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ISSN: 0975-928X

Volume: 10

Number:1

EJPB (2019) 10(1):177-186

DOI: 10.5958/0975-928X.2019.00021.8

https://ejplantbreeding.org

Electronic Journal of Plant Breeding, 10 (1): 177 – 186 (Mar 2019) DOI: 10.5958/0975-928X.2019.00021.8
ISSN 0975-928X

Research Article

Multivariate analysis based on drought tolerance indices for screening drought tolerance in common bean (*Phaseolus vulgaris* L.)

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(Received: 27 Apr 2018; Revised: 18 Jan 2019; Accepted: 8 Feb 2019)

Abstract
Twenty common bean (*Phaseolus vulgaris* L.) genotypes were evaluated based on drought tolerance indices through principal component analysis. All the indices were positively correlated with each other with the exception of drought susceptibility index, which was negatively correlated with all other indices used in the study. The first PC that accounted for 73.01 % of variation, and indices such as yield (non-stress), yield (stress), geometric mean (GM), harmonic mean (HM), drought resistance index(DRI), coefficient of drought resistance (CDR), drought tolerance index (DTI) and relative drought index (RDI) were related to tolerance and percent reduction and DSI were related to susceptibility. The genotypes with higher component scores of PC1 *viz.*, WB-1634 (1.97), WB-341 (1.371), WB-185 (1.268) and WB-451 (1.253) are also tolerant to drought. The Biplot of PC1 and PC2 also revealed WB-1634 as tolerant, whereas genotypes WB-6, WB-1587 and SR-1 as susceptible to drought.

Keywords
Common bean, drought stress, PCA, tolerance indices

Introduction

Drought invariably is a major stress causing significant crop losses in common bean (*Phaseolus vulgaris* L.) and reducing average yields by about 50-60% (Zlatev and Yardonova, 2005, Beebe *et al.*, 2008). Breeding for drought tolerant bean genotypes is a practical and economically viable approach to lessen the negative effects of drought on the productivity of the crops as modification of microclimate is not practically feasible. Breeding for drought tolerance involves combining good yield potential in optimum conditions and the selection of high heritable traits related to drought tolerance (Bennani *et al*, 2016). Yield, undoubtedly, is the principal selection index used under drought stress conditions. However, the yield is a complex polygenic trait and the genes are located differently from those controlling drought (Blum, 1998). Thus, the selection efficiency could be improved if particular physiological and/or morphological attributes related to yield under a stress environment could be identified as selection criteria for complementing conventional breeding (Acevedo, 1991). Genetic improvement of crops for drought tolerance requires a search for possible relationship between agronomic, morphologic and physiological traits and grain yield (Jatoi *et al.*, 2011). These traits should be highly heritable, greatly correlated with stress tolerance and can be easily assessed. Thus the correlations and principal components analysis are used to distinguish significant relationships between traits. Whereas, the correlation coefficient measures the mutual association between a pair of variables independent of the other variables, the principal components analysis is a multivariate analysis method that aims to explain the correlation between a set of variables in terms of small number of underlying independent factors (Baheshtizadeh *et al*, 2013).

The principal component analysis (PCA), one of multivariate analysis methods elucidates among a set of the traits which ones are decisive in genotypic differentiation (Kovacic, 1994). PCA enables easier understanding of impacts and connections among different traits by identifying them and explaining their roles. This method is a powerful multiple method to apply for evaluating yield component (Guertin and Bailey, 1982), identify biological relationships among traits (Acquaah *et al.*, 1992), decrease associated-traits to a few factors (Johnson and Wichern, 1996) and description of correlations among variables.

Physiological and agronomic definitions of drought tolerance differ distinctly; the first stipulates that under drought, tolerant plants remain viable and produce viable seeds, while the second requires sufficient plant growth to produce an economically significant yield. The desirable attributes related to physiological parameters have relevance only when they are translated into higher yield. Therefore various indices based on seed yield have been used to assess the differential response of genotypes to water stress in terms of differential yielding abilities. Schneider *et al.* (1997) and Rosales-Serna *et al*. (2004) suggested that drought resistant lines can be reliably identified using seed yield and drought tolerance indices as selection criteria. Teran and Singh (2002) used geometric mean (GM), percent reduction (PR) and drought susceptibility index (DSI) for yield estimates of drought resistance. Similarly Ramirez- and Kelly (1998) used geometric mean and drought susceptibility index to evaluate the association of specific phenological and physiological traits with resistance to drought in common bean. The present study was undertaken to identify effective drought tolerant indices for screening drought tolerance in common bean (*Phaseolus vulgaris* L.).

Material and Methods

Twenty genotypes of common bean were evaluated in green house conditions at Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir (SKUAST-Kashmir). The experiment was conducted under ambient temperature to prevent the confounding effects on account of heat stress. The genotypes used were selected on the basis of their performance in the yield screening trials and represented diverse market classes in terms of use category, growth habits and seed characteristics. Out of 20 genotypes, 14 were bush determinate and six were indeterminate pole type. The material comprised of 17 breeding lines and three released varieties namely SR-1, SFB-1 and Arka Anoop.

Genotypes were grown in the field as single rows of four meter length, with spacing of 15 cm x 40 cm, with two replications each for drought and irrigated treatments in order to create better managed stress conditions under field conditions. Plants were irrigated regularly until the first fully opened trifoliate leaf and irrigation was withdrawn thereafter in drought treatment whereas the plants in irrigated treatment were watered regularly. Seed yield was calculated as the mean of all the plants in each replication. 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. The calculations were done as follows:

Percent Reduction in Yield = $\{(Y_{NS}-Y_S)/Y_{NS}\}$ x 100

(i) Geometric Mean = $\sqrt{(Y_S \times Y_{NS})}$

(ii) Harmonic Mean = $2\,(Y_{NS} \times Y_S)/(Y_{NS} - Y_S)$

(iii) Drought Susceptibility index = $\{1-(Y_S / Y_{NS})\}/\{1-(X_S / X_{NS}\}$

(iv) Drought Resistance Index = $Y_S \times (Y_S / Y_{NS})/X_S$

(v) Coefficient of Drought Resistance = Y_S/ Y_{NS}

(vi) Drought Tolerance Index = $\{(Y_S - Y_{NS}) / (X_{NS} - X_S)\} \times \sqrt{(Y_S \times Y_{NS})}$

(vii) Relative Drought index = $(Y_S/ Y_{NS}) / (X_S / X_{NS})$

(viii) Where Y_S and Y_{NS} are mean yields of genotypes under stress and non-stress conditions respectively and X_S and X_{NS} are mean of yield of all genotypes under stress and non-stress conditions.

These indices have been mathematically defined: TOL and GMP by Rosielle and Hamblin (1981); SSI by Fischer and Maurer (1978); GMP and STI by Fernandez(1992). The STI out of the listed indices is designed to identify genotypes that produce high yield under both stress and non-stress conditions because the genotypes identified by the use of this index will have higher stress tolerance (Fernandez, 1992). Drought resistance index was given by Lan (1998). These indices measure different parameters and provide a complete picture of the behaviour of the genotypes when exposed to drought stress. The use of all the indices therefore provides complete understanding of the germplasm collection by studying their stability and tolerance mechanisms.

The data pertaining to different traits was analysed through XL-STAT (version 2016.05) whereas principal component analysis was done by Statisti XL (version 1.10)

Results and Discussion

Seed yield per plant was highest in case of WB-1634 (36.05) followed by WB-185 (34.44) and WB-451 (33.72) under irrigated conditions (Table 1) while as under drought highest seed yield was recorded for WB-1634 (31.96) followed by WB-341 (27.44) and WB-451 (23.17). Lowest seed yield under both water regimes was recorded for WB-1587 (13.50 and 8.26 for irrigated and drought conditions respectively). WB-1634 recorded lowest per cent reduction in seed yield under drought (11.33%) followed by SFB-1 (16.01%) and WB-341 (17.88%), whereas highest reduction was recorded in WB-6 (55.09) followed by WB-1492 (51.86). Geometric mean and harmonic mean was highest for WB-1634, followed by WB-341 and WB-451 and lowest in case of WB-1587.

In terms of Drought susceptibility index (DSI), best genotypes were identified in terms of low value of DSI recorded in case of WB-1634 (0.36) followed by SFB-1 (0.51) and WB-341 (0.57) whereas WB-6 was most susceptible with highest value of DSI (1.75) followed by WB-1492 (1.65). The values of

DTI (Drought tolerance Index) were higher in case of WB-1634 (33.94), followed by WB-341 (30.06) and WB-185 (27.36) whereas lowest value was recorded for WB-1587 (10.56) followed by WB-6 (13.10). The coefficient of drought resistance (CDR) identified WB-1634, SFB-1 and WB-341 as tolerant genotypes with values of 0.88, 0.84 and 0.82 respectively, whereas WB-6 recorded lowest value of CDR (0.45). Drought resistance index (DRI) identified WB-1634, WB-341 and WB-1643 as better genotypes with values of 1.64, 1.30 and 0.97 respectively, whereas, WB-6 andWB-1587 was identified as least drought tolerant with a value of 0.23 and 0.29 respectively. Similarly, relative drought index (RDI) identified WB-1634, SFB-1 and WB-341 as better genotypes with values of 1.29, 1.22 and 1.19 respectively, whereas, WB-6 was identified as least drought tolerant with a value of 0.65. The overall rank of genotypes based on mean of individual rankings of various indices was calculated with highest value getting the lowest rank. In terms of overall rank, present study identified WB-1634, WB-341, WB-1643, SFB-1 and WB-451 as the most drought tolerant genotypes and WB-6, WB-1492, WB-1587, WB-112 and WB-22 as most susceptible genotypes.

Porch (2006) used heat tolerance index, stress tolerance index and GM to screen for heat tolerance in common bean and reported that it was possible to identify superior genotypes for heat tolerance based on their stress indices as these indices were correlated. The heat tolerance index and GM proved to be the most useful indices for the evaluation of genotypic performance under heat stress and they were highly correlated (Fernandez 1993). GM was also found to be an effective selection index in common bean (Smith 2004). HTI, GM and HSI were all correlated with yield under heat stress, whereas HTI and GM were more highly correlated with yield under low-stress conditions than HSI. Similarly, high correlation between low yield potential and low SSI (HSI) scores have been reported in drought stress in bean (White and Singh 1991), and may make this index less useful in heat tolerance breeding. Chaudhury *et al* (2011) reported that DSI for seed yield in common bean ranged from 0.5 to 1.54. Habibi (2011) outlined that in common bean STI, GM and Mean productivity were highly effective in understanding differential stress response of common bean genotypes. Phiri (2015) evaluated a set of common bean genotypes for drought response based on different indices and found that the GMP, MP, YI and HM though showing variations were useful in identifying high yielding genotypes adaptable to both drought stressed and non-drought stressed conditions. The results agree with separate and similar observations made by Fernandez (1992) and Mohammadi *et al*.(2010) in case of wheat.

PCA concentrated more variability in first two principal components (Table 2). Total variance explained with the two PC's was more than 99 per cent. The criteria followed for selecting the number of principal components (PC) to be included in the future analysis was based on the height of eigen values of PC or needed summary communality in percentage (Kovacic, 1994). The fact that eigen values are above 1 indicates that the evaluated principle component weight values are reliable (Mohammadi and Prasanna, 2003). In the principal components where the values of Latent roots (Eigen values) was reduced to less than unity, which in present study occurred after the second principal component together accounting for more than 99 % of total variance and as such, the rest of the components were not considered. Latent roots (Eigen values) were 7.30 for the first and 2.66 for the second PCA, where after, it was reduced to below unity. The first component explained 73.01 % of total variation, whereas the second component explained 26.63 %. Phiri (2015) evaluated 120 common bean genotypes for drought tolerance indices and found that two PC,s accounted for more than 99 % variation

In the PCA, the value and sign of each factor are important in determining their effectiveness for selection process. The variance of each factor indicates its importance and the sign of factors' coefficients in each factor represents the relationship between these characters (Habibi, 2011). The first PC that accounted for 73.01 % of variation, and indices such as yield (non-stress), yield (stress), GM, HM, DRI, CDR, DTI and RDI were important whereas indices like percent reduction and DSI were related to susceptibility. Similarly in PC 2, only indices such as yield (non-stress), percent reduction and DSI were important. Since the first PC accounted for substantial variation and contained indices related to drought stress tolerance, the genotypes with higher component scores of PC1 are expected to perform better under stress. Similarly the second PC that accounted for 26.634 % of variation had negative sign for most of the drought stress determining indices. Therefore genotypes with higher component scores of PC2 are expected to perform poorly under stress. The argument is substantiated by the genotype-wise component scores of different PC's (Table 3). The genotypes with higher component scores of PC1 viz., WB-1634, WB-341, WB-185 and WB-451 are also tolerant to drought as indicated by better performance of genotypes for most of the indices and better yield under stress. Similarly genotypes with large negative values of PC 1 vizWB-1587, WB-401, WB-216, ArkaAnoop and andWB-6were susceptible to drought. Similarly, the genotypes with higher value of PC 2 are susceptible to drought and lower values or negative values are fairly tolerant to drought.

A biplot is derived from principal component analysis (PCA) based on the two-way data of traits and genotypes to interpret relationships among traits and to compare genotypes on the basis of traits and to identify genotypes or groups of genotypes with a certain level of drought tolerance (Ashraf *et al*, 2015). The Biplot of PC1 and PC2 (Fig.1) indicated that WB-1634 with higher component score of PC1 having higher values of yield (non-stress), yield (stress), GM, HM, DRI, CDR, DTI and RDI; and lower component score of PC2 was highly tolerant to drought, whereas genotypes WB-6, WB-1587 and SR-1 with higher component scores of PC2 with higher values of DSI as well as lower component scores of PC1were susceptible to drought. Phiri (2015) used biplot to discriminate genotypes based on drought response. The genotypes on right extreme were tolerant to drought where as those on left of plot were susceptible and the bulk of genotypes in the middle of plot could be designated as moderately tolerant or susceptible. Stable genotypes under both favorable and drought conditions are vital for plant breeding programs in areas prone to drought stress. However, the level and time of drought stress events are not predictable in rainfed areas; for this reason it is better to evaluate common bean genotypes under various levels of drought stresses. Therefore, a genotype that shows low fluctuations of yield under various levels of drought stress conditions can be considered drought tolerant (Ali and El-Sadek, 2016).

The correlation matrix among drought tolerance indices (Table 4) revealed that most of the indices were significantly and positively correlated with each other indicating fair correspondence between these indices with the exception of drought susceptibility index, which was negatively correlated with all other indices used in the study. Similarly, GM was also negatively correlated with DSI. All the drought tolerance indices were positively correlated with seed yield under drought except drought susceptibility index (DSI). Positive correlation of these indices suggests that they can be effectively used in combination with other indirect selection criteria to identify drought tolerant genotypes rather than selection on the basis of yield *per se*. Similar results in common bean have been reported by Foster *et al (*1995), Scheneder *et al* (1997), Habibi (2011) and Trapp (2015).

Grain yield is the final outcome of all adaptive mechanisms that crop plants put in place under stress. However, being a complex trait, direct selection with grain yield is seldom fruitful. The drought tolerance indices developed using different ratios from yield under stress and non-stress conditions help to identify genotypes with desirable response in terms of lower reduction, resilience and better productivity under stress conditions. The present study used eight different indices to elucidate differential genotypic response of 20 common bean genotypes to water stress. The higher correlation of indices with seed yield under stress reinforces the current evidence across various crops that they can be effectively used to screen genotypes under stress based on seed yield. The PCA helps to identify the most important variables (indices in present case) that account for variation in response and help identify the genotypes that are tolerant to drought. The present study could identify genotypes such as WB-1634, WB-341 and WB-185 as tolerant to drought stress. These genotypes can be further tested for stability of tolerance response under different rainfed ecologies of J&K state to establish their superiority under water stress conditions.

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Table 1. Mean performance of 20 common bean genotypes for yield and drought tolerance indices

Genotype	Seed Yield (NS)	Seed Yield (S)	Percent reduction	GM	HM	DS1	DR1	CDR	DT1	RDI	Cum. Rank
WB-6	19.55	8.78	55.09	13.10	12.12	1.75	0.23	0.45	13.10	0.65	20
WB-22	29.32	14.35	51.04	20.51	19.27	1.62	0.41	0.49	20.51	0.71	16
WB-83	24.67	16.33	33.81	20.07	19.65	1.07	0.63	0.66	20.07	0.96	14
WB-112	26.06	14.97	42.54	19.75	19.01	1.35	0.49	0.57	19.75	0.83	17
WB-185	34.44	21.74	36.88	27.36	26.65	1.17	0.79	0.63	27.36	0.92	9
WB-216	16.28	12.17	25.27	14.07	13.93	0.80	0.53	0.74	14.07	1.09	12
WB-222	31.10	21.23	31.73	25.69	25.23	1.01	0.84	0.68	25.69	0.99	8
WB-257	25.38	17.41	31.41	21.02	20.65	1.00	0.69	0.68	21.02	0.99	10
WB-341	33.18	27.24	17.88	30.06	29.92	0.57	1.30	0.82	30.06	1.19	2
WB-401	15.10	11.68	22.61	13.28	13.17	0.72	0.52	0.77	13.28	1.12	11
WB-451	33.72	23.17	31.28	27.95	27.46	0.99	0.92	0.69	27.95	1.00	5
WB-956	25.41	18.61	26.74	21.74	21.48	0.85	0.79	0.73	21.74	1.06	6
WB-1446	24.96	17.84	28.53	21.10	20.80	0.91	0.74	0.71	21.10	1.04	7
WB-1492	27.35	13.16	51.86	18.97	17.77	1.65	0.37	0.48	18.97	0.70	19
WB-1587	13.50	8.26	38.77	10.56	10.25	1.23	0.29	0.61	10.56	0.89	18
WB-1634	36.05	31.96	11.33	33.94	33.88	0.36	1.64	0.88	33.94	1.29	1
WB-1643	25.52	20.69	18.90	22.97	22.85	0.60	0.97	0.81	22.98	1.18	3
SR-1	20.18	13.43	33.44	16.46	16.12	1.06	0.52	0.66	16.46	0.97	15
SFB-1	22.11	18.57	16.01	20.26	20.18	0.51	0.90	0.84	20.26	1.22	4
Arkaanoop	17.69	12.50	29.33	14.87	14.65	0.93	0.51	0.70	14.87	1.03	13

Table 2. Eigen values (Latent roots) and rotated component loadings (values of principal component traits of common bean)

Principal component	PC 1	PC 2
Yield (NS)	0.693	0.716
Yield (S)	0.967	0.250
Percent reduction	-0.790	0.612
GM	0.887	0.462
HM	0.911	0.411
DS1	-0.790	0.613
DRI	0.989	0.001
CDR	0.795	-0.606
DTI	0.887	0.462
RDI	0.790	-0.613
Eigen value	7.301	2.663
% of variance	73.01	26.631
Cumulative %age	73.01	99.64

 DOI: 10.5958/0975-928X.2019.00021.8

Table 3. Genotype-wise component scores of 20 common bean genotypes

Genotype	PC 1	PC 2
WB-6	-0.809	1.766
WB-22	0.393	1.742
WB-83	-0.076	0.169
WB-112	0.064	0.953
WB-185	1.268	0.724
WB-216	-1.313	-0.800
WB-222	0.870	0.197
WB-257	0.045	0.008
WB-341	1.371	-0.930
WB-401	-1.508	-1.050
WB-451	1.253	0.220
WB-956	0.073	-0.397
WB-1446	-0.004	-0.261
WB-1492	0.143	1.751
WB-1587	-1.636	0.234
WB-1634	1.947	-1.418
WB-1643	0.130	-1.074
SR-1	-0.718	0.001
SFB-1	-0.409	-1.418
ARKA ANOOP	-1.085	-0.417

Electronic Journal of Plant Breeding, 10 (1): 177 – 186 (Mar 2019) DOI: 10.5958/0975-928X.2019.00021.8
ISSN 0975-928X

Table 4. Correlation matrix for 10 drought tolerance indices in common bean under drought stress

Trait	Yield (NS)	Yield (S)	Percent reduction	GM	HM	DS1	DR1	CDR	DT1	RDI
Yield (NS)	1.000	0.846**	-0.112	0.947**	0.927**	-0.111	0.676**	0.120	0.947**	0.111
Yield (S)		1.000	-0.611**	0.972**	0.984**	-0.610**	0.963**	0.616**	0.972**	0.610**
Percent reduction			1.000	-0.418**	-0.469**	1.000**	-0.777**	-1.000**	-0.418*	-1.000**
GM				1.000	0.998**	-0.418*	0.874**	0.425*	1.000**	0.418*
HM					1.000	-0.468*	0.898**	0.476*	0.998**	0.468*
DS1						1.000	-0.776**	-1.000**	-0.418*	-1.000**
DR1							1.000	0.781**	0.874**	0.776**
CDR								1.000	0.425*	1.000**
DT1									1.000	0.418*
RDI										1.000

DOI: 10.5958/0975-928X.2019.00021.8

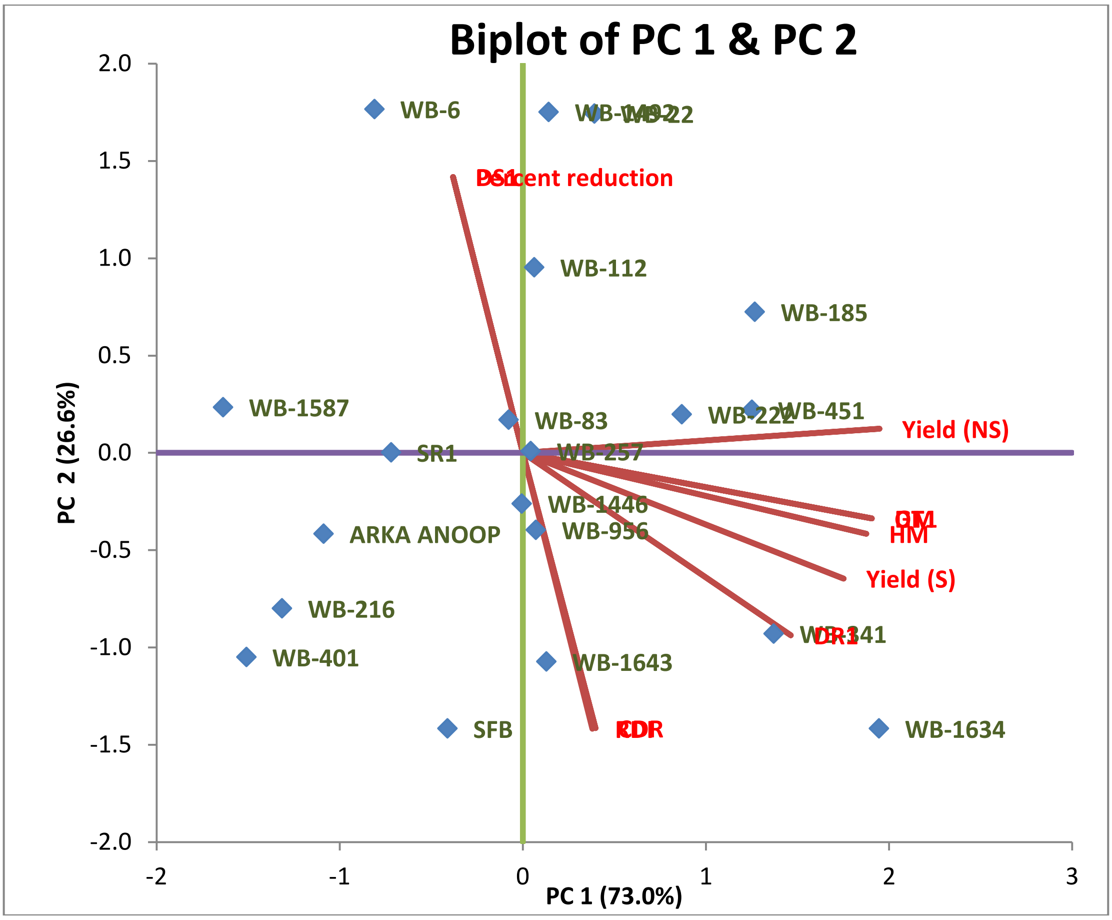

Fig. 1.Genotype x tolerance index biplot of yield under stress and tolerance indices

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