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EVALUATING THE WATERLOGGING TOLERANCE OF FABA BEAN GENOTYPES AT DIFFERENT GROWTH STAGES UNDER FIELD CONDITIONS

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ABSTRACT

Waterlogging stress is one of the most important abiotic stresses in Mediterranean conditions such as north of Iran. The tolerance of faba bean to waterlogging may vary between genotypes. This study investigated the effects of 10 days of waterlogging on grain yield for 21 faba bean genotypes at two stages (flowering and pod-filling stages) during 2016-2017 and 2017-2018 under farm conditions. A randomized complete block design with three replications was used at three field sites (normal and waterlogging sites). Nine indices of endurance were calculated in normal and waterlogging conditions. The results indicated that waterlogging stress reduced the faba bean grain yield. Also, the negative waterlogging effect at flowering stage is more than pod-filling stage. Correlation coefficients and principal component analysis (PCA) results revealed that mean productivity (MP), geometric mean productivity (GMP), harmonic mean (HM), and stress tolerance index (STI) indices could be effectively used for screening of waterlogging stress tolerant genotypes. Waterlogging was caused to decrease significantly grain yield in all genotypes. According to results of three-dimensional graphs the genotypes G21, G18, G15, G6 and G2 with an average yield 4806, 4815, 4789, 4686 and 4681 kg.ha^{-1}, respectively, were selected as waterlogging stress tolerance and suitable grain yield under non-stress and waterlogging stress (waterlogging stress in flowering and pod-filling stages) conditions. Therefore, these genotypes can be used as source of genes in faba bean breeding programs to obtain tolerant cultivars and cultivation in the areas under waterlogging stress.

Keywords: principal component analysis (PCA), stress tolerance index (STI), grain yield.

INTRODUCTION

Faba bean (*Vicia faba* L.) is one of the most important food legumes from the Fabaceae family (Etemadi et al., 2019). Faba bean is native from the Middle East, and is mainly cultivated in Southern Europe, East Asia and North Africa (Esho and Salih, 2021).

Faba bean is mainly cultivated and widely distributed for the seed. Faba bean is a major source of protein and is a very valuable legume crop that contributes to the sustainability of cropping systems through its ability of biological N2 fixation, diversification of cropping systems leading to decreased disease, pest and weed (Etemadi et al., 2019).

Also, faba bean can be used as source of fodder for livestock consumption (Sheikh et al., 2015; Etemadi et al., 2019). Faba bean production and productivity are mainly affected by climate conditions, altitude, different soil conditions, seasonal factors and other environmental features such as waterlogging stress (Hagos et al., 2019).

Soil flooding and submergence, collectively termed waterlogging, are major abiotic stresses (Pampana et al., 2016), that extremely burden crop growth in areas with heavy rainfall, irrigation practices and/or poor soil drainage, imposing major constraints on roots and reduce crop yields (Su et al., 2017; Zhang et al., 2019).

Waterlogging tolerance is explained as the plant abilities to the survival, grow and reproduce satisfactory yield under waterlogging rather than non-waterlogged conditions (Pampana et al., 2016; Su et al., 2017).

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Cool-season grain legumes can be exposed to submersion both at the vegetative and reproductive stages. Limited research has been carried out on these crops with waterlogging imposed at flowering (Pampana et al., 2016). In legumes, waterlogging can reduce photosynthesis, biomass of shoots, seed yield, the formation, function and survival of nodules, N uptake, and cause plant death during or after the end of waterlogging (Pampana et al., 2016; Davies et al., 2000).

The effects of waterlogging stress on legumes depend on the stage of growth and duration of submergence (Pampana et al., 2016). Ability to survive and recover following waterlogging stress decreases with increasing plant age and declines sharply as reproductive growth approaches of legumes. Waterlogging duration is a major factor in plant survival, and with increasing waterlogging period plant growth decreased (Solaiman et al., 2007; Pampana et al., 2016).

Investigation the effects of waterlogging plant growth among various grain legume species showed tolerance to waterlogging varies: faba bean is the most tolerant, followed by the relatively tolerant cowpea, soybean, field bean, grass pea, chickpea, lentil and finally field pea (Solaiman et al., 2007; Pampana et al., 2016).

Some indices have been used to identify the stress-tolerant genotypes. Generally, some researchers for screening of susceptible and tolerance genotypes were used of indices such as stress susceptibility index (SSI) (Fischer and Maurer, 1978), geometric mean productivity (GMP) (Fernandez, 1992), mean productivity (MP) (Rosielle and Hamblin 1981), harmonic mean (HM) (Bidinger et al., 1987), tolerance index (TOL) (Rossielle and Hamblin, 1981), stress tolerance index (STI) (Fernandez, 1992), yield index (YI) (Gavuzzi et al., 1997), yield stability index (YSI) (Khakwani et al., 2011), and relative stress index (RSI) (Fischer and Wood, 1979). These indices identify susceptible and tolerance genotypes based on their yields in non-stress and stress conditions. Fernandez (1992) by using these indices and yield in non-stress and stress conditions categorized genotypes into four groups: genotypes which express uniform superiority in both non-stress and stress environments (group A), genotypes with high yield under either non-stress (group B) or stress (group C) environments, and genotypes with weak yield under both non-stress and stress environments (group D). Also, for selection based on a combination of indices, some researchers have used principal component analysis (PCA) (Gyang et al., 2017; Tiwari and Singh, 2019; Nayana et al., 2022). PCA is one of the most successful techniques for reducing the multiple dimensions of the observed variables to a smaller intrinsic dimensionality of independent variables (Nayana et al., 2022).

Faba bean is mainly cultivated in irrigated and high rainfall regions of the world such as North Iran. These regions experience heavy rainfall and frequent soil waterlogging. The cultivation and breeding of tolerant faba bean genotypes is the most promising strategy to reduce the effects of waterlogging stress. Little information is available on genetic diversity and waterlogging tolerance in faba bean.

Therefore, we attempted to evaluate waterlogging tolerance of 21 faba bean genotypes in different waterlogging treatments to evaluate several waterlogging tolerance indices and identify waterlogging-tolerant genotypes for cultivation and also as source of donor parents in faba bean breeding programs for further improvement of germplasm for waterlogging tolerance.

MATERIAL AND METHODS

Site characteristics and experimental design

This study was conducted at Agricultural Research Station of Gorgan, Golestan - Iran [54º21'E longitude and 36º53'N latitude elevated at 5 metres above sea level (m.a.s.l.)] during 2016-2017 and 2017-2018 in the main cropping seasons (November-June). Gorgan has a moderate and humid climate and it has known as the moderate Caspian climate in north of Iran. The mean annual rainfall for the centre is 450 mm, based on 11 years (2006-2017) data. The average daily mean temperatures in the spring and summer are 20.8 and 27.8°C, respectively. The highest daily mean maximum temperature and the highest daily mean evaporation are 34.6°C and 7.1 mm, respectively. In each year, the experiments were laid out in Randomized Complete Block Design (RCBD) with three replications in three environments. The three waterlogging treatments were one well-drained control, waterlogging stress at flowering initiation (late-February) and waterlogging stress at pod-setting initiation (early-April).

Plant material

A total of twenty one faba bean genotypes originating from various countries, 11 populations and cultivars from ICARDA, 5 cultivars from various provinces of Iran, and 4 genotypes originating from Egypt, Spain, Sudan, were evaluated for resistance to waterlogging stress (Table 1).

Table 1. Genotypic code, name, pedigree, and origin of the tested faba bean genotypes

Code	Name	Pedigree	Origin	Seed size
G1	G-Faba-67	DT/B7/7486/0405-HBP/DS0/2000	ICARDA	medium
G2	G-Faba-66	DT/B7/7327/0405-HBP/DS0/2000	ICARDA	medium
G3	G-Faba-75	DT/A11/9032/2005/06	ICARDA	medium
G4	G-Faba-72	DT/A11/9012/2005/06	ICARDA	medium
G5	G-Faba-65	DT/B7/7038/0405-HBP/DS0/2000	ICARDA	medium
G6	G-Faba-62	selection from ILB1814	ICARDA	medium
G7	G-Faba-61	DT/B7/7380/0405-HBP/DS0/2000	ICARDA	medium
G8	G-Faba-398	55/08/F8/7349/06-HBP/S0E/2000	ICARDA	medium
G9	G-Faba-411	56/08/F8/7350/06-HBP/S0E/2000	ICARDA	medium
G10	G-Faba-401	93/08/F8/7711/06-S 97112 (ILB4365×BPL2282)	ICARDA	medium
G11	G-Faba-335	S 2007,057	ICARDA	medium
G12	G-Faba-293	Aquadulce	Spain	large
G13	G-Faba-294	Reiana Blanca	Egypt	large
G14	G-Faba-290	Lattakia 2	ICARDA	medium
G15	G-Faba-292	line 1/46	Syria	medium
G16	G-Faba-523	Barkat × ILB 4720	Iran	large
G17	G-Faba-524	Barkat × BPL 465	Iran	large
G18	G-Faba-525	Barkat × 98 264-1	Iran	large
G19	G-Faba-520	Barkat × New momomoth	Iran	large
G20	G-Faba-296	Hudiba 93	Sudan	medium
G21	G-Faba-21	Barkat as check	Iran	large

Experimental equipment and crop management

In non-stress condition environments, irrigation was performed as required by the climatic conditions of the region (in pre-flowering, flowering initiation, and grain filling periods). The beginning of flowering occurred on 12 March 2016 and 16 March 2017 and grain filling periods were on 4 April 2017 and 6 April 2018. To create waterlogging stress, heavy irrigation was applied by flooding and plot methods for 10 consecutive days. Soil samples were taken in the soil depth profile of 0-20, 40-20 and 60-40 cm before irrigation using an auger and the standard gravimetric method was used to determine the amount of water. The soil type in the experimental station is silty clay loam (Table 2). The plots were irrigated 3-4 times a day so that water could fully penetrate into the depth of root plus soil and to saturate the root zone. To avoid water runoff from the farm, the farm was bordered. Each experimental unit had 2 rows with 4 m length. The spacing was 2 m between blocks, 0.6 m between plots, 0.6 m and 0.1 m between rows and plants, respectively. All caring practices including the control of weeds, pests, and diseases were taken during the growing season. Plants were harvested at maturity, and then the grain yield was record for each plot.

Table 2. Soil properties of different layers of the experimental field

Soil depth cm	Sand %	Silt %	Clay %	Total N %	P mg kg^{-1}	K mg kg^{-1}	Organic matter %	pH	EC dS m^{-1}
0-20	18	54	28	0.15	8.6	333	1.5	7.2	1.35
20-40	18	52	30	0.11	4.8	220	1.1	7.3	1.27
40-60	14	52	34	0.06	2.0	108	0.6	7.3	1.42

Sampling procedures and measurements

Crops were harvested at maturity: 5 June 2017 and 2 June 2018. Each plot was manually cut at ground level and aerial parts were partitioned into shoots and pods and seed yield were recorded.

Data analyses

Normality of datasets was first tested according to the Anderson and Darling normality method by Statistical Analysis System (SAS) (SAS, 2003). The combined analysis of variance for grain yield under non-stress and waterlogging stress conditions was performed based on RCBD design by SAS (SAS, 2003). The several stress tolerance indices were computed based on grain yield under non-stress and waterlogging stress using an online toolkit, iPASTIC (Pour-Aboughadareh et al., 2019). In this study, to evaluation of faba bean genotypes for waterlogging tolerance was used nine selection indices including SSI, GMP, MP, HM, TOL, STI, YI, and RSI. These indices were calculated based on of grain yield of genotypes under non-stress and waterlogging stress conditions. The indices were calculated using the equations cited in Table 3.

To identify the interrelationships between indices and grain yield under non-stress and waterlogging stress was used a vector view (biplot) of principal component analysis (PCA) based on the two first components. Vector view is a graphical tool for breeders and is a plot that simultaneously displays the effects of indices and the genotypes.

Table 3. Stress tolerance/susceptibility indices used for evaluation of faba bean genotypes to waterlogging tolerance

Stress tolerance indices	Equation	References
Stress susceptibility index	$SSI = \frac{1-(Y_S / Y_P)}{1-(\overline{Y}_S / \overline{Y}_P)}$	Fischer and Maurer, 1978
Geometric mean productivity	$GMP = \sqrt{Y_P \times Y_S}$	Fernandez, 1992
Mean productivity	$MP = \frac{Y_P + Y_S}{2}$	Rosielle and Hambling, 1981
Harmonic mean	$HM = \frac{2(Y_P \times Y_S)}{Y_P + Y_S}$	Bidinger et al., 1987
Tolerance index	$TOL = Y_P - Y_S$	Rosielle and Hambling, 1981
Stress tolerance index	$STI = \frac{(Y_P)\times(Y_S)}{(\overline{Y}_P)^2}$	Fernandez, 1992
Yield index	$YI = \frac{Y_S}{\overline{Y}_S}$	Gavuzzi et al., 1997
Yield stability index	$YSI = \frac{Y_S}{Y_P}$	Khakwani et al., 2011
Relative stress index	$RSI = \frac{Y_S / Y_P}{\overline{Y}_S / \overline{Y}_P}$	Fischer and Wood, 1979

Ys and Yp - grain yield of genotypes under stress and non-stress conditions, respectively.
$\overline{Y}_S$ and $\overline{Y}_P$ - the grain yield of all genotypes under stress and non-stress condition, respectively.

Principal component analysis (PCA) and Correlations coefficients analysis were calculated to established interrelationships among grain yield for each irrigation treatment and waterlogging tolerance indices using an online toolkit, iPASTIC (Pour-Aboughadareh et al., 2019). For specifying the waterlogging-tolerant genotypes with high yielding potential in non-stress and stress environments, a three-dimensional graph based on yield in non-stress and waterlogging stress and the best waterlogging-tolerance indices was performed by SAS method. In each environment, the pooled mean values of two years (2016-2017 and 2017-2018) for grain yield were subjected to statistical analyses.

RESULTS AND DISCUSSION

The results of ANOVA (Table 4) indicated significant differences for grain yield under waterlogging environments, thereby revealing variable performance of genotypes in varying environments. The highest (5160.4 kg ha^{-1}) and the lowest (3922.8 kg ha^{-1}) grain yield were obtained in non-stress condition and waterlogging stress at flowering stage, respectively. Reduction to in mean grain yield was observed in a set of 21 faba bean genotypes evaluated over two seasons (2016-17 and 2017-18) in this study with field waterlogging beginning at flowering and pod-filling stages. The effects of genotypes for grain yield were significantly ($P \leq 0.001$). Also, the interaction between waterlogging treatments and genotypes were significant for grain yield. A lot of research reported the effect of waterlogging stress on yield and other traits in various plant species. For example, effects of waterlogging stress on yield, growth and physiological responses of two genotypes of Mung bean [*Vigna radiata* (L.) Wilczek] were significant and decreased crop growth rate, leaf area, membrane stability index, carotenoid and chlorophyll contents, photosynthesis rate, nodules number and root growth, pod filling, flowering rate and yield (Fazeli et al., 2022). Reduction in grain yield under waterlogging stress condition was also reported in other crops such as in wheat (Araki et al., 2012), cotton (Kuai et al., 2014; Wang et al., 2017), barley and rapeseed (Ploschuk et al., 2018) and faba bean (Tesfaye et al., 2020). In this study, the highest grain yield was obtained in non-stress condition whereas minimum grain yield obtained in waterlogging stress at flowering stage. Waterlogging stress at flowering stage can seriously limit the morphological development and final yield of faba bean because the flowering stage is a main growth stage for the reproductive and vegetative growth of faba bean. However, waterlogging stress at pod-filling stage has little effect on the morphology and yield of the faba bean because plants in this stage have generally finished vegetative growth. It has been indicated that one of the reasons for grain yield reduction under waterlogging stress was due to the lack of oxygen available around the roots of submerged tissues that limits energy generation and nutrient uptake (Yanjun and Hezhong, 2015; Wang et al., 2017). Reduction in grain yields could also be due to reduction in the chlorophyll content and photosynthetic rate of plants under waterlogging stress. Chlorophyll has a critical role in light uptake during the photosynthetic process. It has been reported that the reduction in the chlorophyll content inhibited the photosynthetic rate, total amount of organic formation, and finally leading to a reduction in the yield of plants under waterlogging stress (Wang et al., 2017). In this study, significant differences were obtained for grain yield among genotypes. The difference between genotypes may be due to various geographical environments which they are growing. Generally, the results indicate that is a high genetic variation among genotypes, which could be as a useful resource for cultivation and selection of waterlogging-tolerant genotypes as donor parents in faba bean breeding programs for further improvement of germplasm for waterlogging tolerance.

An appropriate index must have a positive significant correlation with grain yield in the non-stress and stress conditions. So, principal component analysis (PCA) and correlation coefficients analysis were performed to identify the best index of selection for screening of waterlogging-tolerant genotypes (Figures 1, 2, 3 and 4). We used a vector view of biplot of the two first components to discover interrelationships among grain yield in each of the irrigation treatment and waterlogging tolerance indices (Figures 1 and 2). The vector view is one of the applications of the biplot to study the relationships between and among indices. In the vector view of the biplot, a vector is drawn from the biplot origin to each marker of the traits (indices) to facilitate visualization of the relationships between and among the traits (Yan and Rajcan, 2002). The vector view explains a sufficient amount of the total variation of standardized data. Since the correlation coefficient between any two traits is approximated by the cosine of the angle between their vectors, the vector view of biplot is the best way for graphical display interrelationships among traits (Yan and Rajcan, 2002). Two traits are positively correlated if the angle between their vectors is <90°, negatively correlated if the angle is >90°, independent if the angle is 90°. This study demonstrated that biplot was an excellent tool to identify the interrelationships between indices and grain yield under non-stress and waterlogging stress compare with statistical techniques such as linear correlations and other complex methods like path coefficient analysis. This method for studied the interrelationships between traits was used in different crops such as in white lupin (*Lupinus albus* L.) (Rubio et al., 2004), rapeseed (Dehghani et al., 2008) and soybean (Yan and Rajcan, 2002). According to vector view of biplot, the indices of MP, GMP, HM and STI had a positive significant with grain yield in different irrigation treatments and obtained results has been verified from the correlation coefficients data. Therefore, these four indices (MP, GMP, HM and STI) could effectively be used for screening of waterlogging tolerance genotypes under conditions of waterlogging stress at flowering and pod-filling stages. In this study, the three-dimensional plots were employed based on MP, GMP, HM, STI and grain yield under non-stress and waterlogging stress conditions to grouping the genotypes regarding to waterlogging tolerance.

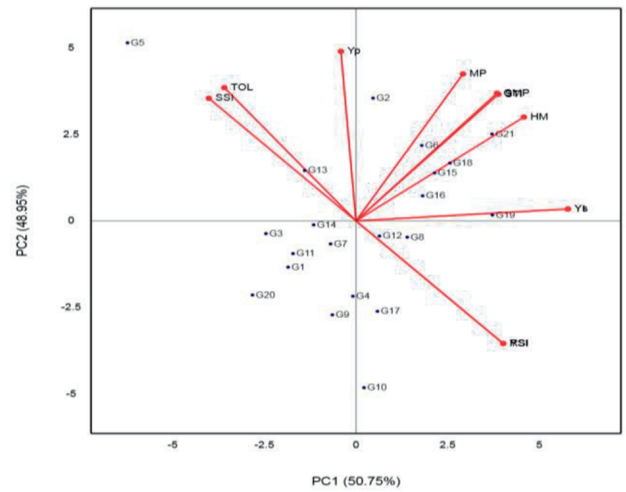
Table 4. Combined analysis of variance for yield of 21 faba bean genotypes

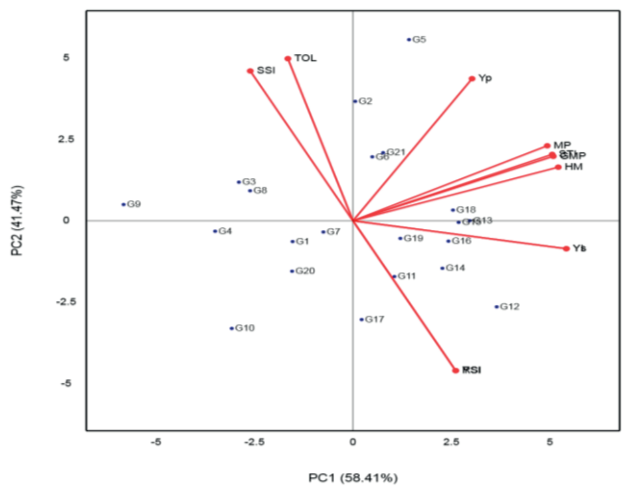
Sources	Df	Mean square
Irrigation treatments (IR)	2	25635543.60**
Replication / IR	6	625431.06
Genotype (G)	20	759328.81**
G × IR	40	397863.58**
Error	120	190512.50

** - significant at the 0.01 probability level.

The best selection index must be able to distinguish genotypes which have uniform superiority in both non-stress and stress conditions. According to Figure 1, STI, MP, GMP and HM indices had a positive significant with grain yield under both conditions of non-stress (Yp) and waterlogging stress at flowering stage (Ys) and obtained results can be verified from the correlation coefficients data (Figure 3). Therefore, these four indices (STI, MP, GMP and HM) could effectively be used for screening of waterlogging tolerance genotypes under conditions of waterlogging stress at flowering stage. The genotypes which had the highest value for these indices can be identified as waterlogging tolerance genotypes.

Thus, according to the values of these indices (Table 5), the genotypes G21, G19, G18, G6 and G2 were selected as the most waterlogging-tolerant genotypes under conditions of waterlogging stress at flowering stage. Also, in conditions of waterlogging stress at pod-filling, the indices of STI, MP, GMP and HM indices had a positive significant with grain yield under both conditions of non-stress (Yp) and waterlogging stress at pod-filling stage (Ys) (Figure 2) and obtained results can be verified from the correlation coefficients data (Figure 4).

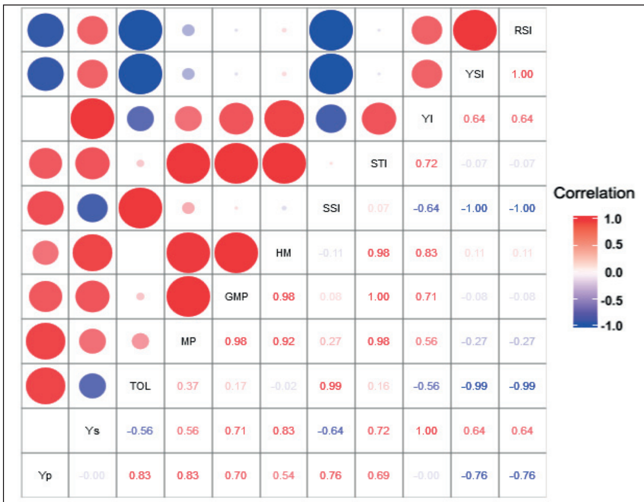


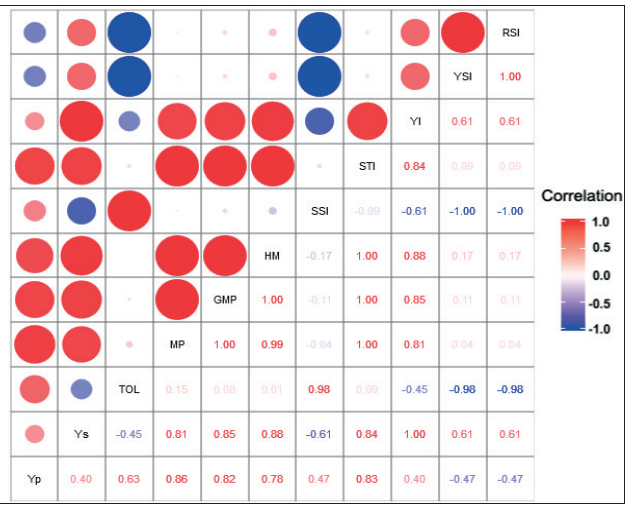


Ys: yield under waterlogging stress at flowering stage; Yp: yield under non-stress; SSI: stress susceptibility index; GMP: geometric mean productivity; MP: mean productivity; HM: harmonic mean; TOL: Tolerance index; STI: stress tolerance index; YI: yield index; YSI: yield stability index; RSI: relative stress index.

Figure 1. Biplot vector view which shows relationships between the yields under waterlogging stress at flowering stage and non-stress conditions and waterlogging tolerance/susceptibility indices

Figure 2. Biplot vector view which shows relationships between the yields under waterlogging stress at pod-filling stage and non-stress conditions and waterlogging tolerance/susceptibility indices





Ys: yield under waterlogging stress at flowering stage; Yp: yield under non-stress; SSI: stress susceptibility index; GMP: geometric mean productivity; MP: mean productivity; HM: harmonic mean; TOL: Tolerance index; STI: stress tolerance index; YI: yield index; YSI: yield stability index; RSI: relative stress index.

Figure 3. Correlation coefficients between tolerance/susceptibility indices and yield under non-stress and waterlogging stress at flowering stage of faba bean genotypes

Figure 4. Correlation coefficients between tolerance/susceptibility indices and yield under non-stress and waterlogging stress at pod-filling stage of faba bean genotypes

Therefore, these four indices could effectively be used for screening of waterlogging tolerance genotypes under waterlogging stress at pod-filling stage conditions. Thus, according to the values of these indices (Table 6), the genotypes G5, G13, G15, and G18 were selected as the most waterlogging-tolerant genotypes under conditions of waterlogging stress at pod-filling stage.

According to the three-dimensional plots, the genotypes were divided in four groups: (1) the genotypes with high grain yield under both non-stress and waterlogging stress conditions (group A); (2) the genotypes with high grain yield under non-stress condition (group B); (3) the genotypes with high grain yield under waterlogging stress condition (group C) conditions, and the genotypes with poor grain yield under both non-stress and waterlogging stress conditions (group D). According to the three-dimensional plots, the genotypes G21, G18, G15, G6 and G2 under waterlogging stress at flowering stage and G18, G15, G13, G21, G6 and G2 under waterlogging stress at pod-filling stage were selected as waterlogging tolerance genotypes because they express uniform superiority in both non-stress and stress conditions (group A). Therefore, these genotypes can be used as source of donor parents in faba bean breeding programs for further improvement of germplasm for waterlogging tolerance and also to cultivation in the areas under waterlogging stress.

Table 5. Mean grain yield in non-stress (Yp) and waterlogging stress at flowering stage (Ys) and tolerance indices for 21 faba bean genotypes

Genotype code	Yp kg ha^{-1}	Ys kg ha^{-1}	MP	GMP	HM	STI
G1	4876.66	3658.30	4267.48	4223.78	4180.52	0.67
G2	5873.76	4012.25	4943.01	4854.58	4767.75	0.88
G3	5072.27	3586.47	4329.37	4265.15	4201.89	0.68
G4	4723.18	3888.56	4305.87	4285.60	4265.43	0.69
G5	6410.31	3098.73	4754.52	4456.88	4177.88	0.75
G6	5573.24	4191.52	4882.38	4833.25	4784.62	0.88
G7	5011.37	3824.17	4417.77	4377.71	4338.01	0.72
G8	5052.03	4114.80	4583.42	4559.40	4535.50	0.78
G9	4618.57	3803.99	4211.28	4191.54	4171.89	0.66
G10	4251.40	3883.93	4067.67	4063.51	4059.37	0.62
G11	4954.87	3681.02	4317.95	4270.71	4223.99	0.68
G12	5057.51	4010.26	4533.89	4503.55	4473.41	0.76
G13	5448.56	3745.58	4597.07	4517.52	4439.35	0.77
G14	5121.53	3766.55	4444.04	4392.10	4340.76	0.72
G15	5411.64	4234.67	4823.16	4787.12	4751.35	0.86
G16	5282.75	4184.56	4733.66	4701.70	4669.96	0.83
G17	4647.52	3974.22	4310.87	4297.70	4284.58	0.69
G18	5466.23	4295.42	4880.83	4845.59	4810.61	0.88
G19	5176.14	4445.28	4810.71	4796.81	4782.95	0.86
G20	4713.72	3515.89	4114.81	4070.99	4027.63	0.62
G21	5625.35	4461.64	5043.50	5009.82	4976.37	0.94

Yp: yield under non-stress; Ys: yield under waterlogging stress at flowering stage; MP: mean productivity; GMP: geometric mean productivity; HM: harmonic mean; STI: stress tolerance index.

Therefore, these four indices could effectively be used for screening of waterlogging tolerance genotypes under waterlogging stress at pod-filling stage conditions. Thus, according to the values of these indices (Table 6), the genotypes G5, G13, G15, and G18 were selected as the most waterlogging-tolerant genotypes under conditions of waterlogging stress at pod-filling stage.

Table 6. Mean grain yield in non-stress (Yp) and waterlogging stress in pod-filling stage (Ys) and tolerance indices for 21 faba bean genotypes

Genotype code	Yp kg ha^{-1}	Ys kg ha^{-1}	MP	GMP	HM	STI
G1	4876.66	4043.63	4460.15	4440.65	4421.25	0.74
G2	5873.76	4159.66	5016.71	4942.96	4870.29	0.92
G3	5072.27	3770.67	4421.47	4373.31	4325.68	0.72
G4	4723.18	3714.56	4218.87	4188.62	4158.59	0.66
G5	6410.31	4298.36	5354.34	5249.17	5146.08	1.03
G6	5573.24	4293.35	4933.30	4891.61	4850.28	0.90
G7	5011.37	4163.92	4587.65	4568.04	4548.51	0.78
G8	5052.03	3824.51	4438.27	4395.63	4353.39	0.73
G9	4618.57	3320.17	3969.37	3915.92	3863.19	0.58
G10	4251.40	3845.99	4048.70	4043.62	4038.55	0.61
G11	4954.87	4499.27	4727.07	4721.58	4716.09	0.84
G12	5057.51	4960.03	5008.77	5008.53	5008.30	0.94
G13	5448.56	4766.63	5107.60	5096.20	5084.83	0.98
G14	5121.53	4695.86	4908.70	4904.08	4899.47	0.90
G15	5411.64	4721.69	5066.67	5054.91	5043.18	0.96
G16	5282.75	4697.01	4989.88	4981.28	4972.69	0.93
G17	4647.52	4391.83	4519.68	4517.87	4516.06	0.77
G18	5466.23	4685.60	5075.92	5060.89	5045.90	0.96
G19	5176.14	4491.94	4834.04	4821.92	4809.83	0.87
G20	4713.72	4064.25	4388.99	4376.96	4364.96	0.72
G21	5625.35	4333.60	4979.48	4937.41	4895.70	0.92

Yp: yield under non-stress; Ys: yield under waterlogging stress at pod-filling stage; MP: mean productivity; GMP: geometric mean productivity; HM: harmonic mean; STI: stress tolerance index.

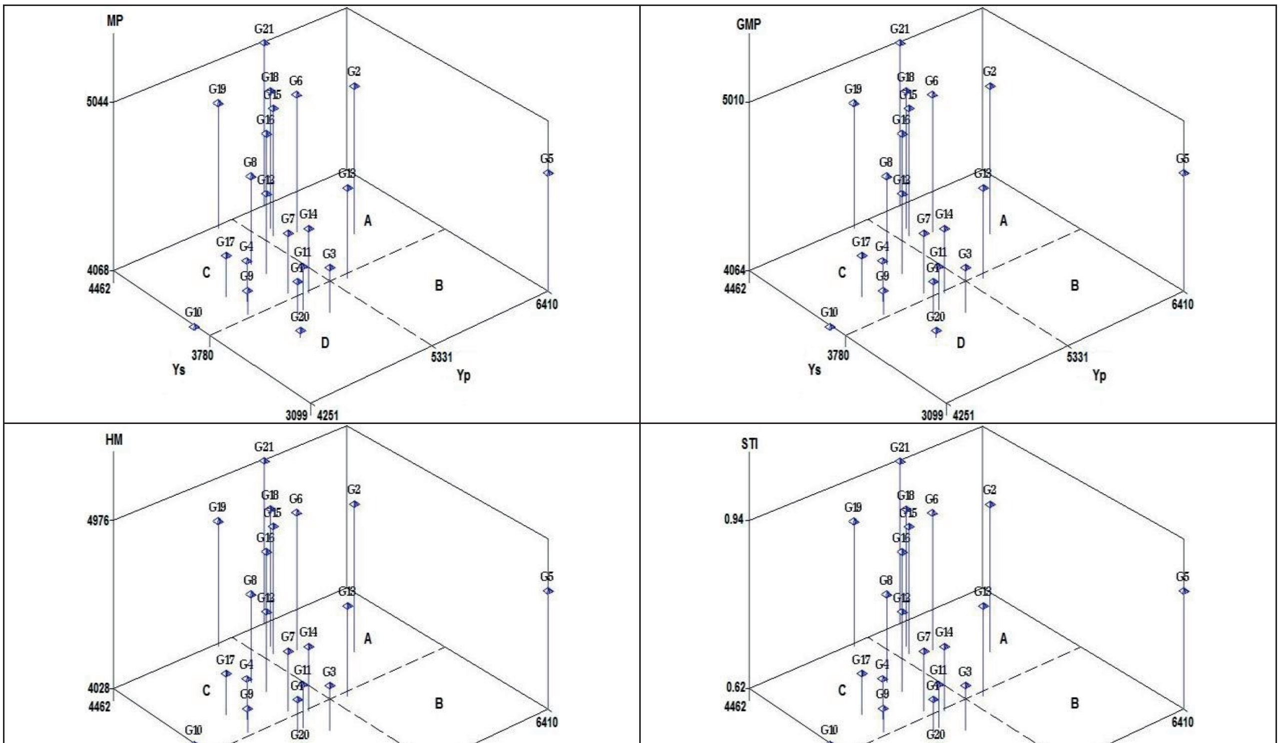


Figure 5. Three dimensional graphs of grain yield under non-stress (YP), waterlogging stress at flowering stage (YS) and mean productivity (MP), geometric mean productivity (GMP), harmonic mean (HM), stress tolerance index (STI) for 21 faba bean genotypes

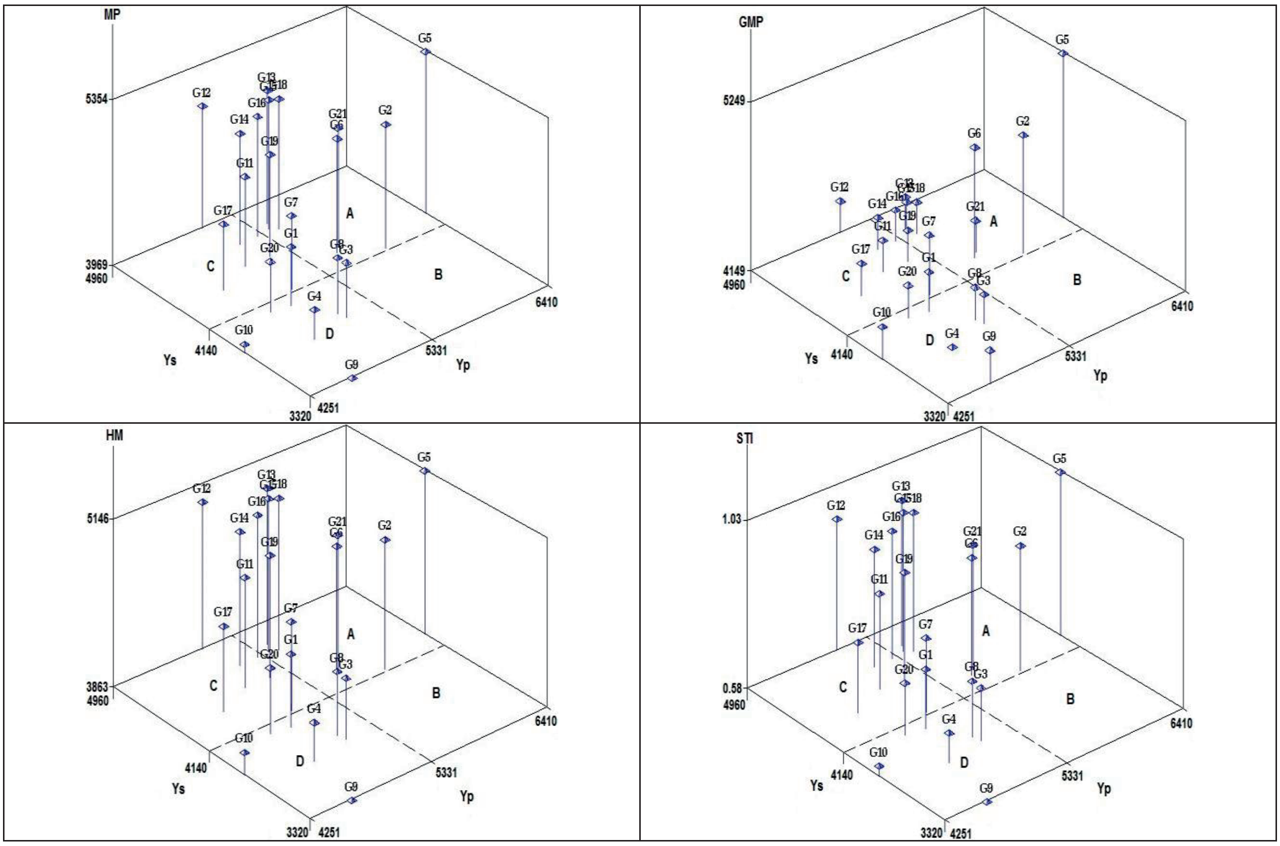


Figure 6. Three dimensional graphs of grain yield under non-stress (YP), waterlogging stress at pod-filling stage (YS) and mean productivity (MP), geometric mean productivity (GMP), harmonic mean (HM), stress tolerance index (STI) for 21 faba bean genotypes

CONCLUSIONS

In order to select a genotype with stable and high grain yield in non-stress and waterlogging stress conditions, geometric mean productivity (GMP), mean productivity (MP), harmonic mean (HM), and stress tolerance index (STI) indices are proposed as the more suitable indices. Selection by these indices can be useful to identify a genotype with desirable grain yield in both non-stress and waterlogging stress conditions (group A).

The genotypes G21, G18, G15, G6, and G2 were selected as waterlogging tolerance genotypes at flowering and pod-filling stages. Therefore, these genotypes can be used as source of parents in faba bean breeding programs and also to cultivation in the areas under waterlogging stress.

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