519B + 0.1874C + 0.1874D + 0.9105F | 8.64 | 191.32 | 38.26 |
| 59 | A+B+C+E+F | 0.8178A + 1.0615B + 0.5752C + 0.9733E + 0.9872F | 24.48 | 542.12 | 108.42 |
| 60 | A+B+D+E+F | 0.8282A + 0.6355B + 0.5348D + 0.9712E + 1.0055F | 23.05 | 510.45 | 102.09 |
| 61 | A+C+D+E+F | 0.7066A + 0.3510C + 0.7823D + 0.9836E + 1.0278F | 26.28 | 582.00 | 116.40 |
| 62 | B+C+D+E+F | 1.1271B + 0.2646C + 0.9495D + 0.9463E + 0.9161F | 16.32 | 361.40 | 72.28 |
| 63 | A+B+C+D+E+F | 0.4596A + 0.5344B + 0.1710C + 0.1710D + 1.0153E + 0.9945F | 22.20 | 491.58 | 81.93 |

efficiency of 491.39%. The maximum gain for the selection index of the combination of the characters was shown by the selection index involving DFF, DM, and NPP (543.10%). Genetic advance and relative efficiency were increased up to 28.58% and 632.97%, respectively in the case of the selection index having four characters *viz*., SYP, RPPD, NPP, and HSW. An increase of 26.28% in genetic gain and 582.00% in relative efficiency was found in the selection index involving five characters *viz*., SYP, DM, RPPD, NPP, and HSW. When all six characters (A to F) are included in the selection index, maximum relative efficiency (491.58%) was observed. Thus, there was an increase in the genetic gain as well as relative efficiency with an increase in the character combinations. Sable *et al.* (2003), Raval and Dobariya (2005), Pandey *et al*. (2010), Meena (2011), Hassan and Deb (2014), Samad *et al*. (2014), Hadiya (2018) and Talekar *et al*. (2023) were also reported the same.

Under late sown condition ($E_4$), among all the 63 selection indices the best index based on four characters *viz*., SYP, RPPD, NPP, and HSW, possessed 26.28%, 582.00%, and 116.40% genetic gain, relative efficiency, and relative efficiency per character respectively as compared to straight selection for SYP. This index had 28.58 genetic gain and 632.97% relative efficiency. The next best index identified was with the inclusion of only three characters *viz*., DFF, DM, and number of pods per pant with 24.52 genetic gain and 543.10% relative efficiency. Both the indices had minimum characters and quite good genetic gain and relative efficiency in comparison to other indices.

Looking at the identification of the best selection index in late sowing, an index comprising SYP, RPPD, NPP, and HSW (A+D+E+F) was found in both years. The main difference between the best index lies in the inclusion of HSW with other characters. It means HSW is more important under late planting.

## CONCLUSION

In selection indices including more characters mostly shows an increase in relative efficiency in selection but ideally selection index consisting of minimum characters could be advantageously exploited in the chickpea breeding program to develop variety for late sown (irrigated condition). For late sown conditions, the index involving three characters *viz*., DFF, DM, and NPP identified as beneficial. While, the index involving four characters SYP, RPPD, NPP, and HSW was found important in late-sown conditions. The present study also revealed that the discriminant function method of making selection in genotypes sown on different dates of sowing appears to be the most useful than the straight selection for seed yield alone and hence, due weightage should be paid to the important selection indices while making selection for sustainable yield advancement in chickpea.

## CONFLICT OF INTEREST

All the authors declared no conflict of interest.

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