*Pak. J. Agri. Sci., Vol. 48(4), 255-261; 2011*
*ISSN (Print) 0552-9034, ISSN (Online) 2076-0906*
*http://www.pakjas.com.pk*

# PHENOTYPIC FLEXIBILITY IN EXOTIC QUINOA (*Chenopodium quinoa* Willd.) GERMPLASM FOR SEEDLING VIGOR AND VIABILITY

**Hassan Munir[1,*], Shahzad Maqsood Ahmed Basra[1], Mumtaz Akhtar Cheema[2] and Abdul Wahid[3]**

**[1]Department of Crop Physiology, University of Agriculture, Faisalabad-38040, Pakistan; [2]Department of Agronomy, University of Agriculture, Faisalabad-38040, Pakistan; [3]Department of Botany, University of Agriculture, Faisalabad-38040, Pakistan**
**[*]Corresponding author's e.mail: hmbajwa@gmail.com**

Exotic quinoa genotypes were evaluated for seedling vigor, viability, heritability, and genotypic and phenotypic variations under lab. conditions. A total of 25 genotypes of quinoa underwent comparison. Distinct demarcation among these genotypes was observed for final germination percentage, mean germination time, time to 50% germination, germination index, root/shoot length and root:shoot ratio. Viable, vigorous genotypes and poorly performing genotypes were identified and grouped from the available exotic germplasm. This selection was made on the assumption that resistance to climatic adversities and better sustainability under poor storage conditions are issues of immense importance in postharvest handling of quinoa seed. For selection of vigorous quinoa genotypes, final germination percentage (more than 90%) and root (more than 3.5 cm) or shoot lengths (more than 4.0 cm) presented themselves as important associated traits, in addition to germination index (22 to 33) and seedling survival percentage (between 90-100%). However, final germination percentage and root length were demonstrated to be reliable and environment-proof traits for the crop.
**Keywords:** Quinoa (*Chenopodium quinoa* Willd.), germination, germplasm, seedling vigor

## INTRODUCTION

Testing of seed vigor is a common practice before field cultivation (Styer *et al*., 1980). Potential assessment for speed and spread of germination of any seed lot facilitates achievement of superior crop productivity (Basra *et al*., 2002). This not only saves time and energy but also capital (AOSA, 1990). Seedling vigor is well established as the ability of plants to emerge through the soil surface and grow vigorously under diverse field conditions. This aspect becomes more significant when addressed for seed of alien crops in a particular region. In general, seed vigor and viability changes over the length of storage with a deteriorating trend and in most of the species this deterioration often leads to sterility (Gregg *et al*., 1994). For such deterioration, vigor is the first indicator resulting in reduced germination (Trawatha *et al*., 1995). However, slow and non-uniform germination or emergence are proven attributes of low seed vigor and viability (Khan, 1992; Basra *et al*., 2002), providing enough information to decide the fate of any seed lot for sowing under field conditions.

Quinoa (*Chenopodium quinoa* Willd.) is an ancient grain of people belonging to the Andean region of Latin America. It is presently under cultivation in a number of countries of the Americas, Europe and Asia (Jensen *et al*., 2000; Jacobsen, 2003). As a pseudo-cereal and a member of *Chenopodeaceae* family, quinoa grain is of high economic, nutritive and edible significance (Jacobsen, 2003; Bhargava *et al*., 2006); however, the size of the grain is very small with an approximate 1000 grain weight ranging between 2-5 g and seed diameter of less than 3 mm (Valencia-Chamorro, 2003). Moreover, its potential to yield abundant seed in spite of adverse climatic conditions such as frost, chilling, drought, freezing, salinity and nutritional stress has made it attractive for introduction in arid, semiarid, saline, and highland regions throughout the world (Choukr-Allah, 1996; Jacobsen, 2003; Schabes and Sigstad, 2005; Erley *et al*., 2005; Bonifacio, 2006). Quinoa is considered among the crops selected for future food security during the 21st century (FAO, 1998a). The significance of quinoa has therefore been increasingly recognized as severe reductions in productivity are being faced due to salinity and water-logging on badly managed irrigated croplands (FAO, 1998b).

A number of external factors affect seed vigor in quinoa with storage conditions as the most critical issue (Bertero and Ruiz, 2010; Abbas *et al*., 2011). During introduction phase of any crop species, large number of accessions is introduced as potential candidate for their cultivation in target environment or to utilize in breeding and selection programs. However, all the accessions cannot be tested in the target environment due to limited resources and financial constraints. Suitable candidate accession may be chosen from the elite germplasm before cultivation and testing in such target environment. For the purpose, seedling vigor traits have been found reliable, cheaper and rapid way for screening large germplasm (Rauf, 2008). Seedling vigor

traits describe the physiological and biochemical condition of the seed. As seed development takes place on the plant, therefore physiological and biochemical properties are greatly affect the plant performance in the field. Therefore, it has been found that genotypic performance on the basis of seedling trait often corroborate to the field performance of genotype.

On the basis of these grounds, quinoa germplasm was assessed before planting. Selection of seed on the basis of seedling vigor traits under controlled conditions will help in the selection of genotypes having superior seedling vigor in field experiments and under field production conditions.

## MATERIALS AND METHODS

Twenty-five quinoa genotypes obtained from United States Department of Agriculture, Plant Introduction Station, Iowa State University, Iowa, USA (Table 1) were analyzed for their vigor by sowing in washed and sterilized 100 mm glass Petri dishes on double-layered Whatman No. 41 autoclaved filter papers using three replications and standard sowing parameters at 20±2°C temperature in a germinator as described by Munir and Basra (2010).

***Vigor analyses:*** Germination and seedling vigor was quantified by daily germination counts at 24 h intervals and was further scrutinized in order to calculate final germination percentage (FGP), mean germination time (MGT), time to 50% germination ($T_{50}$) and germination index (GI). A seed was considered germinated when radical protrusion was measured to 3 mm or more (Basra *et al*., 2005). Seedling vigor was assessed by determining seedling fresh and dry weights, and by measuring root and shoot lengths. Final germination was counted and percentage was calculated out of total seed sown.

Time to 50% germination ($T_{50}$) was determined using the following formula (Coolbear *et al*., 1984) where 'N' stands for number of germinated seeds, '$n_i$' or '$n_j$' refers to cumulative number of germinated seed by adjacent counts at times '$t_i$' and '$t_j$' with the assumption if $n_i < N/2 < n_j$.

**Table 1. Details of quinoa germplasm under test obtained from United States Department of Agriculture**

| Sr. | Code[1] | G. Line* | Plant name* | Origin |
|---|---|---|---|---|
| 1. | Ames30 | Ames-13730 | IESP | New Mexico, USA |
| 2. | Ames37 | Ames 13737 | 2WANT | New Mexico, USA |
| 3. | Ames37 | Ames-13739 | 29TES | New Mexico, USA |
| 4. | Ames60 | Ames 13760 | 22GR | New Mexico, USA |
| 5. | Ames62 | Ames 13762 | 47TES | New Mexico, USA |
| 6. | P32 | PI 510532 | Quinoa de Quiaca. | Peru |
| 7. | P33 | PI 510533 | K'ello quinoa (Quechua) | Peru |
| 8. | P37 | PI 510537 | Koito Juira (Aymara) | Peru |
| 9. | P40 | PI 510540 | Grande (Spain.) | Peru |
| 10. | P42 | PI 510542 | Villa Juira (Aymara) | Peru |
| 11. | P79 | PI 643079 | Pasankalla | Peru |
| 12. | P18 | PI 634918 | Baer | Chile |
| 13. | P19 | PI 634919 | Pichaman | Chile |
| 14. | P21 | PI 634921 | UDEC-2 | Chile |
| 15. | P22b | PI 634922 | UDEC-4 | Chile |
| 16. | P93 | PI 596293 | Colorado 407D | Colorado, USA |
| 17. | P98 | PI 596498 | Rosa de Junin | Peru |
| 18. | P22a | PI 614922 | Sayana | Bolivia |
| 19. | P10 | PI 478410 | R-66 | Bolivia |
| 20. | P24 | PI 584524 | QQ056 | Chile |
| 21. | P05 | PI 614905 | CQ105 | Bolivia (Oruro) |
| 22. | P06 | PI 614906 | CQ106 | Bolivia (Oruro) |
| 23. | P07 | PI 614907 | CQ107 | Bolivia (Oruro) |
| 24. | P08 | PI 614908 | CQ108 | Bolivia (Oruro) |
| 25. | P09 | PI 614909 | CQ109 | Bolivia (Oruro) |

(* as per the germplasm database; [1]coding of genotypes made for local identification)

$$T_{50} = t_i + \frac{\left(\frac{N}{2} - n_i\right)}{n_j - n_i}\left(t_j - t_i\right)$$

However, mean germination time (MGT) was calculated according to the following equation of Ellis and Roberts (1981). Here 'n' refers to total germinated seed counted on day 'D', i.e. the number of days counted from the day on which germination started.

$$MGT = \frac{\sum Dn}{\sum n}$$

The standard procedure for calculating germination index (GI) was adopted as described by the Association of Official Seed Analysts (AOSA, 1990):

$$GI = \frac{\text{No. of germinated seeds}}{\text{Days of first count}} + - - - + \frac{\text{No. of germinated seeds}}{\text{Days of final count}}$$

Seedlings were analyzed for vigor by first removing them carefully from the filter papers. Five seedlings were randomly selected from each replicate and values were averaged. Root and shoot fresh weights were determined at harvest, whereas root and shoot dry weights were taken following four days drying in oven at 70°C on achievement of concordant weight values.

The following formulae were used for calculation of genotypic and phenotypic coefficients of variation (Singh and Chaudhary, 1985):

Phenotypic coefficient of variation (PCV) $= 100\sqrt{\sigma_p^2}/X$

Genotypic coefficient of variation (GCV) $= 100\sqrt{\sigma_g^2}/X$

Where:

$\sigma^2_g$ = (genotypic mean square – error mean square)/number or replications

$\sigma^2_p$ = genotype mean square/number of replications

$X$ = The mean

Heritability, by definition, is the extent to which individual genetic differences contribute to individual differences in observed behavior (the phenotype) in offspring as described by Akinwale *et al.* (2011).

$$H^2 = \frac{\text{Var(G)}}{\text{Var(P)}}$$

Where:

$H^2$ = Heritability

Var(G)= Genotypic variance

Var(P)= Phenotypic Variance

Results obtained were compared at the 5% probability level using Fisher's analysis of variance technique (Steel *et al*., 1997) as summarized in Table 2.

## RESULTS

***Seedling vigor traits*:** Analyses of variance exposed significant variation (P>0.05) among the genotypes for all germination and seedling vigor traits. Seedling vigor traits are represented in Figure 1a,b,c,d,e,f and Figure 2. Genotypes Ames30, Ames37, P37, P40, P42, P79, P19, P93, P22b and P10 were found to have more than 90% final germination. However, the rest of the genotypes including Ames39, Ames60, Ames62, P33, P18, P21, P22a, P98, P12, P05, P06, P07, P08 and P09 had less than 50% seed germination. The highest germination was observed in P37, whereas P05 was recorded with least seed germination. Moreover, genotypes Ames30, Ames37, Ames39, P37, P40, P42, P19, P93, P98, P22b and P10 completed their 50% germination between 1.00 and 1.50 days (Fig. 1b). The lowest $T_{50}$ was observed in P37, whereas P09 exhibited the maximum $T_{50}$ with statistically similar duration observed in genotypes P18 and P07. However, genotypes Ames30, Ames37, Ames62, P37, P40, P42, P19, P22a and P22b showed a maximum of 2.5 days mean germination time, while the rest of the genotypes took longer time to germinate.

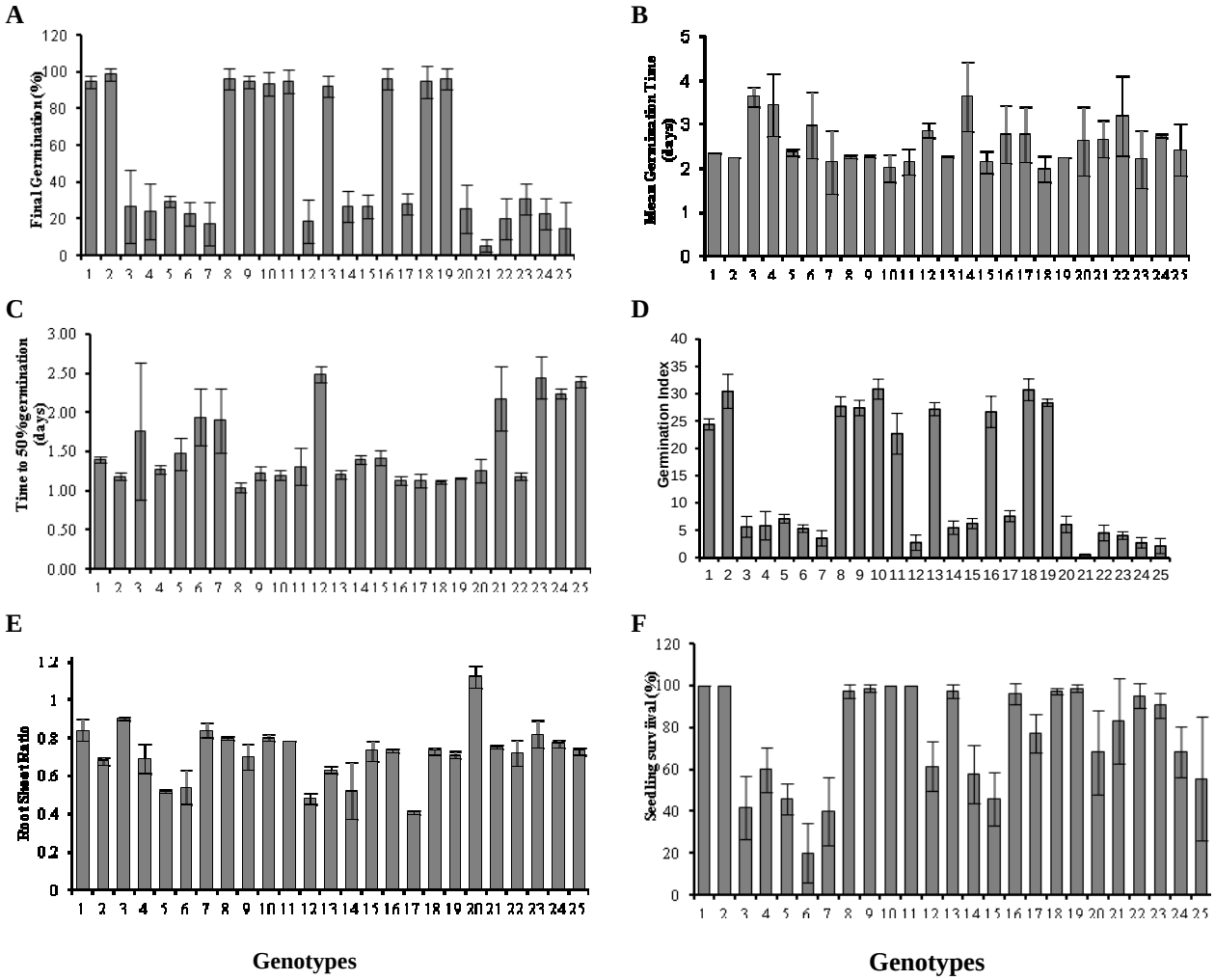
For root length, Ames30, P37, P40, P42, P79, P90, P93, P22b and P10 had significantly longer root lengths, with maximum length observed in P42. Accessions P18 and Ames60 were statistically similar for the shortest root length. Figure 2 explains that genotypes Ames30, Ames37, P37, P40, P42, P79, P19, P93, P22b and P10 had shoot length ranging 4.0 to 5.05 cm. All other genotypes had lesser seedling length, while the lowest value of 0.70 cm was observed in genotype P22a. For root:shoot, genotype P24 had the highest value followed by Ames39 and P07. This ratio was the lowest (0.38) for P98. Genotypes Ames30, Ames37, P37, P40, P42, P93 and P19 had root:shoot between 0.3 and 0.6.

For seedling survival percentage Ames30, Ames37, P42 and P79 exhibited values of one hundred percent, while P19,

**Table 2. Summary of the analyses of variance (ANOVA) in quinoa**

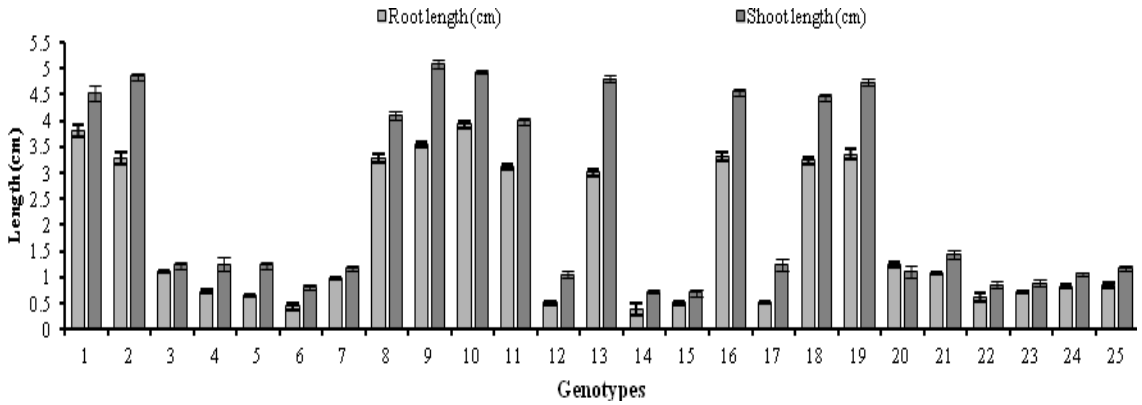
| | DF | FGP (%) | 50G | MGT | RL | SL | R/S | SS% |
|---|---|---|---|---|---|---|---|---|
| Accessions | 24 | 4009.56** | 0.68** | $0.71^{NS}$ | 5.43** | 9.63** | 0.07** | 1812.29** |
| Error | 50 | 41.60 | 0.12 | 0.47 | 0.19 | 0.21 | 0.00 | 273.77 |
| Total | 74 | | | | | | | |

Final germination percentage (FGP), Time to 50% germination (50G), Time to mean germination (MGT), Root length (RL), Shoot length (SL), Root shoot ratio (R/S), Seedling survival (SS%)




**Genotypes: 1.** Ames13730; **2.** Ames13737; **3.** Ames-13739; **4.** Ames13760; **5.** Ames-13762; **6.** PI510532; **7.** PI510533; **8.** PI510537; **9.** PI510540; **10.** PI510542; **11.** PI643079; **12.** PI634918; **13.** PI634919; **14.** PI634921; **15.** PI634922; **16.** PI596293; **17.** PI596498; **18.** PI614922; **19.** PI478410; **20.** PI452512; **21.** PI614905; **22.** PI614906; **23.** PI614907; **24.** PI614908; **25.** PI614909

**Figure1. Seedling vigor traits of quinoa**




*legends for genotypes on x-axis as described in the Fig. 1.

**Figure 2. Seedling root and shoot lengths of the exotic quinoa genotypes**

P93, P22b and P10 had greater than ninety percent survival. In contrast, P32 showed the lowest seedling survival percentage at 20%.

***Heritability, genotypic and phenotypic coefficients*:** In addition to seedling vigor traits, variation among the genotypes was also estimated through genotypic and phenotypic coefficients of variation. For seedling vigor traits, the highest genotypic variation was observed for root length, shoot length and final germination percentage (Table 3). In addition to the highest genotypic and phenotypic variation among the traits, they also showed the highest heritability estimates. Final germination percentage and root or shoot length was with the highest estimates on the basis of genotypic coefficient of variation (GCV) and heritability (H); therefore, these traits appeared to be the bases for selection of genotypes.

***Pearson correlations for seedling vigor traits*:** Among seedling vigor traits correlations were also estimated (Table 3). These showed that final germination percentage positively and significantly correlated with all the seedling vigor traits. Similarly, mean root length and mean shoot length traits also showed significant positive correlations with all the traits. On basis of these findings it may be inferred that the selection of quinoa genotypes on the basis of final germination percentage, mean germination time and means of root or shoot length would also result in positive impacts on other seedling traits such as germination index and seedling survival percentage.

## DISCUSSION

Presence of adequate genetic variation, high heritability and ease with which germplasm may be screened are the basic criteria for rapid evaluation of germplasm (Rauf, 2008). In this regard, better germination and robust seedling vigor have been found as the basic parameters for selecting suitable genotypes from among introduced germplasm (Dodig and Jovic, 2008; Rauf, 2008; Rau *et al*., 2008). Therefore, seedling traits have been extensively used for screening germplasm in various species under diverse environmental conditions (Munir, 2004). However, a few studies have been reported in quinoa, thus there was a need to determine the magnitude of genetic variation and scope of seedling traits as basic parameter for screening germplasm. Under the present study, 25 exotic genotypes were studied. Significant variation regarding germination, seedling vigor and survival of the seedlings was observed. Quinoa seeds are orthodox seeds (Ellis *et al*., 1988). Although orthodox seeds have usually longer storage longevity, the storage life depends upon proper seed drying and storage techniques. Quinoa seeds showed better shelf life if they were dried to the nail dented stage, otherwise the seeds would deteriorate and show poor germination (Ng *et al.,* 2007).

Variation among the genotypes for final germination percentage generated information relevant to the final status of the seed of different genotypes prior to its cultivation in the field. Poor germination seems due to dormancy of the seed. The issue may be due to the incompatibility of genotypes with the storage environment, whereby some of the accessions could not give optimum germination after a two-month storage period. This sort of storage hazard is more pronounced when seed like quinoa undergo cultivation in new lands because of unpredictable storage conditions during transit (Ceccato *et al.,* 2011), and no germplasm dissemination facility can guarantee viability of seed upon arrival at the doorstep of the stakeholder (Ceccato *et al.,*

**Table 3. Genotypic and phenotypic variation parameters in quinoa**

| TRAIT | RANGE | AVERAGE | GCV (%) | PCV (%) | $H^2$ |
|---|---|---|---|---|---|
| Root Length | 0.38-3.93 cm | 1.81 | 74 | 78 | 0.97 |
| Seedling survival | 20-100% | 75.84 | 30 | 37 | 0.61 |
| Shoot length | 0.70-5.09 cm | 2.48 | 72 | 75 | 0.15 |
| Final Germination | 5.33-98.67% | 51.63 | 70 | 72 | 0.91 |
| T50 | 1.04-2.49 days | 1.54 | 28 | 56 | 0.94 |
| Mean Germination | 1.99-3.63days | 2.57 | 11 | 29 | 0.65 |

Genotypic coefficient of variation (GCV), Phenotypic coefficient of variation (PCV), Broad Sense Heritability ($H^2$)

**Table 4. Correlation matrix among the examined traits of quinoa**

| PLANT TRAITS | FGP | MGT | GI | MRL | MSL |
|---|---|---|---|---|---|
| Mean germination time | -0.53 | | | | |
| Germination index | 0.99 | -0.53 | | | |
| Mean root length | 0.96 | -0.55 | 0.96 | | |
| Mean shoot length | 0.97 | -0.54 | 0.98 | 0.98 | |
| Seedling survival | 0.75 | -0.44 | 0.73 | 0.77 | 0.77 |

Final germination percentage (FGP), Mean germination time (MGT), Germination index (GI), Mean root length (MRL), Mean shoot length (MSL)

2011). Germination index and time to 50% germination, in addition to mean germination time, are sufficient to predict performance of any particular seed lot under field conditions (Coolbear *et al*., 1984; Basra *et al.,* 2005). Vigor and root length are important markers for assessment of performance of any seed lot in the field, even under stressful conditions. Genotypic ability to emerge lengthy roots and shoots upon germination of the seed in the absence of exogenous nutrition predicts the potential of any crop for better field performance (Kamoshita *et al*., 2006).

Low heritability values in the presence of high PCV values show high environmental influence (Khan *et al*., 1992). High heritability values for root length, final germination percentage and time to 50% germination show dominant effect of genes. Furthermore, root length also showed high genotypic variation, thus showing higher contribution of genes in the development of phenotype which is in agreement with Malik *et al*. (2000). Similarly, the final germination percentage and root length had high heritability and PCV values which proved significant for determining genetic variability and basic screening of the genotypes as proposed by Ibrahim and Hussain (2006).

According to the correlation matrix of seedling germination and vigor traits; root length, shoot length, seedling survival percentage, germination index, and mean germination time exhibited positive correlations with the final germination percentage, proving dependence of these traits on final seedling count and affirming the above inferences.

In general, two distinct groups of genotypes emerged as a result of their seedling vigor assessment. Ames30, Ames37, P37, P40, P42, P79, P19, P93, P22b and P10 were members of the highly vigorous group due to their uniformity in speed and spread of germination. These quinoa genotypes had higher survival percentage and produced superior seedling stand in less time than that taken by the rest of the genotypes and with negligible fluctuations. Consequently, this group can be selected for further assessment as the better performing germplasm.

## CONCLUSIONS

The selection of quinoa genotypes on the basis of final germination percentage and root or shoot length would also result in positive selection for other seedling traits such as germination index and seedling survival percentage. In addition, final germination percentage and root length are identified as reliable and environment-proof (stable) traits for selection in quinoa germplasm. Pre-sowing assessment of these parameters for quinoa seed lots can help to avoid poor field performance of the crop especially while assessing its adaptability in new regions.

## ACKNOWLEDGEMENTS

The authors thank Mr. David Brenner, Germplasm Curator, USDA-ARS, Iowa, USA for providing quinoa seeds, Dr. Sven-Erik Jacobsen, Associate Professor, Department of Agriculture Sciences, University of Copenhagen, Denmark, Dr. Eric. N. Jellen, University of Brigham Young, Utah, USA and Dr. Saeed Rauf, Assistant Professor, College of Agriculture, University of Sargodha, Pakistan for valuable inputs in this manuscript.

## REFERENCES

Abbas, G., T.M. Khan, A.A. Khan and A.I. Khan. 2011. Discrimination of salt tolerant and susceptible cotton genotypes at seedling stage using selection index. Int. J. Agric. Biol. 13:339-345.

Akinwale, M.G., G. Gregorio, F. Nwilene, B.O. Akinyele, S.A. Ogunbayo and A.C. Odiyi. 2011. Heritability and correlation coefficient analysis for yield and its components in rice (*Oryza sativa* L.). Afric. J. Plant Sci. 5(3):207-212.

AOSA, 1990. Rules for testing seeds; Association of Official Seed Analysts. J. Seed Technol. 12:1-112.

Basra, S.M.A., M. Farooq, R. Tabassum and N. Ahmad. 2005. Physiological and biochemical aspects of seed vigor enhancement treatments in fine rice (*Oryza sativa* L.). Seed Sci. Technol. 33:623-628.

Basra, S.M.A., M.N. Zia, T. Mehmood, I. Afzal and A. Khaliq. 2002. Comparison of different invigoration techniques in wheat (*Triticum aestivum* L.) seeds. Pakistan J. Arid Agric. 5:11-16.

Bertero, D. and R.A. Ruiz. 2010. Reproductive partitioning in sea level quinoa (*Chenopodium quinoa* Willd.) cultivars. Field Crop Res. 118:94-101.

Bhargava, A., S. Shukla and D. Ohri. 2006. Karyotypic studies on some cultivated and wild species of *Chenopodium* (*Chenopodeaceae*). Gene. Res. Crop Evol. 53:1309-1320.

Bonifacio, A. 2006. Frost and hail tolerance in quinoa crop and traditional knowledge to handle these adverse factors, p.68. In: D. Sarvis, I. Mar and L. Sears (eds.), Proc. Workshop 23–27 May, 2005, Budapest, Hungary. International plant genetic resources institute, Rome, Italy.

Ceccato, D.V., H.D. Bertero and D. Batlla. 2011. Environmental control of dormancy in quinoa (*Chenopodium quinoa*) seeds: two potential genetic resources for pre-harvest sprouting tolerance. Seed Sci. Res.1-9. doi:10.1017/S096025851100002X.

Choukr-Allah, R. 1996. The potential of halophytes in the development and rehabilitation of arid and semi-arid zones. In: *Halophytes and Bio-Saline Agriculture* (Ed.

R. Choukr-Allah, C.V. Malcolm & A. Hamdy), p. 3-13. Marcel Dekker, NewYork.

Coolbear, P., A. Francis and D. Grierson. 1984. The effect of low temperature pre-sowing treatment under the germination performance and membrane integrity of artificially aged tomato seeds. J. Exp. Bot. 35:1609-1617.

Dodig, D. and M. Jovic. 2008. Screening wheat genotypes for germination potential and young seedling growth under water stress. p. 355-358. In: J. Prohens, and M.L. Badenes (eds.), Modern variety breeding for present and future needs. Proc. 18th EUCARPIA general congress, 9-12 Sep., 2008, Valencia, Spain.

Ellis, R.A. and E.H. Roberts. 1981. The quantification of ageing and survival in orthodox seeds. Seed Sci. Technol. 9:373-409.

Ellis, R.H., T.D. Hong and E.H. Roberts. 1988. A low moisture content limit to logarithmic relations between seed moisture content and longevity. Ann. Bot. 61:405-408.

Erley, G.S.A., H.P. Kaul, M. Kruse and W. Aufhammer. 2005. Yield and nitrogen utilization efficiency of the pseudo-cereals amaranth, quinoa and buckwheat under differing nitrogen fertilization. Eruop. J. Agron. 22:95-100.

FAO, 1998a. *Under-utilized Andean Food Crops*, p.38. Food and Agriculture Organization, Rome, Italy.

FAO, 1998b. *News & highlights*. International coalition focuses on research and technology to help farmers in developing countries grow ‘‘more crop per drop’’. Food and Agriculture Organization. Rome, Italy.

Gregg, B., S.A.E. Wanis, Z. Bishaw and A.J.G. van Gastel. 1994. *Safe Seed Storage*. WANA Seed Network Publication No. 5/94. ICARDA, Aleppo, Syria.

Ibrahim, M.M. and R.M. Hussein. 2006. Variability, heritability and genetic advance in some genotypes of roselle (*Hibiscus sabdariffa* L.). World J. Agric. Sci. 2:340-345.

Jacobsen, S.E. 2003. The worldwide potential for quinoa (*Chenopodium quinoa* Willd.). Food Rev. Int. 19:167-177.

Jensen, C.R., S.E. Jacobsen, M.N. Andersen, N. Nun˜ez, S.D. Andersen, L. Rasmussen and V.O. Mogensen. 2000. Leaf gas exchange and water relations of field quinoa (*Chenopodium quinoa* Willd.) during soil drying. Europ. J. Agron. 13:11-25.

Kamoshita, A., R.C. Babu, N.M. Boopathi and S. Fukai. 2006. Phenotypic and genotypic analysis of drought-resistance traits for development of rice cultivars adapted to rainfed environments. Field Crop Res. 109:1-23.

Khan, A.A. 1992. Preplant physiological seed conditioning. Hortic. Rev. 14:131-181.

Khan, A.H., T. Mahmood and S.A. Shah. 1992. Path coefficient analysis of morphological parameters with seed yield in Raya. Pak. J. Agric. Res. 3:334-337.

Malik, M.A., A.S. Khan, Saifullah, M.A. Khan, B.R. Khan and S.M. Mahmood. 2000. Study of correlation among morphological parameters in different varieties/accessions of *Brassica* species. Pak. J. Biol. Sci. 3:1180-1182.

Munir, H. 2004. Physiological basis of prime wheat seed under late sown conditions. M.Sc. thesis, Department of Agronomy, University of Agriculture, Faisalabad, Pakistan.

Munir, H. and S.M.A. Basra. 2010. Improved germination and seedling vigor enhancement of quinoa (*Chenopodium quinoa* Willd.) grown at different salinity levels, pp 33-39. In: M. Qadir, D. Wichelns, J. Oster , S.-E. Jacobsen, S.M.A. Basra and R. Choukr-Allah (eds.), Sustainable management of saline waters and salt affected soils for agriculture. 2nd Bridging workshop, 15-18 Nov., 2009, Aleppo, Syira. ICARDA, Aleppo, Syria & IWMI, Colombo, Sri Lanka.

Ng, S.C., A. Anderson, J. Coker, and M. Ondrus. 2007. Characterization of lipid oxidation products in quinoa (*Chenopodium quinoa*). Food Chem. 101:185-192.

Rauf, S. 2008. Breeding sunflower (*Helianthus annuus* L.) for drought tolerance. Commun. Biometry & Crop Sci. 3:29-44.

Rauf, S. and H.A. Sadaqat. 2007. Effect of moisture regimes on combining ability variations of seedling traits in sunflower (*Helianthus annuus* L.). Cand. J. Plant Sci. 88:323-323.

Schabes, F.I. and E.E. Sigstad. 2005. Calorimetric studies of quinoa (*Chenopodium quinoa* Willd.) seed germination under saline stress conditions. Acta Thermochem. 428:71-75.

Singh, R.K. and S.D. Chaudhary. 1985. *Biometrical Methods in Quantitative Genetic Analysis*. Kalyani Publishers, New Delhi, pp.205-214.

Styer, R.C., D.J. Cantliffe and L.C. Hannah. 1980. Differential seed and seedling vigor in sunken-2 compared to three other genotypes of corn at various stages of development. J. Amer. Soc. Hort. Sci. 105:329-332.

Trawatha, S.E., D.M. Tekrony and D.F. Hildebrand. 1995. Relationship of soybean quality to fatty acid and $C_6$–aldehyde levels during storage. Crop Sci. 35:115-142.

Valencia-Chamorro, S.A. 2003. Quinoa. Ency. Food Sci. Nut. 8: 4895-4902.