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Establishment of an early selection method (criteria) for breeding in cowpea (*Vigna unguiculata*)

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Populations with high genetic variability are targeted by breeders as they create opportunity for selection and genetic improvement. To achieve this, multiple populations are created, but resources are often scarce. This calls for identification of populations with the desired traits at early generation. The study was carried out at MUARIK in seasons 2017A and 2017B on 135 F2 and 40 F3 cowpea populations respectively together with 25 parental lines aimed at: Determining best performing populations for yield, resistance to scab, virus and flower thrip based on usefulness criterion and selection index methods. Usefulness criterion computed for yield identified NE 36 x 2392 as the best population. Usefulness criterion computed for yield and its components identified NE 5 x Sanzi as the best population. WC 48A x 2392 was identified as the best population using selection index values that included resistance to virus, thrips, scab, yield and its component and when only yield and its components were fitted in the model. Variability and high yield performance was maintained in the forty best populations identified and therefore amendable for future improvement. No differences were shown among the methods used for selection hence can be adapted for breeding in cowpea.

Key words: Selection index, scab, thrip and virus resistance, usefulness criteria, yield.

INTRODUCTION

Cowpea (*Vigna unguiculata*) occupies an economically important position in production compared to other legume crops in Uganda particularly in the eastern and northern regions where it is a dominant source of protein and household income for the resource poor subsistence farmers (Verlag et al., 2006; Mundua, 2010). Despite its importance, cowpea productivity levels are generally low averaging 300-500 kg/ha yet its yield potential can be between 1500 and 3000 kg/ha as reported elsewhere (Gbaye and Holloway, 2011). The low productivity is attributed to the fact that cowpea varieties that are preferred and commonly grown by farmers are highly affected by pests, scab and viral diseases andpests (Mundua, 2010). Therefore, varietal improvement to increase the potential yield of locally adapted and farmer preferred cowpea varieties, which requires introgression of desirable traits from the elite lines and or other exotic germplasm into the farmer preferred local varieties is needed. It should be kept in mind that the development of elite lines requires the generation of populations with high

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genetic variability and judicious selection of promising lines in the most efficient manner possible (Monteagudo et al., 2019).

Population development highly depends on the inheritance of the traits. For traits such as yield, disease, and pest resistance, which are quantitatively inherited, adequate evaluation and selection could be achieved by generating larger populations (Bijma et al., 2007). Therefore, the cowpea breeding program at Makerere University generated multiple populations by crossing farmers' preferred cowpea cultivars with cowpea lines that have high yielding potential, thrip, scab, and viral diseases resistance background. This being done amidst scarce resources, it becomes a challenge to handle such huge populations from generation to generation.

Nevertheless, analysis of genetic attributes can be done in an early generation to identify desirable segregants, thus reducing the population size in later generations (Bhadru and Navale, 2012a). Early selection may start at F2 (Bernardo, 2003; Simic et al., 2003) or in later generations with emphasis put on populations with high mean performance and adequate genetic variance. It is worth mentioning that the most promising novelties for increasing the rate of genetic gain without greatly increasing program size appear to be related to reducing breeding cycle time. This is likely to be implemented by parental selection on non-inbred progeny, rapid generation advance, and genomic selection (Cobb et al., 2019). These are complex and expensive processes and so techniques that require less resource allocation should be considered. Usefulness criterion and selection index are the inexpensive early selection methods suggested for obtaining prospect lines in a breeding population (Bernado, 2010; Simic et al., 2003).

Usefulness criterion (UC) is a selection method that predicts the gain (response to selection) that can be obtained from a population when a selection pressure is imposed, thereby reducing the selection cycles. Additionally, this method allows suitable amount of genetic variability to be maintained in the population when used as it combines the information of the mean performance and genetic variance of a population to obtain prospect lines (Bernado, 2010; Simic et al., 2003). The variability maintained permits flexibility and survival of individuals in a population in the face of changing environmental circumstances (Hallauer, 2010).

Selection can be done by looking at one trait at a time from one generation to the other or by simultaneously selecting the attributes that are in consideration by creating a selection index (Bernado, 2010). However, single-trait selection becomes highly questionable and unreliable to choose for the traits that are highly correlated like yield and yield-related traits. Therefore, simultaneous selection of traits becomes better as it increases the chance of success in breeding programs and helps in choosing of populations with multiple characters put into consideration (Rodrigues et al., 2017).

Studies have been conducted using selection index as a discriminative function in selection of best genotypes in cowpea (Jost et al., 2013; Khanpara et al., 2016; Sivakumar et al., 2017). Other studies have been conducted in maize using both selection index and usefulness criteria (Nizeyimana, 2013). No research has been conducted using both usefulness selection criteria (UC) and base selection index (BSI) on cowpea for early generation selection of promising populations. Therefore, this study exploits the two selection criteria; base index selection, and usefulness criteria to select the best F2 segregating population for advancement.

MATERIALS AND METHODS

The study was conducted at MUARIK (32°36'24"E, 0°27'60"N) during seasons 2017A and 2017B on populations that were developed by Makerere University Cowpea Breeding Program in 2016A. The parents used in the development of the crosses were earlier characterized by Makerere cowpea breeding program for resistance to diseases (virus and scab) and thrips infestation including other traits like cream colored cowpea genotypes with intermediate grain yield (Table 1).

During Season 2017A study, a total of 135 F_2 populations and 25 parental lines were planted in an alpha lattice design of 5 blocks x 32 plots with two replicates. Each plot consisted of 32 cowpea plants

Season 2017B study comprised of the 24 parental lines and forty best populations selected from season 2017A evaluation. Within each population were the 8 best lines selected from the 64 evaluated plants in season 2017A thus a total of 320 lines. The experiment was set up in an alpha lattice design consisting of 10 blocks and 40 plots with two replications. Each block consisted of four populations (32 lines) and 8 parents planted alongside them.

Data were collected on agronomic parameters notably: number of pods per plant, number of pods per peduncle, seed weight and grain yield from each individual plant. Data on scab were collected on plot basis at vegetative and podding stage at a scale of 1-5 (Afutu et al., 2016a) and at vegetative and senescence stage for virus at a scale of 1-5 (Mbeyagala et al., 2014). Data on thrips was taken 35 days after planting at weekly intervals for three weeks at a scale of 1-9 **(Jackai and Singh, 1988).**

Data analysis

Analysis of variance for the average performances of the thrip damage scores, AUDPC for virus and scab on leaf severity, scab on pod, yield and yield components per plot were analyzed using linear mixed model (ReML: Restricted maximum Likelihood, Genstat 18) approach following alpha lattice design model. The following linear models were used:

ANOVA for 2017A

$$Y_{ijk} = \mu + R_i + B/R_J + G + e_{ijk}$$

ANOVA for 2017B

$$Y_{ijk} = \mu + R_i + B/R_J + Pop_k + P_l + Pop/L_m + PvsCrosses_{lj} + e_{ijk}$$

Where; R_i = the replication effect, B/R_j = the block within replication effect, Pop_k = population effect, Pop / L = line effect, and P_i = the

Table 1. Cowpea parental lines used in the development of bi-parental populations.

S/N	Parent	Seed color	Strength of the genotype
1	2392	Brown	Resistant to virus disease
2	3306	Cream	Intermediate grain yield
3	Ayiyi	Cream	High podding and desired growth architecture
4	Danila	Black	Drought tolerant
5	Eberlat*NE51	Mottle	High grain yield
6	IT 889	Mottle	Virus resistant and high grain yield
7	KVU 27-1	Brown	Resistant to scab disease and intermediate grain yield
8	MU 15	Brown	Resistant to virus and intermediate in grain yield
9	MU 20B	Black	Resistant to scab and intermediate grain yield
10	MU 9	Brown	High grain yield
11	NE 21	Cream	Intermediate grain yield
12	NE36	Mottle	Resistant to virus and scab, and intermediate grain yield
13	NE 48	Brown	Resistant to virus and high grain yield
14	NE 5	Cream	Resistant scab and intermediate grain yield
15	NE 55	Cream	Intermediate grain yield
16	Sanzi	Mottle	Resistant to flower thrips
17	Secow 2w	Cream	Resistant to virus and most genotypically diverse
18	Secow 4w	Cream	Virus resistant
19	Secow 5T	Brown	Virus and Scab resistant
20	VCR 1432	Mottle	Flower thrip resistant
21	WC 27	Cream	Virus resistant
22	WC 48A	Brown	Scab resistant and high grain yield
23	WC 63	Mottle	Resistant to Virus and scab, and high grain yield
24	WC 64	Mottle	Resistant to scab and rust, and high grain yield
25	WC 66	Mottle	Resistant to virus and high grain yield

parental effect, $PvsPop$= parent versus population/crosses effect.

Further analysis to identify populations combining high genetic variance and mean performance for yield and yield components was conducted using usefulness criterion. The usefulness value (expected genetic gain) of each F_2 was computed based on the usefulness formula and the standardized selection differential (k_i). An assumption was made for selecting at least 20% of the best populations with a selection differential (k_i) of 1.40. The phenotypic variance for yield and yield components among the 64 plants for each population (σ^2_{F2}) and the parents ($\sigma^2_{p1} and\ \sigma^2_{p2}$) was calculated using the variance function. The information on phenotypic variance for each population and the parents was used to calculate broad sense heritability (H^2). Broad sense heritability among F_2 families within a population was calculated using Equation 1 as presented by Hanson et al. (1956):

$$H^2 = \left\{\sigma^2_{F2} - (\sigma^2_{P1} + \sigma^2_{P2})/2\right\} / \sigma^2_{F2} \quad (1)$$

The variance components for the F_3 40 best selected cowpea populations were calculated as follows:

Genotypic variance;

$$\sigma^2_g F_3 = \frac{MSgenotype - MSerror}{r}$$

Phenotypic variance;

$$\sigma^2_p F_3 = \sigma^2_g + MSerror$$

Heritability estimates for the F3 best selected populations was calculated as per Equation 2

$$H^2 = \frac{\sigma^2_g F_3}{\sigma^2_p F_3} \quad (2)$$

The genetic gain of each population was calculated using Equation 3 as described by Johnson et al. (1955):

$$G = k_i * \left(\sqrt{\sigma^2_{Phenotype}}\right) * H^2 \quad (3)$$

Usefulness for each population was then calculated using Equation 4 as described by Bernado (2010):

$$U = \mu + G \quad (4)$$

Where; H^2 is the heritability of each trait, σ^2_{F2} is the phenotypic variance for each trait in F2 population, σ^2_{P1} and σ^2_{P2} is the variance for the first and second parents respectively, $\sigma^2_g F_3$ is the genotypic variance of the $F_{2:3}$ populations, $\sigma^2_p F_3$ is the phenotypic variance of the $F_{2:3}$ populations, G is the gain from selection, (k_i) is the selection differential, U is the usefulness of the population, and μ is the mean population for the trait.

Table 2. Assigned weights for the traits used in the formation of selection index for the parental lines and F_2 populations.

Trait	Weight assigned	Rationale
Grain yield	5	Ultimate goal of breeders and farmers
Pod No.[1]	3	Highly correlated with yield
Ped No.[2]	2	Highly correlated with yield
Virus	-2	Selection of resistant population to virus
Thrips	-3	Selection of resistant population to thrips
Scab on leaves	-2	Selection of resistant population to scab
Scab on pod	-1	Selection of resistant population to pod scab

[1]Number of pods per plant; [2]Number of peduncles per plant.

Table 3. Analysis of variance for thrip damage, virus and scab severity and yield and its components among cowpea genotypes evaluated during 2017A season.

SOV[1]	Virus Audpc[2]	Scab on leaf Audpc[2]	Scab on pod	Thrips	Ped No.[3]	Pod No.[4]	Yield
Genotype	51.32***	31.62*	0.36***	1.58[ns]	25.67***	9.59***	338481.6***
Lee[5]	32.48	26.13	0.19	1.36	16.25	40.34	162731.6
SED[7]	5.70	5.11	0.44	1.69	4.03	6.35	403.4

[1]Source of variation, [2]Area under disease progress curve, [3]Number of peduncles, [4]Number of pods, [5]Lattice effective error, [6]Coefficient of variation.

Usefulness value for both grain yield and yield components (number of peduncles and pods) were computed for 135 populations evaluated in season 2017A. A selection index of grain weight, number of pods and peduncles was calculated, and the values were used to generate within population variances and means of each population. Usefulness value for grain yield was calculated for the forty best selected populations evaluated in 2017B.

Index values for each of the 135 populations and 25 parents evaluated in season 2017A were calculated in an Excel spreadsheet using the average means of the traits. Relative weights were assigned to the traits according to their relative contribution in the final product or desired genetic gain where traits with much contribution were given much weights (Table 2). The following formula was used to calculate the index values.

$$I = \sum b_i \; x_i \qquad (4)$$

Where b_i is the weight of the trait (i) and x_i is the phenotypic value of the trait (i) (Bernado, 2010).

Analysis of variance was carried out to test the difference in the methods used using R version 3.4.1 and a boxplot generated. A t-test was also conducted to compare the two methods of selection using the means of the 30 best selected populations by the following formula (Amirtage and Berry, 1994)

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \qquad (5)$$

Spearman rank correlation was carried out to determine the relationship between the two methods used in selection.

Further analysis to determine the realized heritability the realized genetic gain obtained from the selection from the 40 selected plants evaluated in 2017B was carried out using Equation 6 as presented by Rédei (2008)

$$Realized\ heritability\ (Rh) = \frac{Responce\ to\ Selection}{Selection\ Differential} \qquad (6)$$

Where; *Response to Selection (R) = Avg. of the 1s[t] Gen - Avg. of the 2nd Gen*and

$$Selection\ Differential\ (s) = Avg\ of\ the\ 1st\ Gen - Avg\ of\ the\ selected\ popolations$$

$Avg\ of\ the\ 1st\ Gen$ = Average mean of the 135 evaluated populations in season 2017A, $Avg\ of\ the\ 2nd\ Gen$ = Average mean of the forty populations evaluated in season 2017B and $Avg\ of\ the\ selected\ popolations$ = the mean of the selected forty populations evaluated in 2017A

RESULTS

Performance of cowpea genotypes evaluated in season 2017A for biotic stresses, yield and yield components

The populations tested differed significantly (P<0.001) for reaction to virus disease and scab on pod, number of pods, peduncles and grain yield except for severity for scab on leaves which was significant at P<0.05 and thrips infestation which was not significant (Table 3).

Determination of the usefulness value of cowpea populations for yield and yield components

Usefulness values for grain yield ranged from 1.93 to 72.39 (Table 4 and Appendix 1) and between -1.64 and 10.8 for yield and yield components (Table 5, Appendix 2). The highest genetic variance of 576.04 was recorded for NE 36 x 2392 for grain yield, and 24.04 for NE 5 x Sanzifor yield and its components (Table 5). Fourteen populations that ranked top and seven populations that

Table 4. Estimated usefulness value (U) of 21 representative populations for grain yield (I=0.2, k=1.4).

Population	Vpop[1]	VP1[2]	VP2[3]	Vg[4]	H[5]	Gs[6]	μ[7]	U[8]
NE 36 X 2392	695.63	100.80	138.39	576.04	0.83	30.58	41.81	72.39
Danila X NE 48	361.32	48.72	69.78	302.08	0.84	22.25	43.41	65.66
SECOW 5T X Ayiyi	483.79	44.50	67.27	427.90	0.88	27.24	34.72	61.96
NE 5 X Sanzi	342.00	55.78	26.58	300.82	0.88	22.77	38.26	61.03
Ayiyi X WC 66	430.43	67.27	34.81	379.40	0.88	25.60	34.78	60.38
SECOW 5T X 3306	477.08	44.50	59.24	425.21	0.89	27.25	33.07	60.32
NE 5 X 2392	340.92	55.78	138.39	243.83	0.72	18.49	41.51	60.00
Danila X VCR 1432	228.20	48.72	52.20	177.74	0.78	16.47	42.45	58.92
Danila X KVU271	412.67	48.72	78.27	349.17	0.85	24.06	34.75	58.81
WC 48 X WC 27	409.89	72.17	65.31	341.15	0.83	23.59	35.10	58.69
Ayiyi X 2392	414.02	67.27	138.39	311.19	0.75	21.41	35.03	56.44
NE 21 X WC 48	232.92	42.01	72.17	175.83	0.75	16.13	39.87	56.00
WC 63 X NE 48	335.07	47.39	69.78	276.49	0.83	21.15	34.68	55.83
WC 48 X 2392	471.34	72.17	138.39	366.06	0.78	23.61	31.65	55.26
MU 20B X 2392	76.76	30.74	138.39	-7.81	-0.10	-1.25	13.84	12.59
WC 27 X Sanzi	55.62	65.31	26.58	9.68	0.17	1.82	9.17	10.99
Sanzi X 2392	64.05	26.58	138.39	-18.44	-0.29	-3.23	14.20	10.97
Eberlat*NE 51 X MU 20B	66.01	100.00	30.74	0.63	0.01	0.11	9.839	9.95
MU 20B X SECOW 5T	34.37	30.74	44.50	-3.26	-0.09	-0.78	7.231	6.45
WC 66 X 2392	46.94	34.81	138.39	-39.67	-0.85	-8.11	11.32	3.21
WC 63 X 2392	47.18	47.39	138.39	-45.71	-0.97	-9.32	11.25	1.93

[1]Population variance, [2]Variance for the 1st Parent, [3]Variance for the 2nd parent, [4]Genetic variance, [5]Expected genetic gain, [6]Broad sense heritability value, [7]Population mean for grain yield, number of pods and peduncles, [8]Usefulness Value, K: Standardized selection differential.

Table 5. Usefulness value (U) of *21 representative populations* for yield and yield components.

Population	Vpop[1]	VP1[2]	VP2[3]	Vg[4]	H[5]	Gs[6]	μ[7]	U[8]
NE 5 X Sanzi	25.63	2.05	1.12	24.04	0.94	6.65	4.15	10.80
Ayiyi X 2392	25.51	2.49	1.99	23.26	0.91	6.45	3.11	9.56
NE 36 X 2392	22.13	1.53	1.99	20.37	0.92	6.06	3.33	9.39
Danila X NE 48	9.19	1.71	3.04	6.82	0.74	3.15	3.16	6.31
NE 21 X NE 55	13.68	1.43	3.80	11.07	0.81	4.19	1.35	5.53
MU 20B X NE 36	12.42	2.28	1.53	10.51	0.85	4.18	1.36	5.53
WC 48A X WC 27	12.28	4.31	1.31	9.47	0.77	3.78	1.62	5.40
MU 20B X WC 27	10.53	2.28	1.31	8.73	0.83	3.77	1.34	5.11
2392 X Eberlat*NE 51	10.95	1.99	4.67	7.62	0.70	3.23	1.80	5.02
SECOW 5T X Ayiyi	11.66	2.78	2.49	9.02	0.77	3.70	1.33	5.02
KVU 271 X WC 27	9.19	1.38	1.31	7.84	0.85	3.62	1.37	4.99
MU 9 X NE 55	11.55	1.17	5.09	8.41	0.73	3.47	1.49	4.95
Ayiyi X WC 66	11.25	2.49	0.86	9.58	0.85	4.00	0.92	4.92
Danila X KVU 271	9.24	1.71	1.38	7.70	0.83	3.55	1.00	4.55
WC 48A X MU 9	2.45	4.31	1.17	-0.29	-0.12	-0.26	-0.98	-1.24
NE 48 X Ayiyi	3.18	3.04	2.49	0.41	0.13	0.32	-1.66	-1.34
WC 63 X 2392	1.81	1.36	1.99	0.14	0.08	0.14	-1.77	-1.63
Eberlat*NE 51 X NE 48	2.20	4.67	3.04	-1.65	-0.75	-1.56	-0.19	-1.75
WC 64 X NE 55	1.62	1.19	3.80	-0.87	-0.54	-0.96	-1.75	-2.71
MU 9 X NE 36	1.10	1.17	1.53	-0.25	-0.23	-0.34	-2.49	-2.82
MU 20B X SECOW 5T	1.23	2.28	2.78	-1.30	-1.06	-1.64	-2.72	-4.36

[1]Population variance, [2]Variance for the 1st Parent, [3]Variance for the 2nd parent, [4]Genetic variance, [5]Expected genetic gain, [6]Broad sense heritability

Table 6. Estimated Base Selection Index values (BSI) for the 21 representative populations.

Genotype	Virus	Thrips	Scab-a[1]	Scab-b[2]	Ped No.[3]	Pod No.[4]	Yield	BSI-a[5]	BSI-b[6]
WC 48A X 2392	-0.33	-3.97	-3.3	-1.56	6.01	9.74	19.70	35.45	44.61
NE 5 X Sanzi	-3.93	-6.12	-2.87	-1.51	8.11	10.52	9.67	28.31	42.74
Danila X NE 48	-1.23	-2.67	-2.44	-1.54	4.61	6.54	13.16	24.31	32.18
NE 36 X 2392	0.82	-4.69	-2.53	-0.93	4.38	8.03	10.7	23.10	30.43
Danila X VCR 1432	0.01	-6.35	0.53	-1.56	3.29	5.34	11.55	20.19	27.55
NE 5 X 2392	-3.40	1.35	-2.86	-1.22	1.42	3.34	14.47	19.23	25.35
NE 55	-4.81	-3.31	-2.48	-0.32	2.15	4.72	7.49	14.37	25.28
Ayiyi X 2392	-3.40	1.81	-1.2	-1.59	5.87	5.90	7.68	19.44	23.81
SECOW 5T X Ayiyi	0.87	-0.58	-2.86	-1.49	4.45	6.31	7.58	18.34	22.39
MU 20B X NE 36	-4.73	-1.12	-0.32	-1.51	3.56	4.93	4.92	13.41	21.09
WC 48A	-0.32	0.77	-2.93	-1.54	2.19	2.71	10.36	15.26	19.28
2392 X Eberlat*NE 51	2.00	-7.84	-1.20	0.34	4.38	7.59	-0.32	11.65	18.35
Danila X NE 5	-3.80	0.70	-2.43	-0.88	1.96	2.59	6.68	11.23	17.63
3306 X Ayiyi	-1.71	0.00	-1.20	-1.53	1.51	2.78	8.68	12.97	17.41
MU 20B	1.02	3.96	2.24	1.55	-2.55	-4.37	-6.31	-13.23	-22.00
MU 9 X NE 36	3.39	4.69	0.04	0.91	-3.88	-4.89	-7.07	-15.84	-24.86
MU 9	0.46	2.70	1.54	2.79	-3.53	-5.66	-8.25	-17.44	-24.93
WC 63 X 2392	2.27	1.59	7.04	2.13	-1.72	-3.34	-7.22	-12.28	-25.32
MU 20B X NE 55	0.12	1.72	6.97	2.15	-3.00	-3.95	-7.74	-14.70	-25.65
NE 21	1.13	3.26	5.74	2.18	-2.99	-4.29	-7.71	-14.98	-27.30
MU 20B X SECOW 5T	3.13	6.61	7.45	-0.31	-3.81	-5.69	-9.33	-18.82	-35.71

[1]Scab on leaf, [2]Scab on pod, [3]Number of peduncles, [4]Number of pods, [5]Base Selection Index for yield and its components, [6]Base Selection Index for Grain Yield.

Table 7. Correlation (r) values obtained from the association between the selections criteria (Usefulness criterion, Base index Selection Index and Mean performance).

Correlation	UC-1[1]	UC-2[2]	BSI-1[3]	BSI-2[4]	Mean yield
UC-1[1]	1.00				
UC-2[2]	0.76***	1.00			
BSI-1[3]	0.74***	0.88***	1.00		
BSI-2[4]	0.71***	0.84***	0.94***	1.00	
Mean yield	0.82***	0.80***	0.93***	0.87***	1.00

***: P<0.001, [1]UC considering grain yield, [2]UC considering grain yield, pods and peduncles, [3]BSI for grain yield, number, [4]BSI for grain yield, pods and peduncles, resistance to scab on leaf, pod, virus and thrips,

had the least usefulness values were selected as a representative to show the usefulness values of the populations for grain yield (Table 4) and grain yield and its components (Table 5).

Development of selection index for yield and agronomic traits and selection of best populations

The computed indices were based on the weighted mean values of the traits regarded as important and populations with higher selection index value were considered to be the best. WC 48A x 2392 (44.61) ranked first in the selection index for yield, yield components, thrip damage, scab and virus severity, while MU 20B x SEC 5T ranked last (Table 6 and Appendix 3). The same population (WC 48A x 2392) ranked first with a BSI value of 35.71 for the selection index value created for grain yield, number of pods and peduncles (Table 6 and Appendix 3). Fourteen populations that ranked top and seven populations that had the base selection index values were selected as a representative to show the usefulness values of the populations for grain yield (Table 6).

Comparison of the three selection criteria (usefulness criterion, base index selection and mean performance) for determining the best F_2 populations

Using the spearman rank correlation, the result revealed that there was a strong positive correlation (P< 0.001) in the comparison of each selection criteria to the other (Table 7).

Table 8. Comparison of various selection criteria using t-values.

Selection criteria	t-Value	Populations in common
UC[1] Yield Vs. UCYield and yield components	0.19^{ns}	20
UC[1] Yield Vs. BSI[2] for Yield and its components	-0.09^{ns}	20
UC[1] Yield Vs. BSI[2] for 7Traits[3]	0.63^{ns}	16
UC[1] Yield Vs. Mean Yield	1.31^{ns}	19
UC[1] Yield and its components Vs. BSI[2] Yieldand its components	0.10^{ns}	22
UC[2] Yield and its components Vs. BSI[2] for 7Traits[3]	0.81^{ns}	22
UC[2] Yield and its components Vs. Mean Yield	1.47^{ns}	21
BSI[2] for Yield and yield components Vs. BSI[2] for 7 Traits[3]	-0.70^{ns}	25
BSI[2] for Yield and yield components Vs. Mean Yield	1.36^{ns}	24
BSI[2] for 7Traits[3] compared to Mean Yield	0.67^{ns}	20

ns: not significant, [1]Usefulness Criteria, [2]Base selection index, [3]Grain yield, number of pods and peduncles, resistance to thrips, virus, scab on leaf and pod.

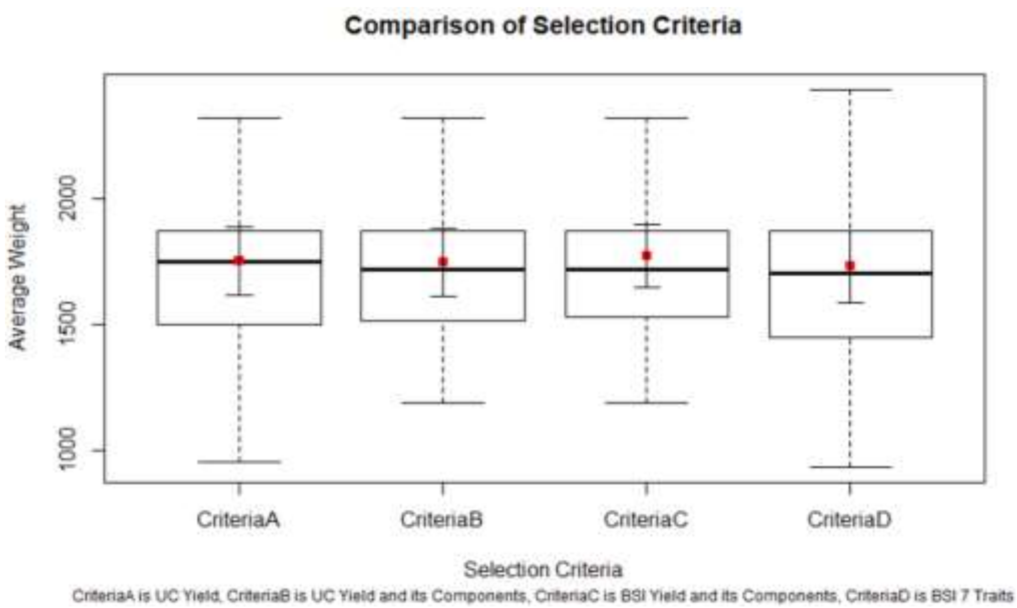

Figure 1. A boxplot showing differences among criteria used in the selection of the best populations.

There were no significant differences (P>0.05) observed for the mean yield of the top ranked populations in the different criteria used in the selection (Table 8 and Figure 1).

Selection of the best F_2 populations

A total of 40 cowpea populations were selected by choosing populations that occured in common when the 30 best populations were ranked in the 5 different selection criteria. Also populations that occurred among the 30 best in only one selection criterion and not in others but had unique capabilities such as disease resistance were selected for instance WC 27 x VCR 1432 (Table 9).

Eight plants that had high mean for grain yield were selected within each population and advanced for evaluation. The 320 lines selected were advanced to determine the effectiveness of the selection methods and populations.

Performances of the cowpea parents and F_3 cowpea as evaluated for virus and scab disease severity, thrips damage, yield and yield componentsin single site in season 2017B

The parents performed significantly different (P<0.001) for all the traits assessed except for their reaction to thrip (Table 10). Similarly, significant differences were

Table 9. Best populations selected from the methods usefulness criteria and base selection index.

Population	Yield (kg/ha)	Rank				
		BSI -1[1]	BSI -2[2]	UC-1[3]	UC-2[4]	Yield (kg/ha)
2392 x Ebelat*NE 51	1187	13	10	99	9	73
2392 x NE 5	1515	25	35	50	31	32
2392 x Sanzi	1202	37	19	56	15	70
3306 x Ayiyi	1947	11	12	18	35	7
3306 x Ebelat*NE 51	1334	21	22	52	28	52
Ayiyi x 2392	1863	6	7	11	2	11
Ayiyi x WC 66	1796	14	28	5	13	13
Danila x Ebelat*NE 51	1532	20	15	19	18	29
Danila x KVU 27-1	1867	16	14	9	14	10
Danila x NE 48	2326	3	3	2	4	3
Danila x NE 5	1778	15	11	45	24	15
Danila x NE 55	1311	91	94	23	97	50
Danila x VCR 1432	2190	5	5	8	25	4
KVU 27-1 x WC 27	1752	26	44	15	11	17
MU 15 x Ebelat*NE 51	1415	24	27	36	40	42
MU 15 x WC 64	1445	38	18	34	21	37
MU 20B x NE 36	1630	9	9	76	6	20
MU 20B x WC 27	1594	23	21	19	8	23
MU 9 x NE 55	1612	18	33	27	12	21
NE 21 x MU 20B	1399	42	72	17	29	44
NE 21 x NE 55	1517	29	27	38	5	31
NE 21 x WC 48A	1784	12	29	12	36	14
NE 36 x 2392	2118	4	4	1	3	5
NE 5 x 2392	2436	7	6	7	16	2
NE 5 x Sanzi	2031	2	2	4	1	6
NE 5 x WC 64	1531	58	25	48	83	30
NE 55 x MU 20B	1554	17	17	24	49	28
NE 55 x MU 9	1458	39	41	22	39	35
NE 55 x NE 5	1359	46	36	32	17	47
SECOW 2W x Ebelat*NE51	1685	10	31	30	20	19
SECOW 5T x 3306	1754	30	32	6	22	16
SECOW 5T x Ayiyi	1854	8	8	3	10	12
WC 27 x VCR 1432	935	34	16	101	51	104
WC 48A x 2392	2878	1	1	14	19	1
WC 48A x WC 27	1874	22	30	10	7	8
WC 48A x WC 66	1389	49	61	26	37	45
WC 63 x MU 9	1564	45	54	21	23	26
WC 63 x NE 48	1875	19	20	13	26	9
WC 64 x 3306	1601	28	13	28	41	22
WC 64 x SECOW 4W	1425	61	63	25	27	39
Total		29	28	28	29	26

[1]Base selection index comprising traits virus, scab on leaves, thrips damage, scab on pod incidence, grain yield, pods and peduncles, [2]Base selection index comprising traits grain yield pods and peduncles, [3]Usefulness criteria for grain yield, [4]Usefulness criteria for grain yield, pods and peduncles.

observed in the performance of the populations for all traits evaluated (Table 10). Significant differences (P<0.001) were also observed in the performance of the cowpea lines within a population for all the traits except for the reaction to thrip, number of peduncles and pods per plant (Table 10). When the performances of the parents were compared to the populations, we observed significant differences in their reaction scab disease

Table 10. Mean squares of cowpea parents and F_3 populations for virus and scab disease severity, thrips damage, yield and yield components for the season 2017B.

SOV[1]	Virus	Thrips	Scab	DF[2]	Ped No.[3]	Pod No.[4]	100 SW[5]	Yield (kg/ha)
Parents	0.23*	2.47^{ns}	0.22***	20.84***	147.20***	281.20***	10.21***	617057***
Populations	0.11***	4.40*	0.29***	27.61***	79.52*	214.93***	16.87***	1810374***
Population/Lines	0.15***	2.44^{ns}	0.15***	17.31***	40.43^{ns}	89.61^{ns}	4.93***	486252***
Par Vs. Crosses[6]	0.11^{ns}	5.58^{ns}	2.11***	66.16**	358.57**	738.30**	3.77^{ns}	341471^{ns}
Residual	0.13	2.82	0.1	9.33	46.12	108.39	1.82	299577
CV[7]	17.69	39.77	18.85	4.93	27.23	28.31	13.64	32.86
SED[8]	0.361	1.68	0.316	3.05	7.11	10.41	1.82	547

***, **, *: Significant at p<0.001, p<0.01 and p<0.5, ns: not significant, [1]Source of variation, [2]Days to 50% flowering, [3]Number of peduncles per plant, [4]Number of pods, [5]weight of 100 seeds, [6]Perfomances of parents as compared to the populations, [7]Coefficient of variation, [8]Standard error of the difference.

(P<0.001), number of days to 50% flowering and number of peduncles and pods per plant at P<0.01 (Table 10).

Mean performance of the cowpea parents, F3 populations and lines evaluated for virus and scab disease severity, thrips damage, yield and yield components in 2017B

The parents reacted differently to the various diseases and pests with their means ranging from 1.6 to 2.5 for virus, 3.2 to 5.9 for thrip and 1.6 to 2.4 for scab (Table 11). In terms of days to 50% flowering, it was observed that the parent Sanzi flowered earlier at 58 days than the rest (Table 11). In terms of yield, NE 48 recorded the highest yield of 2560 kg/ha while the lowest yield was recorded by SECOW 4W (Table 11).

The mean performance of the 19 cowpea lines selected as a representative of the 320 cowpea lines evaluated are presented in Table 12. The mean performance of the cowpea lines for virus disease ranged from 1.2 to 3.0, for thrip damage, ranged from 1.0 to 7.4, and for scab disease ranged from 1.0 to 3.0. The cowpea lines took 51 to 73 days to attain 50% flowering. Line NE 21 x MU 20B/1 registered the highest grain yield of 3533 kg/ha while line Danila x KVU 27-1/7 had the lowest yield of 77 kg/ha (Table 12).

Comparing the performance of parents to the crosses, the results showed that the crosses were better performers than their parents as they recorded the lowest mean scores for scab disease and early flowering time. However, the parents on the other hand performed better than the crosses in terms of the number of peduncles, pods per plant and, consequently had high yield (Table 13).

The populations' mean scores ranged from 1.7 to 2.4 for virus disease, 1.9 to 6.6 for thrip damage and 1.4 to 2.2 for scab disease. The days to 50% flowering ranged from 53 to 68 days. Danila x Ebelat*NE 51 recorded the lowest grain yield of 785 kg/ha and population WC 63 x NE 48 recorded the highest grain yield of 2475 kg/ha (Table 14).

Determination of the effectiveness of the selection methods and populations

Usefulness value of the $F_{2:3}$ populations and the genetic gain (Response to Selection)

Usefulness values obtained in the individual populations ranged from 351.1 to 1277.2 (Table 4). The highest genetic variance (427180.5) and genetic gain (855.7) were recorded on KVU 271 x WC 27 (695.63-Table 15). Thirteen populations had a negative genetic variance which meant there is zero genetic variance in them but due to the high mean that existed on those populations, they still recorded a high usefulness value.

Generally, high realized heritability (Rh) and genetic gain (Gs) were obtained for yield and its components when the realized genetic gain was calculated for the whole 40 populations evaluated (Table 16).

DISCUSSION

There was significant level of variability among the cowpea populations and parents for diseases such as virus and scab, number of pods per plant, grain yield and number of pods per plant assessed and these findings are in agreement with the results obtained in previous studies (Bhadru and Navale, 2012b; Idahosa et al.,2010).This suggests that there was high level of genetic variability among the cowpea genotypes for traits measured which could be utilized to maximize genetic gain for these traits through improved selection.

The large variability that was observed within the populations for yield and yield components made it possible to identify the best populations using the usefulness criteria. Populations with larger genetic

Table 11. Mean performance of cowpea parents evaluated for virus and scab disease severity, thrips damage, yield and yield components in season 2017B.

Parent	Virus	Thrips	Scab	DF[1]	Ped No.[2]	Pod No.[3]	100 SW[4] (g)	Yield (kg/ha)
2392	1.6	3.5	1.7	63	23	32	13.5	1957
3306	1.8	4.3	1.7	62	27	38	11.8	1809
AYIYI	1.9	4.2	1.7	61	27	39	16.3	1886
DANILA	1.9	4.7	1.7	63	25	37	14.8	1139
EBELAT*NE 51	2.2	4.8	2.1	60	42	55	13.3	1198
KVU 271	2.0	3.5	1.8	66	27	26	13.2	1361
MU 15	2.5	5.1	1.7	64	22	33	14.1	1965
MU 20B	2.2	5.5	2.1	66	32	47	13.5	2090
MU 9	2.1	4.1	1.7	63	25	37	12.7	1790
NE 21	2.0	3.9	1.9	64	25	35	12.9	1133
NE 36	2.0	4.6	1.6	66	26	43	17.3	1857
NE 48	1.9	3.6	1.9	62	21	33	14.5	2560
NE 5	1.9	4.2	1.7	62	38	52	12.9	1433
NE 55	2.0	3.3	1.6	64	29	42	13.0	2156
SANZI	2.2	5.5	1.9	58	29	40	12.7	1541
SECOW 2W	2.5	5.1	2.3	61	29	42	13.5	1317
SECOW 4W	1.8	5.9	2.0	63	22	32	12.0	965
SECOW 5T	1.8	4.2	1.9	61	20	28	14.5	1982
VCR 1432	2.4	5.0	2.4	63	25	29	15.0	1174
WC 27	2.0	4.5	1.6	66	23	32	12.3	1850
WC 48A	2.1	4.9	1.8	65	26	37	12.6	1415
WC 63	1.9	3.7	1.6	63	25	35	13.5	2006
WC 64	2.3	5.5	1.8	60	29	44	12.5	2125
WC 66	2.3	4.9	2.4	59	25	34	14.7	2136
LSD	0.5	1.9	0.5	6	11	17	2.2	657

[1]Days to 50% flowering, [2]Number of peduncles, [3]Number of pods, [4]Weight of 100 seeds.

Table 12. Mean performance of the $F_{2:3}$ cowpea lines evaluated for virus and scab severity, thrips damage, yield and yield components in 2017B.

Lines	Virus	Thrips	Scab	DF[1]	Ped No.[2]	Pod No.[3]	100 SW[4] (g)	Yield (kg/ha)
Danila X Ebelat*NE51/6	2.2	4.8	2.2	67	17	19	12.5	443
Danila X KVU 27-1/7	2.0	3.9	2.5	69	7	24	5.0	77
Danila X VCR 1432/5	2.2	5.2	1.7	67	17	23	12.5	885
Danila X VCR 1432/7	1.5	5.6	1.0	59	23	29	20.0	1787
KVU 27-1 X WC 27/8	2.0	3.9	2.5	65	53	65	13.0	613
MU 15 X Ebelat*NE 51/1	3.0	1.0	2.5	55	24	30	16.0	1170
NE 21 X MU 20B/1	1.5	6.8	1.5	67	29	47	15.0	3533
NE 21 X NE 55/2	2.0	4.8	1.5	55	30	31	11.0	993
NE 5 X 2392/7	1.2	4.3	1.5	58	28	45	14.5	1795
NE 55 X MU 9/3	2.5	3.5	1.5	51	25	31	16.0	2046
NE 55 X NE 5/6	1.5	3.1	2.0	65	52	80	13.0	1653
NE 55 X NE 5/7	2.0	5.1	3.0	65	16	25	9.0	130
SECOW 2W X Ebelat*NE51/1	2.2	5.2	3.0	65	26	36	11.0	1208
SECOW 5T X 3306/3	1.8	5.5	1.5	64	20	30	16.5	2070
SECOW 5T X Ayiyi/4	2.2	5.4	1.5	63	29	22	15.5	1199
WC 48A X 2392/7	2.0	2.0	1.0	58	24	31	15.7	2114
WC 48A X WC 66/1	2.5	3.9	1.5	73	40	64	13.0	1587
WC 48A X WC 66/2	2.2	3.8	2.0	66	14	27	9.0	589

Table 12. Contd.

WC 64 X SECOW 4W/8	2.3	7.4	1.8	59	35	53	11.5	2316
LSD	0.7	1.2	0.6	7	12	17	4.0	1091.16

[1]Days to 50% flowering, [2]Number of peduncles, [3]Number of pods, [4]Weight of 100 seeds.

Table 13. Comparison of the parents' performance to the $F_{2:3}$ generation cowpea crosses evaluated for virus and scab disease severity, thrip damage, yield and yield components in season 2017B.

Parents vs. crosses	Virus	Thrips	Scab	DF[1]	Ped No.[2]	Pod No.[3]	100 SW[4] (g)	Yield (kg/ha)
Parents	2.0	4.2	1.7	62	26	37	13.3	1672
Crosses	2.0	4.4	1.8	63	28	39	13.5	1726
LSD	0.07	0.3	0.07	1	1	2	0.4	124.6

[1]Days to 50% flowering, [2]Number of peduncles, [3]Number of pods, [4]Weight of 100 seeds.

Table 14. Mean performance of the $F_{2:3}$ generation cowpea populations evaluated for virus and scab disease severity, thrip damage, yield and yield components in season 2017B.

Population	Virus	Thrips	Scab	DF[1]	Ped No.[2]	Pod No.[3]	100 SW[4] (g)	Yield (kg/ha)
2392 X EBELAT*NE 51	2.1	4.2	1.7	63	24	37	12.2	1540.0
2392 X NE 5	2.1	5.4	1.6	57	23	30	13.2	1762.0
2392 X SANZI	2.1	3.1	1.5	53	26	41	10.1	1076.0
3306 X AYIYI	1.8	4.0	1.7	65	25	34	13.7	1615.0
3306 X EBELAT*NE 51	2.1	4.5	1.6	60	30	46	12.8	1511.0
AYIYI X 2392	1.8	4.3	1.7	65	27	40	12.9	1272.0
AYIYI X WC 66	2.0	4.2	1.6	57	27	41	15.3	2244.0
DANILA X EBELAT*NE51	2.4	4.9	2.2	64	24	26	10.7	785.0
DANILA X KVU 271	2.0	4.1	1.7	65	25	34	14.3	1401.0
DANILA X NE 48	2.3	3.9	1.7	65	24	31	14.3	1374.0
DANILA X NE 5	2.1	3.7	1.8	61	26	35	13.2	1317.0
DANILA X NE 55	2.2	3.5	1.7	59	30	40	13.0	1746.0
DANILA X VCR 1432	1.9	4.9	1.8	63	30	41	15.1	1731.0
KVU 271 X WC 27	2.3	2.9	1.6	60	30	40	14.5	1617.0
MU 15 X EBELAT*NE51	2.2	3.2	2.1	60	25	38	12.5	1365.0
MU 15 X WC 27	2.1	4.9	1.5	63	23	34	11.4	1678.0
MU 20B X NE 36	1.8	4.1	1.5	64	26	39	12.4	2022.0
MU 20B X WC 27	2.3	4.6	1.6	63	23	34	13.9	1625.0
MU 9 X NE 55	2.0	5.3	1.5	66	27	39	13.9	2088.0
NE 21 X MU 20B	1.8	3.7	1.6	68	29	39	12.6	1740.0
NE 21 X NE 55	2.0	5.0	1.6	61	25	34	13.9	1511.0
NE 21 X WC 48A	2.1	4.3	1.6	62	25	36	13.7	1607.0
NE 36 X 2392	2.1	4.3	1.4	62	28	43	12.8	2278.0
NE 5 X 2392	1.9	4.1	1.7	60	26	38	15.3	1450.0
NE 5 X SANZI	2.2	4.6	1.7	60	24	30	12.5	1288.0
NE 5 X WC 64	2.1	5.0	1.5	63	25	37	13.8	2002.0
NE 55 X MU 20B	2.1	3.0	2.0	63	26	35	12.2	1254.0
NE 55 X MU 9	2.3	3.7	1.7	58	26	35	14.7	1556.0
NE 55 X NE 5	1.7	3.8	1.7	64	37	58	13.4	1943.0
SECOW 2W X EBELAT*NE 51	2.0	3.6	2.0	64	28	38	12.1	1551.0
SECOW 5T X 3306	2.0	4.6	1.5	64	25	38	15.1	2203.0

Table 14. Contd.

SECOW 5T X AYIYI	2.1	3.9	1.8	61	23	32	14.7	1761.0
WC 27 X VCR 1432	1.8	4.5	1.4	63	22	31	12.0	1265.0
WC 48A X 2392	2.2	3.9	1.6	57	21	30	13.3	1725.0
WC 48A X WC 27	2.1	4.7	1.7	65	26	39	12.9	2178.0
WC 48A X WC 66	2.4	4.5	1.8	65	25	34	12.7	1152.0
WC 63 X MU 9	1.9	4.4	1.6	64	28	40	13.2	2451.0
WC 63 X NE 48	1.7	3.8	1.5	60	21	30	16.2	2475.0
WC 64 X 3306	2.0	2.5	1.7	61	26	34	14.1	1598.0
WC 64 X SECOW 4W	2.0	6.6	1.6	59	31	43	12.8	1943.0
LSD	0.3	1.2	0.3	2	5	7	1.5	476.5

variances gave high genetic gain and eventually high usefulness value. Populations such as NE 36 x 2392, Danila x NE 48, SECOW 5T x Ayiyi, NE 5 x Sanzi, Ayiyi x WC 66, SECOW 5T x 3306, NE 5 x 2392 showed high genetic gain for grain yield and its components (number of pods and peduncles). This could be due to the high heritability values for yield and yield components that existed in the same populations. In fact, genetic gain (response to selection) depends on the breeding value of the parents used in population development, and it is the deviation of the progeny mean performance from the population mean (Falconer, 1989). The NE 36 x 2392 population was ranked first by the usefulness criterion based on its grain yield as it had a high genetic variance and a genetic gain. The same population ranked third in the usefulness value, based on its yield and yield components (number of pods and peduncles). This may suggest that the high correlation between the three traits namely yield and number of pods (r=0.76), yield and number of peduncles (r=0.75) contributed to the high genetic gain as considered by the usefulness criteria combining yield and its components. These results are consistent with the findings of Singh (2005), who observed that secondary traits showed moderate to high correlation with yield and a higher heritability than yield per se, and as such it can be a good selection criterion in breeding for yield improvement. Some populations like NE 21 x MU 20B and Danila x NE 5 that ranked highly in the usefulness criterion but low in the base selection index and the mean yield (yield perse)indicated the greater role of genetic variance in the populations because as much as the mean yields for the same populations were low, consideration of the genetic variance in those populations improved their ranks. Similar results were reported by Nizeyimana (2013) who evaluated some maize hybrids and found out that some populations improved in their ranks when both genetic variance and means of the populations were considered.

Selection for traits that are highly expressed phenotypically such as plant height, vigor and days to flowering become easier when using visual selection. However, visual rating is said to be unreliable for quantitative traits such as yield and yield components, yet they are highly targeted by breeders (Hallauer, 2010). This calls for selection of individual trait with consideration of how much a trait contributes to the final product. The response of individual traits in the final product largely depends on how each trait has been weighted and selected in the reference population. Several studies suggest that selection based on multi trait index is more convenient in predicting the best genotypes than relying on direct selection (Oliveira et al., 2017; Rodrigues et al., 2017). This was observed in some populations, when visual selection was used for traits such as average yield, they ranked almost the last but when multiple trait selection was used they ranked among the top most populations. For instance, 2392 x Ebelat*NE 51 ranked 73rd in the visual selection and 99th in the usefulness value for grain yield alone yet it ranked 9th in both usefulness value (combining yield and its component) and base selection index for disease and yield components and 13 in the base index selection for yield and its components. Such results show that when traits of importance are put into consideration then potential populations could be identified and strengthened for multiple traits. These results are in accordance to Nizeyimana (2013) who evaluated some maize hybrids and reported that some populations such as E99, E80, E87, E74 and E93 ranked as the best populations when the contributions of AD, SD, ASI, resistance to Turcicum Leaf Blight and Maize Streak Virus, in the inbreds and hybrids, along with yield and 100-kernel weight in the hybrids were put into consideration.

Comparison of the selection criteria used in the selection of the best F_2 populations

The non-significant differences observed when comparing the selection criteria suggest that the criteria are equally the same for selecting the best populations.

Table 15. Estimated usefulness value (U) of the $F_{2:3}$ populations for grain yield (I=0.2, k=1.4).

Population	Vg[1]	Vp[2]	Sqrt Vp[3]	Heritability	K[4]	Gs[5]	Mean	UC[6]
2392 X NE5	-101364	156764	395.9	0.00	1.4	0.0	476.7	476.7
2392 X Sanzi	7854	95623	309.2	0.08	1.4	35.6	315.5	351.1
2392XEbelat*NE51	140917	274398	523.8	0.51	1.4	376.6	474.8	851.4
3306 x Eberlat*NE 51	-184944	401336	633.5	0.00	1.4	0.0	450.4	450.4
3306x Ayiyi	28028	238867	488.7	0.12	1.4	80.3	376.9	457.2
3306xAyiyi	51204	130215	360.9	0.39	1.4	198.7	485.5	684.2
Ayiyi x WC 66	-15296	258013	507.9	0.00	1.4	0.0	643.7	643.7
DANILA X EBELAT*NE51	187600	347427	589.4	0.54	1.4	445.6	212.8	658.4
DANILA X KVU 271	15847	155308	394.1	0.10	1.4	56.3	354.9	411.2
DANILA X NE 48	241398	569926	754.9	0.42	1.4	447.7	416.2	863.9
DANILA X NE 5	78375	448410	669.6	0.17	1.4	163.9	360.8	524.7
DANILA X NE 55	39911	74545	273.0	0.54	1.4	204.6	514.5	719.1
DANILA X VCR 1432	147028	1178742	1085.7	0.12	1.4	189.6	376.6	566.2
KVU 271 X WC 27	427181	488484	698.9	0.87	1.4	855.7	342.1	1197.8
MU 15 X EBELAT*NE 51	-5239	262399	512.2	0.00	1.4	0.0	409.9	409.9
MU 15 X WC 27	-56718	290489	539.0	0.00	1.4	0.0	503.0	503.0
MU 20B X NE 36	147108	291270	539.7	0.51	1.4	381.6	606.5	988.1
MU 20B X WC 27	-111726	192581	438.8	0.00	1.4	0.0	487.1	487.1
MU 9 X NE 55	264726	319990	565.7	0.83	1.4	655.2	598.9	1254.1
NE 21 X MU 20B	140347	425319	652.2	0.33	1.4	301.3	388.5	689.8
NE 21 X NE 55	-7971	148024	384.7	0.00	1.4	0.0	416.8	416.8
NE 21 X WC 48A	157733	269448	519.1	0.59	1.4	425.4	472.3	897.7
NE 36 X 2392	-143273	739223	859.8	0.00	1.4	0.0	550.7	550.7
NE 5 X 2392	-75872	302744	550.2	0.00	1.4	0.0	397.0	397.0
NE 5 X SANZI	75793	343627	586.2	0.22	1.4	181.0	331.4	512.4
NE 5 X WC 64	55282	172233	415.0	0.32	1.4	186.5	590.8	777.3
NE 55 X MU 20B	205186	575073	758.3	0.36	1.4	378.8	358.6	737.4
NE 55 X MU 9	-28946	139676	373.7	0.00	1.4	0.0	432.6	432.6
NE 55 X NE 5	-343980	1671895	1293.0	0.00	1.4	0.0	415.6	415.6
SECOW 2W X EBELAT*NE51	41970	134809	367.2	0.31	1.4	160.0	465.3	625.3
SECOW 5T X 3306	267965	339228	582.4	0.79	1.4	644.1	633.1	1277.2
SECOW 5T X AYIYI	370453	677603	823.2	0.55	1.4	630.0	519.0	1149.0
WC 27 X VCR 1432	425390	546809	739.5	0.78	1.4	805.4	364.9	1170.3
WC 48A X 2392	267785	669679	818.3	0.40	1.4	458.1	517.4	975.5
WC 48A X WC 27	103043	189075	434.8	0.54	1.4	331.8	653.1	984.9
WC 48A X WC 66	145721	364505	603.7	0.40	1.4	337.9	321.9	659.8
WC 63 X MU 9	245986	712114	843.9	0.35	1.4	408.1	617.9	1026.0
WC 63 X NE 48	-6745	247423	497.4	0.00	1.4	0.0	699.6	699.6
WC 64 X 3306	46897	132517	364.0	0.35	1.4	180.4	479.5	659.9
WC 64 X SECOW 4W	-21678	323174	568.5	0.00	1.4	0.0	556.5	556.5

[1]Genetic variance, [2]Phenotypic variance, [3]Square root of the phenotypic variance, [4]Selection intensity, [5]Genetic gain, [6]Usefulness criteria.

This further approved that the best populations with high mean selected in one selection criterion was most likely the ones selected in the other selection criteria and so, any method can be used to select the populations depending on the breeder's objective. If the breeder's main concern is to select populations with high variation and mean yield, then usefulness criteria becomes the best to handle such a selection. Some of the best populations selected in one selection criteria could be similar to the others selected in the different selection criteria, but the ranking of the populations may differ in the different selection criteria. In fact, the strong positive correlations that existed among the selection criteria suggested that the populations that had high usefulness values are more likely to have high base selection index values. For this case, 16 populations happened to be in

Table 16. Realized heritability and estimated genetic gain obtained from selection.

Parameter	Virus	Thrip	Scab	Ped No.[1]	Pod No.[2]	Grain yield
Average 2017A (Uo)	4.7	5.5	3.4	14	20	1214
Average Selected Pop	4.7	5.5	3.4	34	53	1683
Average 2017B (Up)	2.0	4.0	1.7	26	37	1662
Response to Selection (R)	-2.7	-1.5	-1.7	12	17	447
Selection differential (s)	-	-	-	20	33	469
Realized heritability (Rh)	-	-	-	0.62	0.51	0.95
Selection intensity (k)	-	-	-	1.4	1.4	1.4
Genetic variance (Vg)	-	-	-	16.7	53.3	755399
Phenotypic variance (Vp)	-	-	-	62.8	161.7	1054976
Genetic Gain (Gs)	-	-	-	6.9	9.0	1372

[1]Number of peduncles, [2]Number of pods.

common among the 30 ranked best in each method. For instance, WC 48A x 2392 population ranked 1[st] in the base index selection criteria but 14 and 19 in the usefulness criteria for grain yield and yield components and thus ended up being among the 30 best populations in both methods. The high ranking of the populations 2392 x Ebelat*NE 51 and WC 27 x VCR 1432 in the BSI for diseases, pests and yield yet low rankings in the UC and yield, suggested that there was the level of disease and pest resistance in the respective population. Therefore, this further emphasizes the need for selection in reference to the breeder's objective. If resistance to diseases and pest is a major concern to the breeder then BSI that comprises the diseases, pests and yield could be used.

Yield potential of cowpea parents and the selected $F_{2:3}$ lines for identification of transgressive segregants

In determining yield potential, valuable traits such as resistance to diseases, insect pest and other agronomic traits as well as the physiology of the crop were equally important. The parents had better performance than the populations in reaction to scab disease as well as the number of days to flowering. On the other hand, the crosses performed better than their parents in the number of peduncles per plant with a difference of 4% (2 peduncles per plant). This suggested the presence of transgressive segregants as evidently seen in the lines KVU 27-1 x WC27/8 (53 peduncles and 65 pods per plant) and NE 55 x NE5/6 (52 peduncles and 80 pods per plant). These lines outperformed the best parents WC 27 (23 peduncles and 31 pods) and NE 5 (37 peduncles and 52 pods). Similar results have been reported elsewhere by Shivakumar et al*.* (2013) and Kurer (2007). Line NE 21 x MU 20B/1 had high yield performance which probably was as a result of its better performance for some of the yield related component traits such as pod length and number of seeds per pod. This was probably due to the fact that, line NE 21 x MU 20B/1 showed moderate resistance to virus and scab disease infection. Danila x KVU 27-1/7 gave lower yields due to the poor vigor and consistent attack by pests and diseases. WC 63 x NE 48 was the best population in Kabanyolo in terms of grain yield as it had longer pods, which created space for many seeds per pod. This could be attributed to the fact that parents that resulted in its formation performed equally as good in the same location as its parents WC 63 and NE 48 gave yields of 2006 and 2560 kg/ha, respectively. These two parents played a vital role in generating some crosses that inherited their potential as they were known to be high grain yielders and also resistant to both scab and virus disease (Mbeyagala et al*.*, 2014; Afutu et al*.*, 2016b).

High usefulness values were observed in the forty populations that were advanced due to the high predicted genetic gain that was due to the high genetic variance maintained in the populations. This is an indication that the methods worked to select the best populations and that the populations selected were the best. Though some populations had zero genetic gain due to the negative genetic variance observed in them they still had a high mean which guaranteed a high usefulness value for them (Bernado, 2010). Highest magnitude of response to selection and selection differential was recordedfor virus and scab diseases, thrip damage, number of peduncles and pods per plant and yield at harvest on the selected $F_{2:3}$ populations suggesting progress in achievement andeffectiveness of selection for these traits. The selected $F_{2:3}$ populations recorded high realized heritability for characters yield, number of peduncles and pods per plants suggesting the value of these characters in selection programme and the achievement made after selection. The realized genetic gain obtained in the $F_{2:3}$ lines for number of pods, number of peduncles and grain yield at harvest further magnified the importance of selection of such characters in advanced breeding. Similar results were obtained by Bhadru and Navale (2012b).

Conclusion

This study has shown the existence of cowpea populations with substantial genetic variability for traits namely flower thrips, virus and scab resistance, and high yielding potential; which are therefore promising for the advancement of the populations to the next generation that could result in developing superior lines. The selection criteria, that is, the usefulness criterion and base selection index were able to identify the best segregating populations with desired traits (high yields, resistant to virus, scab and flower thrips) for further improvement in future breeding programs. The usefulness criterion revealed that the selection of the best populations should be based on high mean and high genetic variance. Selection index on the other hand proved that populations that are ranked low based on only their yield performance could be highly ranked when several traits were considered including disease and pest resistance which are among key traits in a population like WC 27 x VCR 1432.

When the usefulness criterion and selection index methods were compared, the results indicated no statistical difference. Some of the best populations selected within one criterion were also the best populations selected in another method, suggesting that either of the methods can be used depending on the goal of the breeder. If variability is a prerequisite by the breeder, usefulness criterion is the preferred selection criterion. However, if multiple traits need to be selected at once, then selection index is much preferred. Generally, the approach of using genetic gain and selection index is not only necessary for identifying promising genotypes to increase the efficiency but also useful in the selection of parents used for creation of future crosses.

The results from this study showed the effectiveness of early generation selection while breeding for yield and other agronomic parameters in cowpea.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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APPENDIX

Table 1. Estimated Usefulness value (U) of the evaluated populations for grain yield (I=0.2, k=1.4).

Population	VPop	VP1	VP2	V_G	H	Gs	μ	U
NE 36 X 2392	695.63	100.80	138.39	576.04	0.83	30.58	41.81	72.39
Danila X NE 48	361.32	48.72	69.78	302.08	0.84	22.25	43.41	65.66
SECOW 5T X Ayiyi	483.79	44.50	67.27	427.90	0.88	27.24	34.72	61.96
NE 5 X Sanzi	342.00	55.78	26.58	300.82	0.88	22.77	38.26	61.03
Ayiyi X WC 66	430.43	67.27	34.81	379.40	0.88	25.60	34.78	60.38
SECOW 5T X 3306	477.08	44.50	59.24	425.21	0.89	27.25	33.07	60.32
NE 5 X 2392	340.92	55.78	138.39	243.83	0.72	18.49	41.51	60.00
Danila X VCR 1432	228.20	48.72	52.20	177.74	0.78	16.47	42.45	58.92
Danila X KVU271	412.67	48.72	78.27	349.17	0.85	24.06	34.75	58.81
WC 48 X WC 27	409.89	72.17	65.31	341.15	0.83	23.59	35.1	58.69
Ayiyi X 2392	414.02	67.27	138.39	311.19	0.75	21.41	35.03	56.44
NE 21 X WC 48	232.92	42.01	72.17	175.83	0.75	16.13	39.87	56.00
WC 63 X NE 48	335.07	47.39	69.78	276.49	0.83	21.15	34.68	55.83
WC 48 X 2392	471.34	72.17	138.39	366.06	0.78	23.61	31.65	55.26
KVU 271X WC 27	276.48	78.27	65.31	204.68	0.74	17.23	32.85	50.08
MU 20B X MU 15	275.70	30.74	56.38	232.14	0.84	19.57	30.48	50.05
NE 21 X MU 20B	362.60	42.01	30.74	326.23	0.90	23.98	25.53	49.51
3306 X Ayiyi	218.61	59.24	67.27	155.35	0.71	14.71	34.54	49.25
Danila X Eberlat*NE 51	329.43	48.72	100.00	255.07	0.77	19.67	28.93	48.60
MU 20B X WC 27	279.01	30.74	65.31	230.99	0.83	19.36	28.98	48.34
WC 63 X MU 9	229.79	47.39	40.23	185.98	0.81	17.18	29.98	47.16
NE 55 X MU 9	286.43	62.40	40.23	235.12	0.82	19.45	27.38	46.83
Danila X NE 55	182.61	48.72	62.40	127.05	0.70	13.16	33.31	46.47
NE 55 X MU 20B	233.22	62.40	30.74	186.65	0.80	17.11	29.19	46.30
WC 64 X SECOW 4W	260.28	42.77	58.87	209.46	0.80	18.18	27.7	45.88
WC 48 X WC 66	343.36	72.17	69.00	272.78	0.79	20.61	25.25	45.86
MU 9 X NE 55	406.85	40.23	62.40	355.54	0.87	24.68	20.97	45.65
WC 64 X 3306	211.92	42.77	59.24	160.91	0.76	15.48	30.02	45.50
SECOW 5T X SECOW 4W	243.42	44.50	58.87	191.73	0.79	17.20	28.16	45.36
SECOW 2W X Eberlat*NE 51	339.76	78.61	100.00	250.46	0.74	19.02	25.78	44.80
NE 55 X WC 63	217.62	62.40	47.39	162.73	0.75	15.44	28.37	43.81
NE 55 X NE 5	240.86	62.40	55.78	181.77	0.75	16.40	27.22	43.62
WC 63 X SECOW 4W	178.17	47.39	58.87	125.04	0.70	13.11	29.41	42.52
MU 15 X WC 64	218.83	56.38	42.77	169.25	0.77	16.02	25.42	41.44
Ayiyi X SECOW 2W	323.26	67.27	78.61	250.32	0.77	19.49	21.92	41.41
MU 15 X Eberlat*NE 51	234.21	56.38	100.00	156.02	0.67	14.27	27	41.27
Ayiyi X IT889	193.89	67.27	82.56	118.97	0.61	11.96	29.3	41.26
NE 21 X NE 55	409.82	42.01	62.40	357.62	0.87	24.73	16.28	41.01
MU 9 X NE 5	137.94	40.23	55.78	89.94	0.65	10.72	30.22	40.94
WC 66 X MU 9	234.73	34.81	40.23	197.21	0.84	18.02	22.81	40.83
NE 55 X WC 48	198.09	62.40	72.17	130.80	0.66	13.01	27.11	40.12
NE 55 X Danila	187.10	62.40	48.72	131.54	0.70	13.46	26.63	40.09
WC 66 X Danila	170.12	34.81	48.72	128.35	0.75	13.78	26.27	40.05
SECOW 2W X Sanzi	210.61	78.61	26.58	158.02	0.75	15.24	24.72	39.96
Danila X NE 5	205.89	48.72	55.78	153.64	0.75	14.99	24.29	39.28
MU 15 X Ayiyi	160.65	56.38	67.27	98.82	0.62	10.92	28.22	39.14
NE 21 X NE 5	140.13	42.01	55.78	91.23	0.65	10.79	28.16	38.95
NE 5 X WC 64	154.62	55.78	83.48	84.99	0.55	9.57	28.76	38.33
Ayiyi X Danila	217.91	67.27	48.72	159.92	0.73	15.17	23.1	38.27

Table 1. Contd.

2392 X NE 5	228.05	138.39	55.78	130.96	0.57	12.14	25.78	37.92
WC 64 X WC 27	116.79	42.77	65.31	62.75	0.54	8.13	29.1	37.23
3306 X Eberlat*NE 51	201.81	59.24	100.00	122.20	0.61	12.04	25	37.04
NE 21 X Ayiyi	148.03	42.01	67.27	93.40	0.63	10.75	26.17	36.92
Eberlat*NE 51 X KVU 271	195.28	100.00	78.27	106.14	0.54	10.63	26.03	36.66
MU 20B X 3306	140.28	30.74	59.24	95.28	0.68	11.26	25.25	36.51
2392 X Sanzi	223.45	138.39	26.58	140.97	0.63	13.20	22.63	35.83
IT889 X WC 27	178.69	82.56	65.31	104.75	0.59	10.97	24.38	35.35
3306 X NE 5	152.59	59.24	55.78	95.08	0.62	10.78	24.32	35.10
WC 63 X NE 36	189.79	47.39	100.80	115.69	0.61	11.76	23.02	34.78
IT889 X SECOW 2W	183.19	82.56	78.61	102.61	0.56	10.61	24.16	34.77
NE 55 X Sanzi	174.95	62.40	26.58	130.46	0.75	13.81	20.31	34.12
NE 5 X MU 9	164.17	55.78	40.23	116.16	0.71	12.69	21.33	34.02
NE 48 X SECOW 5T	164.45	69.78	44.50	107.31	0.65	11.72	22.24	33.96
VCR1432 X WC 27	176.47	52.20	65.31	117.71	0.67	12.41	21.46	33.87
3306 X MU 9	170.42	59.24	40.23	120.68	0.71	12.94	20.7	33.64
MU 9 X NE 48	143.68	40.23	69.78	88.68	0.62	10.36	23.08	33.44
MU 20B X NE 55	173.18	30.74	62.40	126.60	0.73	13.47	19.56	33.03
WC 66 X NE 5	105.48	34.81	55.78	60.19	0.57	8.20	24.48	32.68
SECOW 2W X SECOW 4W	152.32	78.61	58.87	83.58	0.55	9.48	23.08	32.56
Danila X WC 48	130.26	48.72	72.17	69.81	0.54	8.56	23.76	32.32
NE 5 X 3306	136.40	55.78	59.24	78.90	0.58	9.46	22.02	31.48
WC 64 X SECOW 5T	135.63	42.77	44.50	92.00	0.68	11.06	20.38	31.44
NE 36 X Eberlat*NE 51	168.30	100.80	100.00	67.90	0.40	7.33	23.98	31.31
NE 5 X KVU271	126.57	55.78	78.27	59.54	0.47	7.41	23.55	30.96
SECOW 4W X MU 20B	109.02	58.87	30.74	64.21	0.59	8.61	21.56	30.17
MU 20B X NE 36	331.01	30.74	100.80	265.24	0.80	0.00	29.8	29.80
SECOW 5T X Eberlat*NE 51	154.29	44.50	100.00	82.04	0.53	9.25	19.89	29.14
WC 48 X SECOW 2W	164.87	72.17	78.61	89.48	0.54	9.76	19.37	29.13
KVU 271 X NE 21	139.24	78.27	42.01	79.10	0.57	9.38	19.55	28.93
Eberlat*NE 51 X 2392	211.54	100.00	138.39	92.35	0.44	8.89	19.89	28.78
WC 64 X NE 36	112.11	42.77	100.80	40.32	0.36	5.33	23.38	28.71
NE 5 X IT889	189.67	55.78	82.56	120.50	0.64	12.25	16.43	28.68
MU 15 X MU 20B	134.56	56.38	30.74	90.99	0.68	10.98	17.39	28.37
3306 X WC 66	136.15	59.24	34.81	89.13	0.65	10.69	17.45	28.14
MU 20B X NE 21	113.88	30.74	42.01	77.50	0.68	10.17	17.96	28.13
Eberlat*NE 51 X Ayiyi	129.89	100.00	67.27	46.26	0.36	5.68	22.12	27.80
2392 X NE 21	172.04	138.39	42.01	81.84	0.48	8.74	18.89	27.63
SECOW 4W X MU 9	128.06	58.87	40.23	78.51	0.61	9.71	17.87	27.58
WC 48 X NE 48	163.43	72.17	69.78	92.45	0.57	10.12	16.33	26.45
WC 66 X NE 55	155.64	34.81	62.40	107.03	0.69	12.01	14.44	26.45
WC 48 X IT889	118.93	72.17	82.56	41.56	0.35	5.34	21	26.34
2392 X WC 48	146.44	138.39	72.17	41.16	0.28	4.76	21.56	26.32
WC 48 X MU 9	96.73	72.17	40.23	40.53	0.42	5.77	20.34	26.11
Sanzi X WC 27	94.13	26.58	65.31	48.19	0.51	6.95	19.09	26.04
NE 48 X Ayiyi	138.46	69.78	67.27	69.94	0.51	8.32	16.96	25.28
KVU 271X 2392	144.02	78.27	138.39	35.68	0.25	4.16	19.93	24.09
Eberlat*NE 51 X MU 15	142.88	100.00	56.38	64.69	0.45	7.58	16.38	23.96
IT889 X 2392	202.81	82.56	138.39	92.34	0.46	9.08	14.69	23.77
2392 X Eberlat*NE 51	129.06	138.39	100.00	9.87	0.08	1.22	22.53	23.75
NE 55 X SECOW 2W	124.46	62.40	78.61	53.95	0.43	6.77	16.9	23.67
WC 27 X VCR1432	101.30	65.31	52.20	42.55	0.42	5.92	17.53	23.45

Table 1. Contd.

Sanzi X NE 36	195.05	26.58	100.80	131.36	0.67	0.00	23.29	23.29
WC 27 X WC 63	62.92	65.31	47.39	6.57	0.10	1.16	21.43	22.59
WC 27 X WC 48	95.63	65.31	72.17	26.89	0.28	3.85	18.64	22.49
SECOW 5T X 2392	108.85	44.50	138.39	17.41	0.16	2.34	20.15	22.49
NE 21 X MU 9	85.92	42.01	40.23	44.80	0.52	6.77	15.61	22.38
WC 64 X 2392	120.72	42.77	138.39	30.14	0.25	3.84	18.49	22.33
2392 X WC 63	139.15	138.39	47.39	46.26	0.33	5.49	16.69	22.18
WC 27 X IT889	143.35	65.31	82.56	69.42	0.48	8.12	14.05	22.17
WC 64 X NE 21	84.59	42.77	42.01	42.20	0.50	6.42	15.41	21.83
Danila X 2392	128.95	48.72	138.39	35.39	0.27	4.36	17.33	21.69
WC 64 X NE 5	132.64	42.77	55.78	83.37	0.63	10.13	11.21	21.34
WC 27 X MU 20B	90.54	65.31	30.74	42.52	0.47	6.26	14.52	20.78
Sanzi X NE 21	65.24	26.58	42.01	30.95	0.47	5.36	14.94	20.30
Eberlat*NE 51 X WC 27	104.07	100.00	75.49	16.32	0.16	2.24	17.76	20.00
Ayiyi X MU 9	92.65	67.27	40.23	38.91	0.42	5.66	14.18	19.84
Eberlat*NE 51 X NE 48	82.59	100.00	69.78	-2.30	-0.03	-0.35	19.67	19.32
KVU 271 X NE 55	82.01	78.27	62.40	11.67	0.14	1.80	15.84	17.64
WC 64 X NE 55	40.15	42.77	62.40	-12.43	-0.31	-2.75	19.86	17.11
MU 9 X MU 20B	67.26	40.23	30.74	31.77	0.47	5.42	11.56	16.98
SECOW 4W X VCR1432	91.31	58.87	52.20	35.77	0.39	5.24	11.61	16.85
MU 9 X NE 36	32.64	40.23	100.80	-37.87	-1.16	0.00	16.75	16.75
VCR1432 X 2392	87.39	52.20	138.39	-7.91	-0.09	-1.18	17.27	16.09
VCR1432 X WC 66	56.96	52.20	34.81	13.46	0.24	2.50	13.39	15.89
KVU 271 X NE 36	192.24	78.27	100.80	102.70	0.53	0.00	15.81	15.81
NE 55 X NE 36	110.20	62.40	100.80	28.60	0.26	3.81	11.53	15.34
NE 21 x Eberlat*NE 51	77.56	42.01	100.00	6.55	0.08	1.04	13.8	14.84
WC 27 X Eberlat*NE 51	72.19	65.31	100.00	-10.46	-0.14	-1.72	16.07	14.35
MU 20B X 2392	76.76	30.74	138.39	-7.81	-0.10	-1.25	13.84	12.59
WC 27 X Sanzi	55.62	65.31	26.58	9.68	0.17	1.82	9.174	10.99
Sanzi X 2392	64.05	26.58	138.39	-18.44	-0.29	-3.23	14.2	10.97
Eberlat*NE 51 X MU 20B	66.01	100.00	30.74	0.63	0.01	0.11	9.839	9.95
MU 20B X SECOW 5T	34.37	30.74	44.50	-3.26	-0.09	-0.78	7.231	6.45
WC 66 X 2392	46.94	34.81	138.39	-39.67	-0.85	-8.11	11.315	3.21
WC 63 X 2392	47.18	47.39	138.39	-45.71	-0.97	-9.32	11.25	1.93

Table 2. Estimated usefulness value (U) of the evaluated *populations* for yield and yield components.

Population	Vpop	VP1	VP2	Vg	H	Gs	μ	U
NE 5 X Sanzi	25.63	2.05	1.12	24.04	0.94	6.65	4.15	10.80
Ayiyi X 2392	25.51	2.49	1.99	23.26	0.91	6.45	3.11	9.56
NE 36 X 2392	22.13	1.53	1.99	20.37	0.92	6.06	3.33	9.39
Danila X NE 48	9.19	1.71	3.04	6.82	0.74	3.15	3.16	6.31
NE 21 X NE 55	13.68	1.43	3.80	11.07	0.81	4.19	1.35	5.53
MU 20B X NE 36	12.42	2.28	1.53	10.51	0.85	4.18	1.36	5.53
WC 48A X WC 27	12.28	4.31	1.31	9.47	0.77	3.78	1.62	5.40
MU 20B X WC 27	10.53	2.28	1.31	8.73	0.83	3.77	1.34	5.11
2392 X Eberlat*NE 51	10.95	1.99	4.67	7.62	0.70	3.23	1.80	5.02
SECOW 5T X Ayiyi	11.66	2.78	2.49	9.02	0.77	3.70	1.33	5.02
KVU 271 X WC 27	9.19	1.38	1.31	7.84	0.85	3.62	1.37	4.99

Table 2. Contd.

MU 9 X NE 55	11.55	1.17	5.09	8.41	0.73	3.47	1.49	4.95
Ayiyi X WC 66	11.25	2.49	0.86	9.58	0.85	4.00	0.92	4.92
Danila X KVU 271	9.24	1.71	1.38	7.70	0.83	3.55	1.00	4.55
2392 X Sanzi	9.83	1.99	1.12	8.28	0.84	3.70	0.77	4.47
NE 5 X 2392	7.98	2.05	1.99	5.96	0.75	2.95	1.49	4.44
NE 55 X NE 5	11.62	3.80	2.05	8.70	0.75	3.57	0.74	4.32
Danila X Eberlat*NE 51	10.24	1.71	4.67	7.06	0.69	3.09	1.22	4.31
WC 48A X 2392	14.94	4.31	1.99	11.79	0.79	4.27	-0.06	4.21
SECOW 2W X Eberlat*NE 51	7.43	1.34	4.67	4.42	0.60	2.27	1.93	4.20
MU 15 X WC 64	8.48	2.14	1.19	6.82	0.80	3.28	0.86	4.14
SECOW 5T X 3306	10.14	2.78	2.28	7.61	0.75	3.35	0.61	3.95
WC 63 X MU 9	6.81	1.36	1.17	5.55	0.81	2.98	0.84	3.82
Danila X NE 5	5.73	1.71	2.05	3.85	0.67	2.25	1.36	3.61
Danila X VCR 1432	7.93	1.71	2.21	5.97	0.75	2.97	0.64	3.60
WC 63 X NE 48	6.71	1.36	3.04	4.51	0.67	2.44	1.13	3.57
WC 64 X SECOW 4W	7.70	1.19	1.98	6.11	0.79	3.08	0.46	3.55
3306 X Eberlat*NE 51	8.07	2.28	4.67	4.60	0.57	2.27	1.25	3.52
NE 21 X MU 20B	10.73	1.43	2.28	8.87	0.83	3.79	-0.38	3.41
WC 63 X SECOW 4W	6.22	1.36	1.98	4.55	0.73	2.55	0.80	3.35
2392 X NE 5	6.58	1.99	2.05	4.56	0.69	2.49	0.83	3.31
NE 5 X KVU 271	6.04	2.05	1.38	4.32	0.72	2.46	0.83	3.29
Ayiyi X IT 889	5.26	2.49	1.61	3.21	0.61	1.96	1.32	3.28
3306 X Ayiyi	5.38	2.28	2.49	3.00	0.56	1.81	1.45	3.26
VCR1432 X WC 27	7.66	2.21	1.31	5.90	0.77	2.98	0.27	3.26
NE 21 X WC 48A	4.83	1.43	4.31	1.96	0.41	1.25	1.98	3.23
WC 48A X WC 66	8.44	4.31	0.86	5.86	0.69	2.82	0.38	3.20
WC 66 X MU 9	6.59	0.86	1.17	5.58	0.85	3.04	0.11	3.15
NE 55 X MU 9	7.61	3.80	1.17	5.13	0.67	2.60	0.49	3.10
MU 15 X Eberlat*NE 51	6.65	2.14	4.67	3.24	0.49	1.76	1.31	3.07
WC 64 X 3306	5.46	1.19	2.28	3.73	0.68	2.23	0.83	3.06
SECOW 2W X SECOW 4W	6.40	1.34	1.98	4.74	0.74	2.62	0.34	2.96
Eberlat*NE 51 X Ayiyi	7.84	4.67	2.49	4.26	0.54	2.13	0.80	2.93
2392 X NE 21	7.44	1.99	1.43	5.73	0.77	2.94	-0.03	2.91
Sanzi X NE 36	4.74	1.12	1.53	3.41	0.72	2.20	0.70	2.90
NE 55 X Danila	5.68	3.80	1.71	2.93	0.52	1.72	1.12	2.84
Eberlat*NE 51 X KVU 271	6.84	4.67	1.38	3.82	0.56	2.04	0.72	2.76
Eberlat*NE 51 X 2392	7.80	4.67	1.99	4.47	0.57	2.24	0.41	2.65
NE 55 X MU 20B	5.14	3.80	2.28	2.10	0.41	1.30	1.35	2.65
Ayiyi X SECOW 2W	7.64	2.49	1.34	5.72	0.75	2.90	-0.32	2.57
WC 27 X VCR1432	5.00	1.31	2.21	3.24	0.65	2.03	0.49	2.52
WC 64 X WC 27	3.31	1.19	1.31	2.06	0.62	1.59	0.87	2.45
SECOW 5T X SECOW 4W	6.08	2.78	1.98	3.70	0.61	2.10	0.29	2.39
WC 64 X NE 36	4.38	1.19	1.53	3.02	0.69	2.02	0.33	2.35
WC 64 X 2392	5.39	1.19	1.99	3.80	0.71	2.29	0.05	2.35
IT 889 X SECOW 2W	5.65	1.61	1.34	4.18	0.74	2.46	-0.21	2.25
SECOW 2W X Sanzi	5.88	1.34	1.12	4.65	0.79	2.68	-0.57	2.11
WC 66 X Danila	4.41	0.86	1.71	3.13	0.71	2.08	-0.02	2.06
MU 20B X 3306	4.49	2.28	2.28	2.21	0.49	1.46	0.55	2.01
NE 36 X Eberlat*NE 51	5.37	1.53	4.67	2.27	0.42	1.37	0.63	2.00
NE 21 X Ayiyi	4.79	1.43	2.49	2.83	0.59	1.81	0.15	1.96
NE 5 X MU 9	5.46	2.05	1.17	3.84	0.70	2.30	-0.35	1.95
IT 889 X WC 27	5.71	1.61	1.31	4.25	0.74	2.49	-0.56	1.93

Table 2. Contd.

NE 55 X WC 63	3.78	3.80	1.36	1.21	0.32	0.87	1.05	1.92
Ayiyi X Danila	5.58	2.49	1.71	3.48	0.62	2.06	-0.15	1.92
Sanzi X WC 27	4.54	1.12	1.31	3.32	0.73	2.19	-0.35	1.83
Danila X 2392	4.89	1.71	1.99	3.04	0.62	1.92	-0.18	1.74
SECOW 5T X 2392	4.68	2.78	1.99	2.30	0.49	1.49	0.24	1.72
SECOW 4W X VCR1432	4.93	1.98	2.21	2.83	0.57	1.79	-0.29	1.50
KVU 271 X 2392	4.44	1.38	1.99	2.75	0.62	1.83	-0.35	1.48
3306 X WC 66	5.08	2.28	0.86	3.51	0.69	2.18	-0.73	1.45
Eberlat*NE 51 X MU 15	6.91	4.67	2.14	3.50	0.51	1.87	-0.47	1.40
WC 48A X SECOW 2W	5.89	4.31	1.34	3.07	0.52	1.77	-0.39	1.38
MU 9 X NE 48	3.79	1.17	3.04	1.68	0.44	1.21	0.15	1.36
MU 9 X NE 5	4.26	1.17	2.05	2.65	0.62	1.80	-0.45	1.34
3306 X MU 9	4.67	2.28	1.17	2.94	0.63	1.91	-0.59	1.32
MU 15 X Ayiyi	3.11	2.14	2.49	0.79	0.25	0.63	0.67	1.30
WC 64 X NE 5	4.33	1.19	2.05	2.71	0.63	1.82	-0.65	1.17
NE 5 X 3306	3.77	2.05	2.28	1.60	0.43	1.16	-0.04	1.12
WC 63 X NE 36	3.60	1.36	1.53	2.15	0.60	1.59	-0.48	1.11
WC 48A X NE 48	5.54	4.31	3.04	1.87	0.34	1.11	-0.04	1.07
KVU 271 X NE 21	3.83	1.38	1.43	2.42	0.63	1.73	-0.68	1.05
NE 5 X WC 64	2.95	2.05	1.19	1.33	0.45	1.08	-0.10	0.99
NE 55 X Sanzi	4.65	3.80	1.12	2.19	0.47	1.42	-0.47	0.95
WC 64 X SECOW 5T	3.37	1.19	2.78	1.39	0.41	1.06	-0.16	0.90
KVU 271 X NE 36	4.72	1.38	1.53	3.27	0.69	2.10	-1.24	0.87
IT 889 X 2392	5.43	1.61	1.99	3.64	0.67	2.18	-1.34	0.84
Danila X WC 48A	3.90	1.71	4.31	0.89	0.23	0.63	0.11	0.74
MU 20B X NE 21	4.34	2.28	1.43	2.48	0.57	1.67	-0.92	0.74
WC 27 X Sanzi	3.87	1.31	1.12	2.66	0.69	1.89	-1.27	0.62
MU 20B X MU 15	3.48	2.28	2.14	1.27	0.36	0.95	-0.38	0.57
3306 X NE 5	4.15	2.28	2.05	1.99	0.48	1.37	-0.80	0.57
NE 5 X IT 889	5.02	2.05	1.61	3.20	0.64	2.00	-1.55	0.45
Eberlat*NE 51 X WC 27	3.56	4.67	1.31	0.58	0.16	0.43	0.01	0.44
NE 55 X WC 48A	4.16	3.80	4.31	0.11	0.03	0.07	0.33	0.40
SECOW 4W X MU 20B	3.22	1.98	2.28	1.09	0.34	0.85	-0.48	0.37
Danila X NE 55	4.99	1.71	3.80	2.24	0.45	1.40	-1.10	0.31
NE 55 X NE 36	3.60	3.80	1.53	0.94	0.26	0.69	-0.42	0.27
MU 15 X MU 20B	3.32	2.14	2.28	1.10	0.33	0.85	-0.61	0.24
WC 27 X WC 48A	4.07	1.31	4.31	1.27	0.31	0.88	-0.66	0.22
WC 27 X IT 889	3.59	1.31	1.61	2.13	0.59	1.58	-1.37	0.21
2392 X WC 63	3.26	1.99	1.36	1.58	0.49	1.23	-1.07	0.16
SECOW 5T X Eberlat*NE 51	4.26	2.78	4.67	0.53	0.13	0.36	-0.21	0.15
WC 27 X WC 63	2.27	1.31	1.36	0.94	0.41	0.87	-0.76	0.11
WC 66 X 2392	2.62	0.86	4.80	-0.21	-0.08	-0.17	0.26	0.09
SECOW 4W X MU 9	3.49	1.98	1.17	1.91	0.55	1.43	-1.35	0.08
Eberlat*NE 51 X MU 20B	5.77	4.67	2.28	2.29	0.40	1.34	-1.41	-0.07
Sanzi X 2392	2.53	1.12	1.99	0.97	0.39	0.86	-0.94	-0.08
WC 66 X NE 5	3.32	0.86	2.05	1.87	0.56	1.43	-1.53	-0.10
NE 55 X SECOW 2W	3.74	3.80	1.34	1.17	0.31	0.85	-0.96	-0.12
WC 64 X NE 21	3.03	1.19	1.43	1.72	0.57	1.38	-1.51	-0.13
WC 27 X Eberlat*NE 51	3.71	1.31	4.67	0.72	0.19	0.52	-0.70	-0.18
NE 21 X MU 9	2.42	1.43	1.17	1.12	0.46	1.01	-1.22	-0.22
VCR1432 X WC 66	2.44	2.21	0.86	0.90	0.37	0.81	-1.07	-0.26
WC 48A X IT 889	2.96	4.31	1.61	0.01	0.00	0.00	-0.35	-0.35

Table 2. Contd.

VCR1432 X 2392	2.32	2.21	1.99	0.22	0.10	0.20	-0.56	-0.36
NE 48 X SECOW 5T	3.04	3.04	2.78	0.13	0.04	0.11	-0.53	-0.42
Sanzi X NE 21	1.88	1.12	1.43	0.61	0.32	0.62	-1.08	-0.46
2392 X WC 48A	2.78	1.99	4.31	-0.37	-0.13	-0.31	-0.29	-0.60
WC 27 X MU 20B	2.88	1.31	2.28	1.08	0.38	0.89	-1.51	-0.62
WC 66 X NE 55	2.41	0.86	3.80	0.08	0.03	0.07	-0.74	-0.66
NE 21 x Eberlat*NE 51	4.09	1.43	4.67	1.05	0.26	0.72	-1.55	-0.82
Ayiyi X MU 9	2.53	2.49	1.17	0.69	0.27	0.61	-1.46	-0.85
NE 21 X NE 5	1.58	1.43	2.05	-0.16	-0.10	-0.18	-0.74	-0.92
MU 9 X MU 20B	2.79	1.17	2.28	1.07	0.38	0.89	-1.83	-0.94
KVU 271 X NE 55	2.86	1.38	3.80	0.27	0.09	0.22	-1.23	-1.00
MU 20B X NE 55	3.59	2.28	3.80	0.55	0.15	0.40	-1.48	-1.08
MU 20B X 2392	2.53	2.28	1.99	0.39	0.16	0.35	-1.48	-1.13
WC 48A X MU 9	2.45	4.31	1.17	-0.29	-0.12	-0.26	-0.98	-1.24
NE 48 X Ayiyi	3.18	3.04	2.49	0.41	0.13	0.32	-1.66	-1.34
WC 63 X 2392	1.81	1.36	1.99	0.14	0.08	0.14	-1.77	-1.63
Eberlat*NE 51 X NE 48	2.20	4.67	3.04	-1.65	-0.75	-1.56	-0.19	-1.75
WC 64 X NE 55	1.62	1.19	3.80	-0.87	-0.54	-0.96	-1.75	-2.71
MU 9 X NE 36	1.10	1.17	1.53	-0.25	-0.23	-0.34	-2.49	-2.82
MU 20B X SECOW 5T	1.23	2.28	2.78	-1.30	-1.06	-1.64	-2.72	-4.36

Table 3. Estimated base selection index values of the evaluated populations.

Genotype	Virus	Thrips	Scab-a[1]	Scab-b[2]	PedNo[3]	PodNo[4]	Yield	BSI-a[5]	BSI-b[6]
WC 48A X 2392	-0.33	-3.97	-3.30	-1.56	6.01	9.74	19.70	35.45	44.61
NE 5 X Sanzi	-3.93	-6.12	-2.87	-1.51	8.11	10.52	9.67	28.31	42.74
Danila X NE 48	-1.23	-2.67	-2.44	-1.54	4.61	6.54	13.16	24.31	32.18
NE 36 X 2392	0.82	-4.69	-2.53	-0.93	4.38	8.03	10.70	23.10	30.43
Danila X VCR 1432	0.01	-6.35	0.53	-1.56	3.29	5.34	11.55	20.19	27.55
NE 5 X 2392	-3.40	1.35	-2.86	-1.22	1.42	3.34	14.47	19.23	25.35
NE 55	-4.81	-3.31	-2.48	-0.32	2.15	4.72	7.49	14.37	25.28
Ayiyi X 2392	-3.40	1.81	-1.20	-1.59	5.87	5.90	7.68	19.44	23.81
SECOW 5T X Ayiyi	0.87	-0.58	-2.86	-1.49	4.45	6.31	7.58	18.34	22.39
MU 20B X NE 36	-4.73	-1.12	-0.32	-1.51	3.56	4.93	4.92	13.41	21.09
WC 48A	-0.32	0.77	-2.93	-1.54	2.19	2.71	10.36	15.26	19.28
2392 X Eberlat*NE 51	2.00	-7.84	-1.20	0.34	4.38	7.59	-0.32	11.65	18.35
Danila X NE 5	-3.80	0.70	-2.43	-0.88	1.96	2.59	6.68	11.23	17.63
3306 X Ayiyi	-1.71	0.00	-1.20	-1.53	1.51	2.78	8.68	12.97	17.41
WC 64 X 3306	-1.44	-5.13	-1.11	-0.89	1.54	1.90	4.58	8.02	16.58
Danila X KVU271	-1.44	-0.09	-1.54	-1.48	1.65	1.68	7.73	11.05	15.60
Danila X Eberlat*NE 51	-1.68	-2.85	0.46	-0.89	2.50	3.50	3.76	9.76	14.72
WC 27 X VCR 1432	-1.71	-6.03	0.04	-0.95	3.45	5.36	-3.30	5.50	14.16
2392	0.31	-3.13	-1.29	-0.87	-0.13	0.24	8.91	9.03	14.01
NE 55 X MU 20B	-1.00	0.37	-2.43	-0.11	2.85	3.91	4.02	10.78	13.97
MU 15 X WC 64	-0.36	-6.16	-1.20	-0.90	0.30	2.08	2.73	5.11	13.74
2392 X Sanzi	0.24	-6.04	-1.23	-1.53	2.13	3.15	-0.14	5.14	13.69
WC 63 X NE 48	-1.54	0.35	0.07	-1.54	0.87	2.01	7.82	10.70	13.36
MU 20B X WC 27	1.66	-4.25	-0.79	-0.88	1.49	2.68	4.50	8.67	12.92
3306 X Eberlat*NE 51	-2.69	-2.29	-0.85	2.72	3.30	4.94	1.42	9.66	12.77

Table 3. Contd.

NE 21 X Ayiyi	-1.54	-2.45	-2.10	-0.32	0.93	2.50	2.82	6.24	12.65
Sanzi X NE 36	-1.10	-1.97	-3.41	-0.87	1.10	1.77	2.36	5.23	12.58
NE 5 X WC 64	-0.33	-8.59	-0.77	-0.28	-0.46	-0.90	3.75	2.40	12.37
NE 21 X NE 55	-1.29	0.64	-2.58	-0.92	1.50	2.91	3.59	8.00	12.17
MU 15 X Eberlat*NE 51	1.59	-4.99	0.13	-0.32	2.53	3.61	2.38	8.52	12.10
Ayiyi X WC 66	-2.03	-0.56	3.15	-0.90	1.68	2.98	6.89	11.55	11.90
NE 21 X WC 48A	-1.83	2.22	0.10	0.33	2.21	3.33	6.75	12.29	11.46
WC 48A X WC 27	0.40	-1.60	-2.93	2.13	1.13	0.51	7.81	9.45	11.45
SECOW 2W X Eberlat*NE 51	-0.47	5.34	-1.65	-0.91	1.89	5.67	5.58	13.13	10.81
SECOW 5T X 3306	-1.77	-1.08	0.96	-0.95	0.16	0.33	6.39	6.88	9.72
MU 9 X NE 55	-1.23	1.16	1.86	-0.31	2.73	3.29	4.71	10.73	9.24
MU 15 X Ayiyi	-2.79	-0.98	0.61	-0.27	1.22	1.37	3.23	5.82	9.24
2392 X NE 5	2.27	-2.19	0.13	-0.90	1.76	3.11	3.60	8.47	9.16
NE 55 X NE 5	-1.10	-2.66	-0.69	-0.27	1.79	0.74	1.72	4.25	8.97
MU 20B X 3306	-2.35	-1.74	-0.33	-0.34	1.01	0.87	1.55	3.43	8.18
WC 66 X MU 9	-2.71	-1.69	-0.32	-0.95	0.00	0.51	1.69	2.20	7.87
WC 48A X NE 48	-3.38	0.68	-0.43	-0.33	1.14	1.17	1.55	3.86	7.32
NE 55 X Danila	-1.04	0.00	0.54	-0.29	1.34	2.12	2.39	5.85	6.64
NE 55 X MU 9	-0.68	0.68	-1.73	0.28	0.65	1.43	2.89	4.97	6.42
SECOW 5T X SECOW 4W	-0.34	-2.68	-0.86	0.89	0.42	-0.48	3.41	3.34	6.34
Ayiyi	-2.92	-1.64	0.12	0.30	-0.03	-0.20	2.24	2.01	6.14
WC 63 X SECOW 4W	0.21	0.86	-1.65	-0.30	0.25	0.47	4.19	4.91	5.78
KVU271 X WC 27	0.65	1.35	0.08	0.32	0.14	1.63	6.37	8.15	5.75
Eberlat*NE 51 X KVU271	-0.76	-5.00	-0.41	0.25	1.53	2.66	-4.37	-0.18	5.75
SECOW 2W X SECOW 4W	0.12	-2.20	1.43	-0.92	1.23	2.73	0.02	3.99	5.57
NE 55 X WC 63	-1.97	-2.72	2.63	0.91	0.56	0.90	2.40	3.86	5.01
NE 36 X Eberlat*NE 51	0.93	-0.94	0.02	0.25	1.60	2.84	0.72	5.17	4.92
NE 5 X KVU 271	-0.66	1.89	0.61	-1.49	1.66	2.10	1.04	4.81	4.46
Eberlat*NE 51 X Ayiyi	-0.76	4.06	0.09	0.30	2.39	3.78	1.98	8.15	4.45
WC 27 XWC 63	-1.67	-5.56	0.07	-0.90	-1.27	-1.66	-1.02	-3.94	4.12
NE 5 X MU 9	-0.43	-4.92	-1.61	0.91	-0.63	-0.75	-0.90	-2.28	3.78
2392 X NE 21	2.38	-2.03	-0.69	-0.32	0.17	1.20	1.33	2.69	3.36
WC 63 X MU 9	0.99	0.14	0.04	0.29	0.14	0.34	4.14	4.62	3.17
WC 66 X Danila	-2.84	2.22	-1.63	-0.88	-0.46	-0.64	1.09	-0.01	3.11
SECOW 2W X Sanzi	0.59	-0.85	0.50	0.30	0.75	2.21	0.67	3.63	3.10
VCR 1432 X WC 27	0.99	0.23	-1.66	-0.90	0.10	-0.21	1.65	1.54	2.88
NE 55 X WC 48A	-1.11	0.68	0.08	0.93	0.71	-0.16	2.72	3.27	2.69
WC 64 X WC 27	1.90	1.43	-0.78	-0.30	0.07	0.75	4.10	4.92	2.67
Danila X WC48 A	0.12	0.46	-1.54	-0.26	0.56	-0.16	0.62	1.01	2.24
WC 48A X WC 66	-2.79	2.97	0.02	1.47	0.57	1.23	2.07	3.87	2.19
Eberlat*NE 51 X NE 48	0.25	-1.00	-1.65	-0.31	0.53	0.10	-1.75	-1.13	1.58
WC 64 X SECOW 4W	-0.36	2.47	-1.66	-0.30	-0.56	-0.21	2.50	1.72	1.57
IT 889 X SECOW 2W	1.16	-1.89	0.07	0.29	-0.36	0.63	0.80	1.07	1.43
WC 27 X Eberlat*NE 51	2.38	1.33	-0.69	-0.27	-1.12	-0.69	5.87	4.06	1.32
Ayiyi X SECOW 2W	-1.88	-0.21	0.88	-0.32	0.31	-0.05	-0.54	-0.28	1.25
Ayiyi X IT 889	0.69	2.45	1.48	-0.90	0.52	-0.11	4.30	4.71	1.00
MU 9 X NE 48	-1.10	3.41	-0.31	-0.34	1.17	0.61	0.28	2.06	0.40
WC 64 X NE 36	0.35	0.77	0.61	-0.27	0.37	0.90	0.40	1.67	0.21
WC 63 X NE 36	-0.87	-0.21	-0.79	-0.32	-1.07	-1.45	0.53	-1.99	0.21
Eberlat*NE 51	-6.44	-8.40	4.39	3.05	-3.21	-3.75	-0.36	-7.32	0.08
WC 64 X 2392	1.21	-0.58	-2.60	0.35	0.27	0.67	-2.69	-1.75	-0.14

Table 3. Contd.

NE 21 X MU 20B	2.28	0.74	2.63	-0.36	0.90	1.72	2.19	4.82	-0.46
3306 X NE 5	-0.32	1.33	0.61	-0.27	0.22	-0.41	1.07	0.88	-0.47
MU 20B X NE 21	-1.77	0.74	-3.02	-0.28	-0.84	-1.44	-2.63	-4.91	-0.57
Eberlat*NE 51 X 2392	1.60	0.04	1.91	0.34	1.67	1.89	-0.25	3.31	-0.58
3306	0.68	-1.08	-1.23	-0.29	-1.40	-1.67	0.48	-2.59	-0.68
NE 5 X 3306	-0.32	0.77	-0.69	-0.27	-0.24	-0.53	-0.47	-1.25	-0.73
Sanzi	-0.77	-6.04	1.09	0.32	0.14	-0.77	-5.60	-6.23	-0.83
SECOW 5T X 2392	-1.20	0.90	1.33	0.35	1.27	1.00	-1.75	0.52	-0.86
NE 48	-1.04	2.80	-1.73	-0.90	-0.29	-0.60	-0.99	-1.88	-1.00
KVU 27-1 X NE 36	-1.44	-1.64	-0.78	-0.31	-1.17	-1.67	-2.40	-5.25	-1.08
WC 48A X IT 889	-0.58	1.57	0.44	-0.31	0.25	-1.03	0.40	-0.38	-1.50
MU 9 X NE 5	-1.35	1.24	-0.84	-0.29	-0.62	-1.18	-1.21	-3.01	-1.76
WC 64 X NE 5	-3.04	3.48	-2.93	0.35	-0.99	-1.30	-1.84	-4.12	-1.98
WC 64 X SECOW 5T	-0.34	0.68	3.04	-0.11	0.09	0.75	0.39	1.23	-2.04
WC 48A XSECOW 2W	0.58	2.29	-2.48	-0.93	0.40	-0.79	-2.19	-2.58	-2.05
WC 66 X NE 55	-0.70	-6.72	-0.76	0.91	-3.17	-4.10	-2.19	-9.46	-2.19
NE 55 X Sanzi	-0.01	-2.12	1.31	0.28	-0.49	-0.96	-1.28	-2.73	-2.19
3306 X WC 66	-1.44	-0.94	0.46	0.22	-0.15	-1.01	-2.79	-3.96	-2.27
KVU 27-1 X 2392	-0.62	1.76	-2.58	-0.31	-1.14	-1.46	-1.84	-4.44	-2.68
Sanzi X NE 21	-1.10	-2.89	-2.41	0.91	-1.38	-2.19	-5.19	-8.76	-3.27
Ayiyi X Danila	-0.66	1.89	-0.26	2.18	-0.02	-0.36	-0.02	-0.40	-3.55
SECOW 4W X VCR 1432	0.77	-1.79	0.01	-0.31	-1.11	2.68	-6.98	-5.41	-4.09
NE 21 X NE 5	-0.43	0.15	-1.20	0.34	-0.85	-0.62	-3.93	-5.40	-4.27
Sanzi X WC 27	-0.68	1.12	1.41	0.33	0.02	0.05	-2.30	-2.22	-4.39
WC 66 X 2392	2.17	1.34	-1.12	0.94	0.81	-0.26	-2.04	-1.48	-4.81
Danila X NE 55	2.61	1.82	-2.43	-0.27	-1.39	-3.17	1.15	-3.41	-5.15
SECOW 5T X Eberlat*NE 51	-0.36	2.47	-1.66	0.32	-1.33	-1.79	-1.49	-4.62	-5.38
KVU 27-1 X NE 21	-1.37	0.23	-0.35	-0.90	-2.62	-3.15	-2.01	-7.79	-5.38
2392 X WC 48A	3.80	-1.79	1.82	0.32	0.26	-1.03	-0.76	-1.52	-5.68
WC 48A X MU 9	1.26	1.16	-1.98	0.91	-1.56	-2.13	-1.53	-5.22	-6.57
WC 64	-0.89	1.02	-1.57	-0.87	-2.33	-4.02	-2.56	-8.91	-6.60
NE 48 X SECOW 5T	-1.04	-0.43	0.90	2.10	-2.00	-2.95	-0.30	-5.25	-6.79
WC 27 XWC 48A	1.78	2.13	-0.43	0.92	-0.32	-1.20	-0.92	-2.44	-6.84
3306 X MU 9	-0.33	-0.61	3.93	0.89	-0.58	-1.15	-1.27	-3.00	-6.87
VCR 1432 X WC 66	0.92	-3.21	1.91	-0.88	-0.96	-1.41	-5.79	-8.15	-6.90
KVU 27-1 X NE 55	0.93	-2.07	-0.67	0.25	-1.79	-2.43	-4.70	-8.92	-7.36
Eberlat*NE 51 X WC 27	3.96	0.15	1.04	1.57	0.72	1.71	-3.14	-0.71	-7.42
NE 5	-0.47	0.30	-0.33	-0.91	-2.09	-2.21	-4.64	-8.93	-7.54
KVU 27-1	1.41	1.20	-1.28	-0.31	-2.10	-2.82	-1.92	-6.84	-7.85
NE 55 X NE 36	-1.44	4.06	0.52	-1.49	-0.62	-0.94	-4.88	-6.44	-8.09
MU 20B X MU 15	2.14	-0.10	0.19	-0.26	-1.09	-2.10	-3.10	-6.29	-8.26
SECOW 4W	-0.92	2.13	0.01	0.31	-0.92	-2.53	-3.34	-6.79	-8.31
Eberlat*NE 51 X MU 20B	1.93	-0.85	3.58	-0.90	-1.54	-1.07	-1.95	-4.57	-8.32
VCR 1432 X 2392	7.68	-2.53	-2.54	0.92	-0.86	-0.70	-3.45	-5.01	-8.53
VCR 1432	-0.33	-2.99	3.57	1.55	-0.77	-1.45	-5.14	-7.36	-9.15
Sanzi X2392	3.04	-1.17	0.89	-0.34	-0.64	-0.94	-5.41	-6.99	-9.42
IT 889	0.25	0.04	-1.23	-0.31	-2.90	-4.05	-3.76	-10.71	-9.46
NE 48 X Ayiyi	0.68	1.49	-1.20	-0.90	-2.15	-3.74	-3.58	-9.46	-9.54
NE 55 X SECOW 2W	0.33	3.91	-0.32	0.37	-0.88	-1.30	-3.79	-5.97	-10.27
Danila X 2392	4.59	2.78	0.54	0.27	0.54	0.39	-3.29	-2.37	-10.55
2392 X WC 63	1.02	0.60	1.37	-0.29	-1.75	-2.36	-3.84	-7.95	-10.66
NE 21 X Eberlat*NE 51	0.92	2.71	0.04	-0.26	-1.17	-1.65	-4.59	-7.41	-10.82

Table 3. Contd.

MU 15 X MU 20B	2.00	2.93	-0.69	0.27	-1.67	-1.87	-2.90	-6.44	-10.95
SECOW 4W X MU 20B	0.48	5.26	2.78	0.95	-0.81	-0.99	-0.32	-2.12	-11.60
WC 27 X IT 889	1.81	1.58	-1.11	-0.26	-1.63	-2.85	-5.28	-9.76	-11.78
NE 21 X MU 9	1.93	1.26	-0.78	-0.11	-1.67	-3.15	-4.74	-9.55	-11.85
WC 66 X NE 5	-0.68	-0.01	2.19	0.94	-1.88	-2.98	-4.87	-9.72	-12.16
NE 5 X IT 889	-1.02	6.16	0.55	-0.90	-1.57	-2.75	-3.60	-7.92	-12.71
IT 889 X WC 27	3.35	2.93	3.51	0.88	-0.83	-1.63	0.34	-2.11	-12.79
SECOW 5T	1.47	-0.99	1.47	0.35	-2.24	-3.55	-5.04	-10.83	-13.13
WC 27	4.02	0.79	0.52	0.32	-2.75	-3.44	-2.05	-8.24	-13.88
WC 64 X NE 21	-0.22	4.52	0.12	0.29	-2.16	-2.68	-4.76	-9.61	-14.32
WC 27 X MU 20B	3.16	1.58	1.49	-0.90	-1.83	-3.14	-4.04	-9.01	-14.33
WC 66	1.93	2.94	-0.26	-0.27	-2.48	-4.32	-3.61	-10.41	-14.76
SECOW 2W	-1.88	0.78	3.58	0.91	-1.91	-3.61	-6.00	-11.52	-14.91
SECOW 4W X MU 9	1.34	3.35	0.98	-0.28	-1.92	-3.77	-4.03	-9.71	-15.09
MU 15	2.03	4.52	-1.67	1.55	-1.83	-3.40	-3.49	-8.72	-15.16
IT 889 X 2392	4.63	1.23	0.08	0.96	-1.41	-2.34	-5.10	-8.85	-15.75
WC 27 X Sanzi	2.71	-0.61	3.07	1.50	0.19	-1.02	-8.58	-9.41	-16.07
MU 9 X MU 20B	-1.34	4.98	0.61	0.32	-1.67	-2.98	-7.15	-11.80	-16.37
Eberlat*NE 51 X MU 15	1.60	2.42	2.24	1.52	-0.69	-0.43	-7.60	-8.71	-16.49
Danila	-1.59	1.57	3.51	2.72	-1.83	-2.90	-6.78	-11.51	-17.71
WC 63	1.81	4.05	0.61	-0.26	-3.12	-4.42	-4.56	-12.10	-18.30
WC 64 X NE 55	1.70	3.57	-0.69	0.94	-2.51	-3.43	-7.53	-13.47	-18.99
MU 20B X 2392	1.32	4.48	1.76	0.91	-2.56	-3.51	-5.74	-11.82	-20.29
Ayiyi X MU 9	2.51	5.39	1.37	0.90	-2.25	-3.30	-5.41	-10.96	-21.14
MU 20B	1.02	3.96	2.24	1.55	-2.55	-4.37	-6.31	-13.23	-22.00
MU 9 X NE 36	3.39	4.69	0.04	0.91	-3.88	-4.89	-7.07	-15.84	-24.86
MU 9	0.46	2.70	1.54	2.79	-3.53	-5.66	-8.25	-17.44	-24.93
WC 63 X 2392	2.27	1.59	7.04	2.13	-1.72	-3.34	-7.22	-12.28	-25.32
MU 20B X NE 55	0.12	1.72	6.97	2.15	-3.00	-3.95	-7.74	-14.70	-25.65
NE 21	1.13	3.26	5.74	2.18	-2.99	-4.29	-7.71	-14.98	-27.30
MU 20B X SECOW 5T	3.13	6.61	7.45	-0.31	-3.81	-5.69	-9.33	-18.82	-35.71

[1]Scab on leaf, [2]Scab on pod, [3]Number of peduncles, [4]Number of pods, [5]Base Selection Index for yield and its components, [6]Base Selection Index for Grain Yield.