Productivity and resilience based indices for identification of water stress resilient genotypes in cowpea (Vigna unguiculata L.)

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ABSTRACT

This paper reports the usefulness of a new method for identification of productive and resilient cowpea genotypes. The new indices called as Yield Susceptibility Score Index (YSSI) and Yield Production Score Index (YPSI) are based on a scoring scales, offer simple and easy visualization and identification of genotypes that possess resilience, productivity, both or none. A set of 40 cowpea genotypes was evaluated and stress indices were combined in terms of new indices based on a combination of stress susceptibility index, the stress tolerance index, the mean productivity index and the tolerance index, which have been previously used either in isolation or together for understanding water stress adaptation. This new selection method could help breeders and researchers by defining clear and strong criteria to identify genotypes with high resilience and high productivity and provide a clear visualization of contrasts in terms of grain yield production under stress. The approach is highly useful in initial evaluation of large germplasm sets for identification of resilient and productive cowpea genotypes.

Key words: Cowpea, Index score, Productivity, Resilience, Water stress.

INTRODUCTION

Cowpea [Vigna unguiculata (L.) Walp.] (2n = 22) is one of the most important arid legume crop in the Semi Arid Tropics covering Asia, Africa, Southern Europe and Central and South America (Pasquet and Baudoin, 2001). It is a relatively drought tolerant and warm weather crop that is well adapted to the drier regions of the tropics, where other food legumes do not perform well (Singh, 2003). Globally cowpea is grown over an area of 12.61 million hectares, with a production of 5.59 million tones and a yield of 443.20 kg/ha. Africa leads both in area and production accounting for about 95 per cent, while as yields is highest in Europe and lowest in Africa and Asia. Niger and Nigeria are the leading producers of cowpea, together accounting for about 70% of area and 67% of production in the world. However, yields are highest in Egypt and Serbia (FAO, 2015). As per the report compiled by Ministry of Agriculture (GOI), India accounts for about 15.06 percent of global cowpea area and 8.45 per cent of global cowpea production. (Singh, 2014).

Water stress is the major abiotic constraint of cowpea production. Since cowpea is grown mainly in the drier areas of the world with no or scanty irrigation facilities, irregular rainfall especially early in the season have adverse effects on the growth of the crop. In the field experiments usually the classification of genotypes is based on the premise that the tolerance and susceptibility response are quite distinguishable. However, invariably, the genotypic responses are never so distinct and extreme, but overlapping. A number of indices based on seed yield have been developed that elucidate genotypic response to stress. Drought stress indices are quantitative measures that characterize water stress response by yield data from one or several environments based on timing, duration and intensity of stress. Such an index is more readily useable than raw yield data. Since drought resistance is a yield based trait, selection could vary depending on which index is chosen by the breeder.

As pointed out by Thiry et al., (2016) and Sofi et al., (2017), a major drawback of using these indices is the lack of correspondence in rankings across indices and their failure to discriminate overlapping responses in terms of yield under stress. Also, there have been contrasting reports about their discriminatory powers in identifying optimally yielding genotypes (Ramírez-Vallejo and Kelly, 1998: Mohammadi et al., 2011; Sareen et al., 2012). Although all these indices are mathematical derivations of the same yield data, selection based on a combination of different indices may provide a more useful criterion for improving water stress adaptation of cowpea. However, there are not yet any accurate screening indices that can be used in breeding programmes to select genotypes for abiotic stress adaptation and high yield. The original indices suffer from few basic shortcomings as outlined by Fernandez (1992), Thiry et al., (2016) and Sofi et al., (2017) that warrant use of new indices to have a reliable estimation of differential genotypic response under stress environments.

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Genotypic response under the stress and non-stress conditions can be grouped into four broad classes (Thiry et al., 2016, Sofi et al., 2017). The class A represents those genotypes that express uniform superiority in both stress and non-stress conditions; the class B genotypes that express good performance only in non-stress and not under stress conditions; the class C genotypes that exhibit higher yield only under stress and the class D genotypes that express poor yield performance in both environments. The genotypic responses can seldom be represented as extremes of tolerance and susceptibility and invariably falls in any of these four classes. It seems practically viable to use a combination of different indices to have a much better picture by taking into account different discriminatory powers of indices. The index worked well in wheat and was also validated in common bean (Sofi et al., 2017). The objective of the present study was to test the hypothesis that the index is equally effective across different crops. We used a set of cowpea landraces to further establish the usefulness of such combined index in crop breeding programmes aimed at identifying cowpea genotypes resilient to water stress.

MATERIALS AND METHODS

Plant material: A set of 40 genotypes of cowpea including 39 landraces collected from different areas of the Kashmir valley and one released variety viz, Shalimar Cowpea-1 released by SKUAST-Kashmir as check were used for the present study.

Experimental setup: The present study was conducted during 2017-18 at the research fields of Division of Genetics and Plant Breeding, Faculty of Agriculture Wadura, SKUAST-K, Sopore. All the 40 genotypes were grown in the research field of Faculty of Agriculture, Wadura, Sopore (34° 17’ North and 74° 33 E at altitude of 1594 metres above sea level). Each genotype was represented by two rows of four meter length, with spacing of 40 cm x 15 cm, with two replications each for drought and irrigated treatments. Plants were irrigated regularly until the first fully opened trifoliate leaf and irrigation was withdrawn thereafter in water stressed conditions whereas the plants in irrigated treatment were watered regularly.

Drought tolerance indices: Various drought tolerance indices were calculated based on the values of seed yield per plant under irrigated and drought conditions to discriminate genotypes on the basis of drought response in terms of grain yield (data not shown). The calculations were done as follows:

\[
\text{Stress susceptibility (SSI)} = \frac{1 - (Y_s / Y_{ss})}{1 - (X_s / X_{ss})}
\]

\[
\text{Tolerance index (TOL)} = Y_{ss} - Y_s
\]

\[
\text{Mean productivity (MP)} = \frac{Y_s - Y_{ss}}{2}
\]

Where \(Y_s\) and \(Y_{ss}\) are mean yields of genotypes under stress and non-stress conditions respectively and \(X_s\) and \(X_{ss}\) are mean of yield of all genotypes under stress and non-stress conditions.

Estimation of score indices: Two new indices defined as resilience and production capacity indices (Thiry et al., 2016) were used. The original indices were divided these indices into two classes viz., Class 1 (SSIs and TOLs) and Class 2 (MPs and STIs) based on the premise that these classes tend to identify genotypes based on resilience and productivity respectively. These score indices have been classified within two new scales called resilience capacity index (RCI) and production capacity index (PCI). For detailed method of scoring scale for each index refer to Thiry et al., (2016) and Sofi et al., (2017). The index scores were combined as follows:

\[
\text{Yield Susceptibility Score Index (YSSI)} = \frac{\text{SSI} \pm \text{SSIs}}{2}
\]

\[
\text{Yield Production Score Index (YPSI)} = \frac{\text{MP} + \text{SSIs}}{2} - \frac{\text{SSIs} + \text{TOLs}}{2}
\]

RESULTS AND DISCUSSION

Comparison of original indices and index scores: The mean yields of the 40 genotypes under stress and non-stress conditions and the per cent reductions under stress are presented in Table 1. From the mean yield data, the indices namely SSI, TOL, MP and STI (data not shown) were calculated as per the standard formulae for each. We created index scores for each index namely SSIs, TOLs, MPs and STIs as per the method used in Thiry et al., (2016) and Sofi et al., (2017). The score indices were first tested against their original value from each index (Table 2). The correlation coefficient between the three stress susceptibility index (SSIs) and the score tolerance index (TOLs) values and their original index values (SSI and TOL) was highly negative (ranging from -0.990 to -0.995), as the score scale has been inverted in order to create a scale showing resilience instead of susceptibility. On the other hand, the correlation coefficients between the original values for MP and STI and the score indices MPs and STIs were highly significant (0.992 and 0.993). The high correlations reported here are in conformity to the results reported by Thiry et al., (2016) and Sofi et al., (2017) indicating that the score indices can be used as an effective surrogates of their original index values. The score indices are presented in Table 3 using grain yield data of 40 genotypes. The most important observation from the correlation of index scores and original indices, in the present study as well as the one reported by Thiry et al., (2016) and Sofi et al., (2017b), is that within each class the values are almost same. Therefore, these score values and the correlation coefficients (Table 2) substantiate...
Table 1: Mean seed yield of 40 cowpea genotypes and per cent reduction under water stress.

| Genotype | Seed Yield Per Plant (g) | Per cent reduction under water stress |
|----------|--------------------------|--------------------------------------|
|          | IRRIGATED                | DROUGHT                              |
| C1       | 25.51                    | 19.81                                | 22.31 |
| C2       | 20.18                    | 13.06                                | 35.27 |
| C3       | 18.48                    | 8.73                                 | 52.76 |
| C4       | 40.13                    | 25.01                                | 37.68 |
| C5       | 20.91                    | 12.97                                | 37.98 |
| C6       | 42.28                    | 35.54                                | 15.93 |
| C7       | 41.81                    | 35.27                                | 15.64 |
| C8       | 16.46                    | 14.39                                | 12.57 |
| C9       | 39.62                    | 23.94                                | 39.56 |
| C10      | 28.89                    | 25.54                                | 11.59 |
| C11      | 41.76                    | 36.46                                | 12.69 |
| C12      | 12.01                    | 5.33                                 | 55.58 |
| C13      | 25.78                    | 21.04                                | 18.37 |
| C14      | 29.03                    | 14.55                                | 49.87 |
| C15      | 12.87                    | 6.13                                 | 52.32 |
| C16      | 32.75                    | 27.86                                | 14.92 |
| C17      | 48.05                    | 42.68                                | 11.17 |
| C18      | 60.04                    | 34.20                                | 43.04 |
| C19      | 20.52                    | 16.47                                | 19.74 |
| C20      | 41.78                    | 27.16                                | 34.98 |
| C21      | 19.33                    | 16.65                                | 13.86 |
| C22      | 18.3                     | 9.92                                 | 45.82 |
| C23      | 29.33                    | 20.88                                | 28.78 |
| C24      | 53.01                    | 42.82                                | 19.22 |
| C25      | 35.71                    | 14.58                                | 59.16 |
| C26      | 44.06                    | 20.10                                | 54.37 |
| C27      | 20.63                    | 16.91                                | 18.03 |
| C28      | 17.64                    | 12.36                                | 29.93 |
| C29      | 37.35                    | 23.98                                | 25.16 |
| C30      | 71.12                    | 31.50                                | 55.70 |
| C31      | 27.46                    | 23.54                                | 14.27 |
| C32      | 28.20                    | 19.77                                | 29.89 |
| C33      | 23.60                    | 14.78                                | 37.39 |
| C34      | 49.77                    | 19.46                                | 60.90 |
| C35      | 28.83                    | 24.31                                | 15.68 |
| C36      | 23.95                    | 14.34                                | 40.10 |
| C37      | 27.56                    | 18.92                                | 31.34 |
| C38      | 25.95                    | 11.61                                | 55.24 |
| C39      | 14.86                    | 9.35                                 | 37.06 |
| C40      | 15.85                    | 13.46                                | 15.08 |
| Mean     | 30.28                    | 20.36                                | 32.02 |

Table 2: Pearson correlation coefficient between the score indices (SSI, TOL, STI and MP) and their original indices (SSI, TOL, STI and MP).

| INDEX   | SSI         | TOL         | STI         | MP          |
|---------|-------------|-------------|-------------|-------------|
| CLASS I | -0.995**    | -0.718      | -0.126      | -0.124      |
| CLASS II TOLs | -0.695      | 0.473       | 0.510       |
| STIs    | 0.153       | -0.444      | 0.993       | 0.976       |
| MPs     | 0.131       | -0.501      | 0.973       | 0.992       |

Table 3: Score indices and mean rank based on grain yield for four tolerance indices (SSI, TOL, STI, MP) in 40 cowpea genotypes.

| Genotype | CLASS I SSI | CLASS I TOL | CLASS I STI | CLASS I MP | Mean rank |
|----------|-------------|-------------|-------------|------------|-----------|
| C1       | 8           | 10          | 2           | 4          | 6.00      |
| C2       | 6           | 9           | 1           | 2          | 4.50      |
| C3       | 2           | 8           | 1           | 2          | 3.25      |
| C4       | 5           | 7           | 5           | 6          | 5.75      |
| C5       | 5           | 9           | 1           | 2          | 4.25      |
| C6       | 10          | 9           | 7           | 8          | 8.50      |
| C7       | 10          | 9           | 7           | 8          | 8.50      |
| C8       | 10          | 10          | 2           | 5          | 7.25      |
| C9       | 5           | 7           | 5           | 6          | 5.75      |
| C10      | 10          | 10          | 4           | 5          | 7.25      |
| C11      | 10          | 10          | 7           | 8          | 8.50      |
| C12      | 2           | 9           | 1           | 1          | 3.25      |
| C13      | 9           | 10          | 3           | 4          | 6.50      |
| C14      | 3           | 7           | 2           | 4          | 4.00      |
| C16      | 2           | 9           | 1           | 1          | 3.25      |
| C17      | 10          | 10          | 4           | 6          | 7.50      |
| C18      | 10          | 10          | 9           | 7          | 9.75      |
| C19      | 4           | 4           | 10          | 10         | 7.00      |
| C20      | 9           | 10          | 2           | 3          | 6.00      |
| C21      | 6           | 7           | 5           | 7          | 6.25      |
| C22      | 10          | 10          | 2           | 3          | 6.25      |
| C23      | 4           | 9           | 1           | 2          | 4.00      |
| C24      | 7           | 9           | 3           | 4          | 5.75      |
| C25      | 9           | 8           | 10          | 10         | 9.25      |
| C26      | 1           | 5           | 3           | 4          | 3.25      |
| C27      | 2           | 5           | 4           | 6          | 4.25      |
| C28      | 9           | 10          | 2           | 3          | 6.00      |
| C29      | 7           | 10          | 1           | 2          | 5.00      |
| C30      | 8           | 10          | 1           | 2          | 5.25      |
| C31      | 2           | 1           | 10          | 10         | 5.75      |
| C32      | 10          | 10          | 3           | 4          | 6.75      |
| C33      | 7           | 9           | 3           | 4          | 5.75      |
| C34      | 6           | 9           | 2           | 3          | 5.00      |
| C35      | 1           | 3           | 5           | 7          | 4.00      |
| C36      | 10          | 10          | 3           | 4          | 6.75      |
| C37      | 5           | 8           | 2           | 3          | 4.50      |
| C38      | 6           | 9           | 3           | 4          | 5.50      |
| C39      | 2           | 7           | 2           | 3          | 3.50      |
| C40      | 5           | 10          | 1           | 1          | 4.25      |
| SCP-1    | 10          | 10          | 1           | 2          | 5.75      |

the premise that SSI and TOL can be associated to class I and MP and STI, can be associated to class II.

Identifying the best indices combination: To identify the best combination of indices, the linear regression was performed and the coefficient of determination of the different score indices v/s yield under non-stress and water stress environments, calculated on 40 genotypes which
In contrast, MPs, STIs and TOLs show a close relationship under water stress (R\textsuperscript{2}SIs showed the closest relationship (Table 1) with yield class of index (susceptibility and tolerance), MPs, STIs and study with wheat and common bean respectively. In each conforms to the result reported by Khayatnezhad independently of the environment (Fig 1). This observation clearly indicated that none of the indices, used individually, could clearly identify the high yielding genotypes, independently of the environment (Fig 1). This observation conforms to the result reported by Khayatnezhad et al., (2010), Thiry et al., (2016) and Sofi et al., (2017) from a study with wheat and common bean respectively. In each class of index (susceptibility and tolerance), MPs, STIs and SSIs showed the closest relationship (Table 1) with yield under water stress (R\textsuperscript{2} = 0.864, 0.850 and 0.201 respectively). In contrast, MPs, STIs and TOLs show a close relationship with yield potential (non-stress) environment (R=0.916, 0.865 and 0.493 respectively). These results are similar as reported by Thiry et al., (2016) in wheat and Sofi et al., (2017) in common bean. In terms of class I (SSIs and TOLs) index scores, C6, C7, C8, C10, C11, C18, C22, C25, C32, C36 and SCP-1 turn out as better C26, C35, C3, C12, C16, C27 and C39 are poor. Similarly in terms of class II (MP and TOL) index scores, C18, C19, C25 and C31 are better genotypes while C2, C3, C5, C12, C16, C23, C30, C40 and SCP-1 turn out to be poor genotypes. The mean score index showed very high correlation with yield under stress (R\textsuperscript{2} = 0.824) indicating usefulness of combining the indices after

**Fig 1:** Linear regression and coefficient of determination (R\textsuperscript{2}) between yields under stress and non-stress and score indices.
The proposed approach is of paramount importance for plant breeding programmes as it helps identification of resilient and productive genotypes or only highly resilient ones for crossing with highly productive genotypes. Contrasting genotypes in terms of resilience or productivity only (Class B), resilience only (Class C) and possessing resilience and neither productivity (Class D). Combined into YSSI (yield stress score index) and YPSI (yield potential score index), we could identify C25, C19 and C31 having both resilience and productivity, C18, C11, C6, C7 and C10 as having better resilience, C35 as having better productivity, C6, C7, C11 and C18 having better resilience while as genotypes such as C3, C5, C12, C14, C16, C23, C39 and C40 possessing neither resilience nor productivity. The genotypes C25 and C19 probably escaped stress as they flowered early under stress as compared to susceptible ones (2.875 and 2.375 days earlier than population mean respectively). In our study, the reduction in yield under stress was largely contributed by reduction in pods per plant probably on account of abortion. The genotypes C25 and C18 underwent small reduction in pod number under stress (10.01 and 10.32 % respectively), while as susceptible genotypes such as C3, C5, C39 and C40 underwent decrease in pod number to the tune of 74.87%, 59.97%, 58.93% and 40.92% respectively.

**Practical utility:** The proposed approach is of paramount importance for plant breeding programmes as it helps identification of resilient and productive genotypes or only highly resilient ones for crossing with highly productive genotypes. Contrasting genotypes in terms of resilience or productivity could provide an understanding of the possible role of underlying morphological, phenological, biochemical
and physiological adjustments that crop plants make under stress and non-stress environments. We observed some peculiar genotypic scores in terms of RCI and PCI (Table 4). The genotypes C19 had exactly similar values of YSSI (6.0) and YPSI (6.00) indicating that the genotype had similar capacities of productivity and resilience. Similarly, the genotype C25 shared the similar relationship as it had comparable values of YSSI and YPSI. On the contrary, C6 and C7, C29 and C30, C11 and C18, and C20 and C28 had comparable values of YSSI but almost opposite values of YPSI, indicating that in such instances, genotypes differed in their productive and resilience capacities. In order to develop a potential array of genotypes that could have high yield potential as well as climate resilience it would be advisable to select and cross the parents with high level of resilience and productivity. Plant breeders would be fortunate enough to identify genotypes having both resilience and productivity. However, in most of cases, genotypes invariably fall in class B or C that creates an opportunity for hybridisation amongst the best genotypes from each class. In our study we could identify a potential combination of C25 and C18 as having highest degrees of productivity and resilience.

**CONCLUSION**

The present paper reports the evaluation of a set of 40 cowpea genotypes for water stress adaptation in terms of a set of new indices based on index scores that define differential genotypic response in terms of resilience and productivity. It is concluded that the new indices originally proposed and used in wheat (Thiry et al., 2016) and common bean (Sofi et al., 2017) can be effectively used across crops to understand genotypic response to water stress in terms of two major responses viz., resilience and productivity. The method fairly undoes the obvious limitations of using different indices including the ones used in the present study in isolation, especially the inconsistencies in ranking of genotypes.

| GENOTYPE | RCI | PCI | YSSI | YPSI |
|----------|-----|-----|------|------|
| C1       | 8   | 2   | 5    | -3   |
| C2       | 6   | 1   | 3.5  | -3.5 |
| C3       | 2   | 1   | 1.5  | -3   |
| C4       | 5   | 5   | 5    | -0.5 |
| C5       | 5   | 1   | 3    | -3.5 |
| C6       | 10  | 7   | 8.5  | -0.5 |
| C7       | 10  | 7   | 8.5  | -0.5 |
| C8       | 10  | 1   | 5.5  | -4   |
| C9       | 5   | 5   | 5    | -0.5 |
| C10      | 10  | 4   | 7    | -2.5 |
| C11      | 10  | 7   | 8.5  | 1    |
| C12      | 2   | 1   | 1.5  | -4   |
| C13      | 9   | 3   | 6    | -3   |
| C14      | 3   | 2   | 2.5  | -1.5 |
| C16      | 2   | 1   | 1.5  | -4   |
| C17      | 10  | 4   | 7    | -2   |
| C18      | 10  | 10  | 10   | -0.5 |
| C19      | 4   | 10  | 7    | 3    |
| C20      | 9   | 2   | 5.5  | -3.5 |
| C21      | 6   | 5   | 5.5  | -3   |
| C22      | 10  | 2   | 6    | -3.5 |
| C23      | 4   | 1   | 2.5  | -3.5 |
| C24      | 7   | 3   | 5    | -2.5 |
| C25      | 9   | 10  | 9.5  | 1    |
| C26      | 1   | 3   | 2    | -0.5 |
| C27      | 2   | 4   | 3    | 0.5  |
| C28      | 9   | 2   | 5.5  | -3.5 |
| C29      | 7   | 1   | 4    | -4   |
| C30      | 8   | 1   | 4.5  | -4   |
| C31      | 2   | 10  | 6    | 4.5  |
| C32      | 10  | 3   | 6.5  | -3   |
| C33      | 7   | 3   | 5    | -2.5 |
| C34      | 6   | 2   | 4    | -3   |
| C35      | 1   | 5   | 3    | 2    |
| C36      | 10  | 3   | 6.5  | -3   |
| C37      | 5   | 2   | 3.5  | -2.5 |
| C38      | 6   | 3   | 4.5  | -2.5 |
| C39      | 2   | 2   | 2    | -2   |
| C40      | 5   | 1   | 3    | -4.5 |
| SCP-1    | 10  | 1   | 5.5  | -4   |

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