Plant & Fungal Research (2019) 2(2): 31-40
http://dx.doi.org/10.29228/plantfungalres.22

December 2019

Comparative studies of reproductive biology, seed morphology and anatomy of new salt tolerant accessions of Quinoa (*Chenopodium quinoa* Willd.) introduced in Kur-Araz lowland (Azerbaijan)

Khatira H. Gasimova[1]
Valida M. Ali-zade
Institute of Botany, Azerbaijan National Academy of Sciences, Badamdar 40, Baku, AZ1004, Azerbaijan
Dildora M. Yusupova
Institute of Gene Pool of Plants and Animals of Academy of Sciences of the Republic of Uzbekistan, Bagishamol 232, Tashkent, 100125, Uzbekistan
Kristina N. Toderich
The International Platform for Drylands Research and Education (IPDRE), 1390 Hamasaka, Tottori-city, TOTTORI, Japan 680-0001Tottori University, Japan; The International Center for Biosaline Agriculture for Central Asia and Caucasus (ICBA-CAC) regional sub-office, Tashkent 100000, 6A Osiyo street, Tashkent, Uzbekistan
Tura Rakhimova
National University of Uzbekistan, Universitetskiy street 4 Tashkent, 100174, Uzbekistan

Abstract: Investigated salt tolerant top-ranking accessions of Quinoa introduced on drought prone and salt affected soils with higher clay contents, water holding capacity, evapotranspiration and shallow water in Kur-Araz (Azerbaijan) undergone all ontogenetic reproductive (pollen grain productivity, embryo and fruit developmental stages) and produce viable seeds. The floral initiation stage varies between 66-77 days depending on genotype, plant height, days to flowering and to seed maturity, and dry weight biomass ($p > 0.05$). The interaction effect of location and genotypes was significant for days to flowering and seed maturity and dry weight, though not for plant height and seed yield. Three early-middle and late-flowering, and thus early-middle and late seed maturation clusters of quinoas was described. Quinoa is predominantly self-pollinating species, but pollination inside the inflorescence by means of wind (anemophilous) or with support of small insects (entomophilous) occurs. There was no significant difference in the fruit and seed morphology among investigated accessions of quinoa cultivated under new environments. Fruits of quinoa are simple, dry, indehiscent, achene, monosperm with white pericarp in the mature state and remainans of perigonium, albuminous white or yellowish seed 1.8-2.5 mm in diameter. In quinoa seeds the pericarp is very thin; as a result, the achene is also referred to as utricle. Viable seed contains a peripheral, curved embryo surrounding by perisperm and pericarp. Pronounced micropylar endosperm (a non-embryonic tissue) of one or two cell layers thick forms a cone surrounds the root apical meristem of the embryo. Anatomy of quinoa micropylar endosperm revealed similarities in structure with coleorhiza cells in cereals. Both tissues serve as store reserve and play vital role by protecting the root apical meristem in the quiescent seed and control dormancy during germination. Further investigation of micropylar cellular tissue of quinoa, where stores lipids, proteins and minerals should be considered to select better adapted genotypes with high seed yields and nutritional quality combined with salt-and drought-tolerance. Freshly collected quinoa seeds have endogenous physiological type of dormancy. All investigated quinoa accessions, except Quinoa-Q2 showed high germination rate (78-85%) through 16 hours at room temperature (24-25 ºC). Identification of desirable genotypes needs to be followed by work on optimization of cultural practices and seed storage to maximize productivity under the drought-prone and salt affected of Kur-Araz farming areas. Early seed sowing in the field is required, thus early flowering and seed maturation occurs long before heat summer season starts.

Key Words: *pollen grain, dry utricle fruit, micropylar endosperm, pseudocereal plant, salinity, desertification, Quinoa*

INTRODUCTION

Kur-Araz lowland is highly susceptible to environmental degradation and affected by desertification, land degradation and drought (DLDD) owing to its geographical and climatic characteristics. Harsh climate, scarcity of fresh water and increasing ground water salinity are severe limitation to productivity. Some 30-40% of the cultivated areas have groundwater salinity of > 4dS/m and soil quality rather poor to support the production of the traditionally grown forages and vegetables. Most of the salt-affected and alkaline agricultural lands (electrical conductivity [EC] = 4-20 dS/m) with heavy clay soil texture and low fertility is located in the central part of Kur-Araz lowland. Many of the currently grown major crops are water-thirsty (e.g. alfalfa, corn and salt-sensitive vegetables). It is likely to become hotter and

---

Accepted for publication: 5 November 2019

[1] E-mail: xatira1987@gmail.com

drier due to climate change - increased water scarcity and salinity further impacting agricultural production.

Diversification of production systems through introduction of new salt-tolerant and water-use efficient crops is a key adaptation measures for rural communities to improve their incomes under climate change. Promotion of alternative agricultural production systems can assist in exploiting the available soil, water and crop resources, and transferring of innovations in agriculture [Hirich et al., 2014; FAO, 2016; Rao et al., 2019]. Appropriate evaluation of non-traditional and traditional crops tolerant to abiotic and biotic stress, including high salinity (e.g. quinoa, sorghum, amaranthus, pearl millet, legumes, perennial grass and bioenergy halophytes) may become an integral component in improving local food, crop-livestock feeding, farming production and land rehabilitation systems [Toderich et al., 2014; Choukr-Allah et al., 2016; Gasimova, 2018].

The family Amaranthaceae (former Chenopodiaceae) comprises 100 genera and 1500 species. It is originated in Andean region of South America; Ecuador, Bolivia, Colombia and Peru [Elham, 2014]. One of high nutrition crops recognized all around the world is Quinoa -*Chenopodium quinoa* Willd. (Amarantaceae). Quinoa ecotypes (*Chenopodium quinoa*) adapted to various environments, displaying wide genetic variability with diverse growing periods (100-160 days), and have been introduced into agriculture practices in more than 70 countries. Quinoa seeds are highly nutritious due to the quality of their proteins and lipids and the wide range of minerals and vitamins they store. The ability of quinoa to produce high-quality proteins under extreme environmental conditions makes it an important crop not only for Andean communities but also for the diversification of future agricultural systems over the world [Rao et al., 2019]. Certain varieties grow well in difficult conditions because they are drought- and salt-resistant; plants grow in mountainous areas and lowlands, which confirms its universality as a crop that adapts to the surrounding climatic conditions [Zaman et al., 2018; Toderich et al., 2013; Rao et al., 2019]. Due to its high adaptability to different climatic conditions and effective water consumption, quinoa is an excellent alternative grain cash crops under ongoing climate change. Quinoa is considered a healthy food due to its high nutritional value, high protein content distinguishes quinoa from most other foods of plant origin (with the exception of legumes): it contains all the essential amino acids, and is also rich in minerals, vitamins, fatty acids and other nutrients [Bertero, 2001; Solız-Guerrero et al., 2002; Bosque-Sanchez et al., 2003; Jacobsen et al., 2005, 2011; Razzaghi et al., 2011; Bazile et al., 2015; Choukr-Allah et al., 2016]. Quinoa grain is recommended as an organic agricultural product during long-term space expedition by NASA [Schlick, Bubenheim, 1993].

According to A. Zurita-Silva et al. [2014] and B.L. Graf et al. [2015] the worldwide inte-rest in quinoa as a pseudocereal has grown extensively, thanks to its nutritional qualities and its ability to adapt to marginal soils with high salinity contents [Eisa et al., 2012], dry environments prone to frosts [Jacobsen et al., 2007] and scarce water resources [Garcia et al., 2003].

This adaptability has allowed quinoa to be considered as a promising alternative to traditional crops in a climate change scenario [Sosa-Zuniga et al., 2017]. Phenological growth stages of quinoa were studied in Chile [Sosa-Zuniga et al., 2017]. Thin parenchyma contains biologically active substances involved in metabolic processes [Sapankevich, 1964; Rays, 1978].

Based on literature overview we have concluded that there is insufficient information on quinoa seed morphology and anatomy related to seed germination. There is evidence that soil salinity, heavy clay texture and temperature variables induced abnormalities during reproductive stages development, which leads to formation of sterile and low viability of pollen grain, low rate of pollen tube growth, embryo differentiation, thus early seed set low seed yield quantity and quality [Tapia et al., 2007; Toderich, 2008; Vega-Galvez et al., 2010]. Data on the impacts of climate change on crop seed set and production of quinoa is still limited.

Evaluating the effects of environment on quinoa seed development stages and seed quality is very important. Three cellular compartments were distinguished within the quinoa mature seed: embryo, endosperm, and perisperm responsible for nutrients accumulation and allocation [Herman Burrieza et al., 2014]. However, there is not information to which range soil salinity and drought (summer heat) affects the cellular structure of these storage tissues in quinoa seeds. Endosperm development has only recently begun to be studied in quinoa [López-Fernández, Maldonado, 2013b].

The main purpose of this study was to investigate the peculiarities of the development of reproductive organs, seed morphology and anatomy related to seed germination and seed yield for five new salt tolerant accessions (genotypes) of quinoa introduced under marginal environments of Kur-Araz lowlands (KAL) in Azerbaijan.

MATERIAL AND METHODS

Location and soil. The field trials were carried out in Kurdamir Experimental Station (KES) of the Institute of Botany, ANAS, located on the right side of Baku-Tbilisi highway, in the middle part of Kur-Araz lowland, 7 m a. s. l., during 2015-2018 (Fig. 1). The laboratory experiments and trials were also conducted in the greenhouse of the Institute of Botany to clarify the relevant mechanisms (Fig. 1). Soil has clay heavy texture, mostly moderate to high salinity (EC=6-12 dS m^{-1}) with chloride- sulphate type, low organic matter (<1.5 %) moderately alkalinity level (pH<8.4), high bulk density (1.36 g cm^{-1}) and low nutrient (NP < 12-15 ppm) content. Soil had high swelling potential due to montmorillinitic clay minerals and low structure stability. Volumetric water content for field capacity and wilting point were 0.42 g g^{-1} and 0.23 g g^{-1}. Shallow water (1.5-2.1) with mineralization 5-14 g l^{-1} was available.

Quinoa plant germplasm - five selected salt tolerant quinoa lines marked as Q1, Q2, Q3, Q4, Q5 were obtained from International Center for Biosaline Agriculture (ICBA). Each accession was planted in six field trials. The plot size was 2 x 3 m, and distances between plots in two directions were 1.2 m and 2 m. The distance between the rows was 60 cm, depth of planting was 1 cm, density of seedling was two seeds per cell 98 per plot as recommended by ICBA. All trials were conducted in three replications.

The plots were hand harvested when seeds were at physiological maturity and contained 20 to 30% water. After harvest the plants were dried at low air moisture condition; during dry season, threshed, seeds were cleaned and stored in cold room at 10 °C temperature at 12% water content.

RESULTS AND DISCUSSION

Flower and pollen morphology. All investigated accessions (improved lines) of *C. quinoa* are characterized by the presence of flat petiolate leaves and flowers arranged in dense thyroid inflorescences usually called glomerules. Leaves are 1-5 cm long and 0.4-2 cm broad; they are waxy-coated and mealy in appearance, with a whitish coat on the underside. Flowers are bisexual, rarely monosexual. Flowers consist of (4-) 5 perianth segments connate: basally or close to the middle, usually membranous margined and with a roundish to keeled back; almost always 5 stamens, and one ovary with 2 stigmas.

Investigated improved lines of quinoa cultivated in open field were characterized by extended flowering period. Significant differences among studied quinoa accessions were revealed in dynamics of flowering process. The floral initiation stage occurs at 66-77 days after planting. Investigated quinoa genotypes showed insignificant differences for plant height, days to flowering and maturity, and dry weight (p>0.05). The interaction effect of location and genotypes was significant for days to flowering and maturity and dry weight, though not for plant height and seed yield.

Table 1 illustrates the difference in flowering dynamics of *C. quinoa* in Kur-Araz environment (calculated at 50% of flowers).

As seen from Table 1 three quinoa clusters were identified based on biology of flowering: early, middle and late flowering, which was also reflecting on seed maturation duration of quinoa accessions.

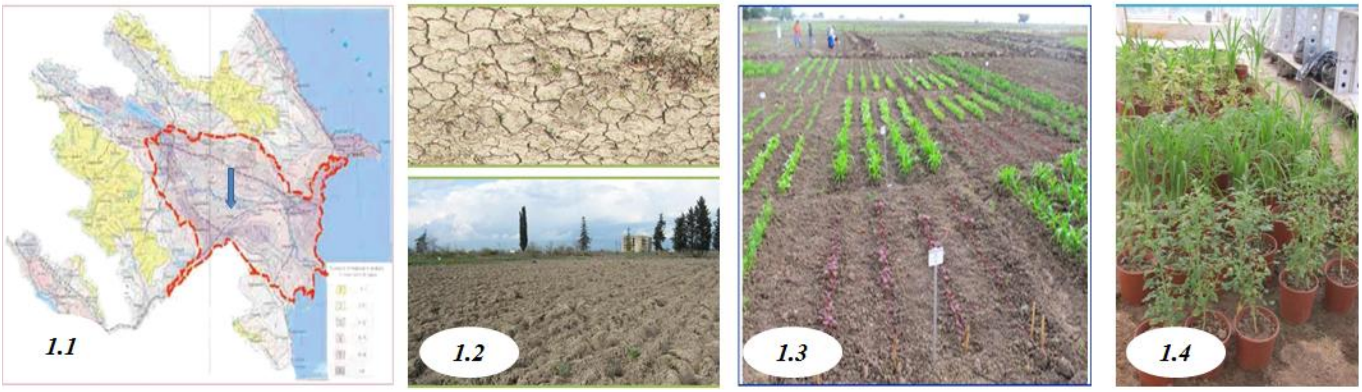

Figure 1. Study area: 1.1. Central part of Kur-Araz lowland; 1.2. Clay structure of soil; 1.3. Quinoa field trials; 1.4. Greenhouse experiments on Quinoa.

Table 1. Dynamic of flowering of accessions of *C. quinoa* 50% of opening flower the period of anthers dehiscence. Average data for 2015-2017 years.

Accessions	Number of days before flowering	Number of days at 5% flowering	Number of days up to 100% flowering
Q1	52	60	67
Q2	56	67	78
Q3	50	59	64
Q4	58	70	78
Q5	48	54	60

Quinoa is a predominantly self-pollinating species and considerable variation exists between cultivars for many of the desired characters. Pollination can also occur by geytonogamy (pollination inside the inflorescence) by means of wind (anemophilous) or with support of small insects (entomophilous). Analysis of pollen grains at the 50% of flowering plants revealed development of heterogeneity of pollen grains. Early flowers produced a high percent of sterile pollen grains. The pollen produced differ in its shape, size and dynamics of growth of pollen tube that indicate the hybrid origin of quinoa accessions. Fertile sprouted pollen grain has long pollen tube with well differentiated nucleus and cytoplasm (Fig. 2). Despite of the presence of significant quantity of sterile pollen grains the investigated quinoa lines, especially Q2 and Q5 have high seed set value. Even low fertility of pollen provides success of pollination and double fertilization.

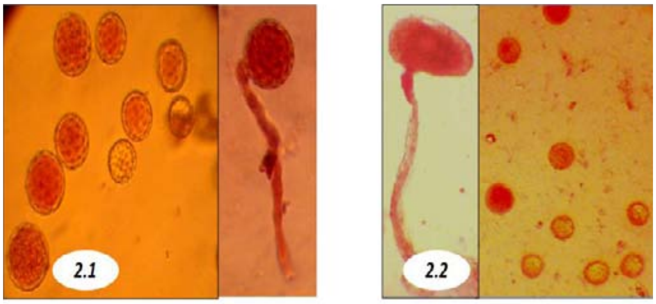

Figure 2. Evaluation of the germination of pollen grain: 2.1. Accession Q2; 2.2. Accession Q5, pollen germination, formation of germination tube.

Seed morphology. There was no significant difference in the fruit and seed morphology among investigated accessions of quinoa cultivated in new environments. Fruits of plant are simple, dry, indehiscent, achene, monosperm with white pericarp (Fig. 3), in the mature state with remnants of perigonium, albuminous white or yellowish seed 1.8-2.5 mm in diameter. In quinoa seeds the pericarp is very thin; as a result, the achene is also referred to as utricle. In mature fruit is always dry and often uncoloured and consists of one or several, rarely multiple, undifferentiated layers of parenchymatous cells. Thickness of pericarp does not exceed 40-60 µm. The innermost pericarp layer, if present, often consists of thick-walled parenchymatous cells. Druses of crystals are relatively rare and are deposited in the subepidermal cell layers.

The seeds are with a thin (5-15 µm) yellow testa. Studied samples have slightly depressed seeds with ovoid outlines in cross-section. The shape of the seed corresponds to the shape of the embryo. Seed of Q1 accession is fine (5-15 µm) and light yellow colour. Unlike early described other types of *C. quinoa* thin light-yellow seeds of lacks stalactites [Suxorukov, 2015]. Pericarp is partially separated by seed coat at harvest time. Seed coat thickness in *C. quinoa* varies among studied accessions and is composed of two cell layers, the endotegmen (the inner layer) and the exostema (the external one). The presence of oblate unicellular papillae is noted in the outer layer of the pericarp. In mature fruits the papillous cells often fail to maintain turgidity thereby appearing crater-like. Morphology and anatomy of embryo of investigated for Q1 and Q5 accessions of quinoa shown close similarities.

Quinoa mature fruits are characterized by the presence of large central perisperm and well differentiated peripheral embryo. Mature fruits of quinoa have a pronounced micropylar endosperm, which is presented by two cells layered surrounding the hypocotyl-radicle axis of the embryo.

The biology of seed germination. The biology of seed germination is a part of the general biology of the plant, reflecting its formation and development in connection with environmental factors. The fruits and seeds of the Amaranthaceae species differ by biology of seed germination [Butnik, 1981, 1991]. Seeds of many species either do not have dormancy period, or it is short, about 1-3 months [Martin, 1946]. Exogenous dormancy of seeds is caused by the pericarp, endogenous - by the properties and ontogenetic stages of embryo: its morphological or anatomic underdevelopment, or a special physiological state. Thin parenchyma contains biologically active substances involved in metabolic processes, which is manifested in the allelopathic effect of seeds of some species during germination [Sapankevich, 1964; Rays, 1978]. According to archaeological data, seeds of species of the genus *Chenopodium* remain viable for 1500 years [Odum, 1965]. As the literature data showed, the long-term preservation of seeds in fossils

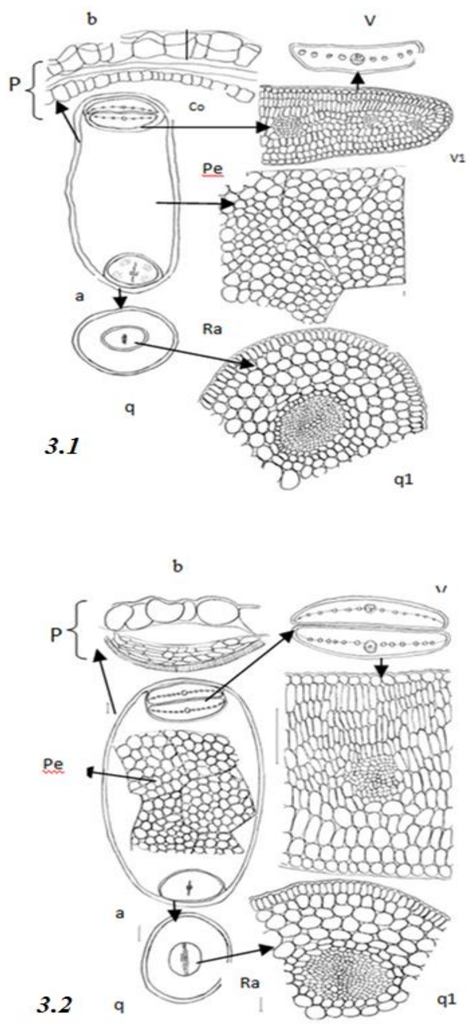

Figure 3. The structure of mature fruit at harvest time in *Chenopodium quinoa*: 3.1-Accession Q1, 3.2-Accession Q5: a - the location of the embryo (E) and the perisperm (Pe) in the seed; b - pericarp (P); v, v1 - cotyledon; q, q1 - radicle.

(fossil remains) is ensured by the presence of poorly decomposing dead cells tests, therefore, representatives of Amaranthaceae are stored in fossil residues [Suxorukov, 2015].

Our studies shown that in the structure of the seed of all *C. quinoa* accessions there are no visible obstacles to germination: the leaflets of the perianth, the pericarp and spermoderm are thin parenchymatous, easily swelling, the embryo with well-formed organs is structurally prepared for germination. Apparently, the reason for the short dormancy of seed is the peculiarities of metabolic processes, and this type of dormancy is shallow endogenous physiological. Seeds of accessions Q1, Q3, Q4, Q5 showed high germination rate (71- 85%), except for accession Q2 (0%). Germination began after 7-9 hours at room temperature 24-25 °C (Fig. 4).

Freshly collected seeds of Q5 are more uniform in size than other samples, however, there are both larger and slightly smaller seeds. There were no germinated seeds among them (Fig. 5.5). Seed collection of sample Q-3 was carried out immediately on three replications (Fig. 5.3). Both larger and smaller seeds are present, with normally developed embryo and perisperm. Seed collected of accession Q2 was held after rain on third plot (Fig. 5.2). Seeds were placed in cloth bags. After four days, individual germinated seeds were found. After drying in germinated seeds, the formed roots broke off, which affected the quality of the seeds. Humidity caused the germination of seed in cloth bags and, consequently, the death of germinated seeds. The seeds of this sample are more heterogeneous in size. However, both large and small seeds have well differentiated organs of mature embryo. The collected of Q1 seeds was also held after rain on third replications (Fig. 5.1). Seeds are very heterogeneous in size. However, both large and

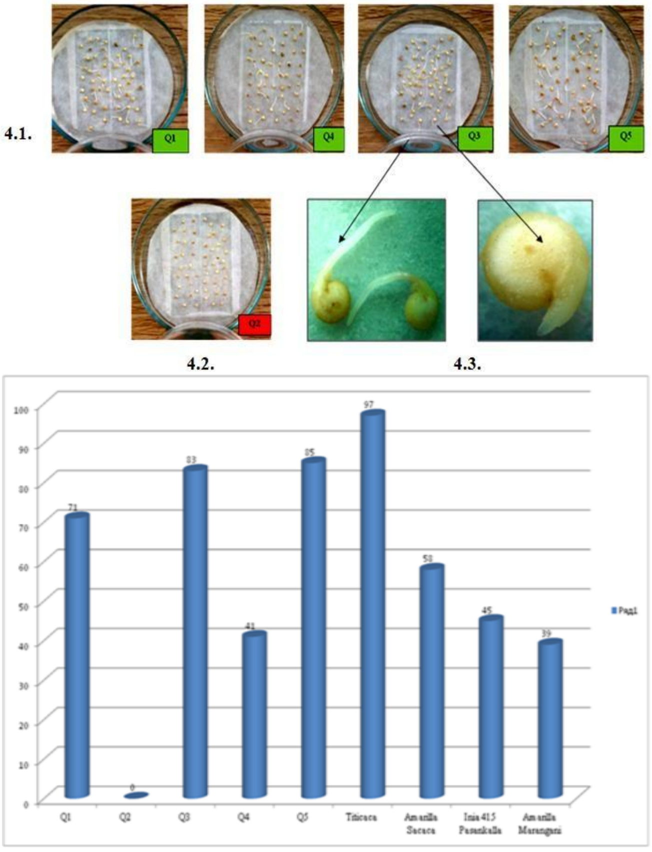

Figure 4. Laboratory germination of seeds provided by the ICBA for sowing in 2016 in the territory of the KES. 4.1. Q1, Q3, Q4, Q5-germinated seeds; 4.2. Q2-not germinated seed; 4.3. seed germination; 4.4. results germination of seeds in Petri dishes.

small seeds contain an embryo. Seeds were placed in cloth bags, in which both small and large individuals were sprouted.

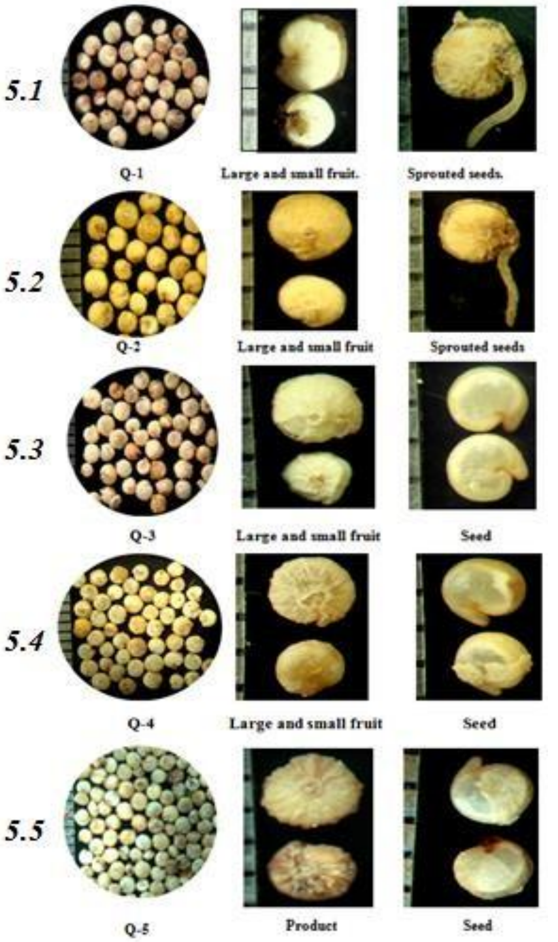

Figure 5. Seed collection: 5.1. Q-1. Seeds harvested after the rain caused the germination of individual seeds. The roots formed after drying the seeds broke off. Thus, it is confirmed that the collection of seeds should be carried out in dry weather; 5.2. Q-2. Seed harvested after the rain caused the germination of individual seeds. Seeds are very heterogeneous in size. However, both large and small seeds contain an embryo, small ones also germinate, like large ones; 5.3. Q-3. in dry warm weather. Seeds are more uniform in size. No germinated seeds; 5.4. Q-4. in dry warm weather. Seeds are more uniform in size. No germinated seeds; 5.5. Q-5. Seeds harvested in dry warm weather. Seeds are more uniform in size. No germinated seeds.

Thus, it is confirmed that the collection of seeds should be carried out in dry weather. Humidity causes germination of seeds, stored in cotton bags, consequently, leads to the death of germinated seeds.

The germination of seeds in Petri dishes on distilled water under the laboratory conditions began after one day. It is interesting to note that the seeds are aligned in size. The tip of the radicles of some seeds was damaged. Perhaps this happened when the seeds were washed, and this caused low germination rate. Some of the seedlings were sown in pots of soil, and they continued to grow, despite of damaged root. This experience confirms unusually high viability of quinoa seeds.

CONCLUSION

Our results shown that the seeds of *C. quinoa* accessions have thin (5-15 mm) yellow testa that dominate only in *C. pamiricum*, *C. pallidicaule* and, are unusual for all lineages of earlier *C. quinoa*. The micropylar endosperm (a non-embryonic tissue) forming a cone surrounds the root apical meristem of the embryo. In quinoa micropylar endosperm being represented by one or two cell layers thick, whereas described by P.B. Hernan et al. [2014] has similarities with anatomy of coleorhiza cells in cereals. Both seed structures serve the same role during germination: both tissues store reserves, protecting the root apical meristem in the quiescent seed and control dormancy during germination. Because of the supposedly independent origin of monocotyledons and dicotyledons, efforts to solve questions related to seed evolution and particularly that of what determines the fate of storage tissues should be furthered for both grasses and quinoa. Hence, the present study may constitute a contribution toward a more complete understanding of seed biology and thus may provide support for broader phylogenetic studies.

During quinoa seed storage reserves starch (forming compound and simple grains) localized in the seed perisperm tissue [Prego et al., 1998]. Quinoa starch granules of investigated Quinoa lines range in size from 0.6 to 2.0 µm. Seeds of quinoa Q1, Q3, Q4, Q5 accessions provided for sowing had high laboratory germination (71-85%), except for sample Q2 (0%). Freshly collected seeds of all samples, including Q2, sown in Petri dishes under laboratory conditions at room temperature (24-25 ºC) began to germinate after 7 hours and showed high germination rate (95-100%) through 16 hours. The reason for the short dormancy of the seeds are, apparently, the peculiarities of metabolic processes. This type of dormancy is shallow endogenous physiological and is characteristic of many members of the Amaranthaceae family [Gus Gintzburger et al., 2003; Bazile et al., 2015]. Apparently, the reason for the short dormancy of seed is the peculiarities of metabolic processes, and this type of dormancy is shallow endogenous physiological many members of the Amaranthaceae family. Harvesting after a rain causes the germination of individual seeds and then, upon drying, causes damage to the root, which will further affect the sowing qualities. Low field seed germination and seedling establishment are the main constraints in the Kur-Araz dryalnds environments. Grain filling of quinoa occurred during hot summer season. It is supposed that temperature and photoperiod of the mother plant also influence seed dormancy. Spring sowing, in which grain fill occurs in the summer, promotes dormancy in quinoa seed. However, autumn ripening reduces dormancy [Ceccato et al., 2015].

In conclusion all provided quinoa accessions under the conditions of the KES went through all stages of ontogenesis and formed viable seeds. Our studies showed that quinoa has high adaptation to Kur-Araz agroclimatic conditions with soils with higher clay contents, water holding capacity, evapotranspiration and shallow water and, therefore, has excellent potential as an alternative crop to rehabilitate salt-affected farms which have become uneconomical for the cultivation of the traditionally grown crops. The high seed yield obtained under marginal agro-climatic conditions of Kur-Araz (Azerbaijan) are indicative of the quinoa potential. However, further investigations are needed to study the performance of a much wider range of genetically diverse accessions at various soil and water salinities to fully exploit the available genetic diversity within the crop. The identification of each new high-yield and stress drought- and salt tolerant accessions will result in better products for growers, marketers, and processors.

REFERENCES

Bazile D., Bertero H.D., Nieto C. (eds) (2015) State of the art report on Quinoa around the world in 2013 (Rome: FAO and CIRAD), 603 p.

Bertero H.D. (2001) Effects of photoperiod, temperature and radiation on the rate of leaf appearance in Quinoa (*Chenopodium quinoa*) under field conditions. *Annals Bot.*, 87: 495-502.

Bosque-Sanchez H., Lemeur R., Van Damme, P., Jacobsen S.E. (2003) Ecophysiological analysis of drought and salinity stress of quinoa. *Food Rev. Int.*, 19: 111-119.

Butnik A.A. (1981) Karpologicheskaya kharakteristika predstaviteley semeystva Chenopodiaceae Vent. *Bot. jurn.*, 66(10): 1433-1443. [In Russian]

Butnik A.A. (1991) Chenopodiaceae Vent. Sravnitelnaya anatomiya semyan. 77-83. [In Russian]

Ceccato D., Bertero D., Batlla D., Galati B. (2015) Structural aspects of dormancy in quinoa (*Chenopodium quinoa*): Importance and possible action mechanisms of the seed coat. *Seed Science Research*, pp 1-9. DOI: 10.1017/S096025851500015X

Choukr-Allah R., Rao N.K., Hirich A., Shahid M., Alshankiti A., Toderich K., Gill Sh., Butt Kh., Ur R. (2016) Quinoa for marginal environments: toward future food and nutritional security in MENA and Central Asia regions. *Front. Plant Sci.*, 7: 1-11. (paper 346).

Convention on Biological Diversity. Government of Azerbaijan 2014. Azerbaijan fifth national report. Retrieved from https:www.cbd.int/reports/search

Eisa S., Hussin S., Geissler N., Koyro H.W. (2012) Effect of NaCl salinity on water relations, photosynthesis and chemical composition of Quinoa (*Chenopodium quinoa* Willd.) as a potential cash crop halophyte. *Aust. J. Crop Sci.*, 6: 357-368.

Elham F. Gomaa (2014) Studies on Some Micro-Macromorphological and Anatomical Characters of Quinoa (*Chenopodium quinoa* Willd.) *Plant. Res. J. Agric. & Biol. Sci.*, 10(1): 24-36.

Garcia M., Raes D., Jacobsen S.E. (2003) Evapotranspiration analysis and irrigation requirements of quinoa (*Chenopodium quinoa*) in the Bolivian highlands. *Agric. Water Manag.*, 60: 119-134.

Gasimova Kh.H., Husiyev E.K., Ali-zade V.M. (2018) The potential for developing non-traditional and traditional forage plants for the salt-affected areas of Kur-Araz lowland. *Transactions of the Institute of Molecular Biology & Biotechnologies, ANAS,* 2:21-25.

Gintzburger G., Toderich K.N., Mardonov B.K., Makhmudov M.M. (2003) Rangelands of arid and semiarid zones of Uzbekistan. CIRAD-ICARDA Publisher, France: 478p.

Graf B.L., Rojas-Silva P., Rojo L.E., Delatorre-Herrera J., Baldeyn M.E., Raskin I. (2015) Innovations in health value and functional food development of quinoa (*Chenopodium quinoa* Willd.). *Compr. Rev. Food Sci. Food Saf.*, 14: 431-445.

Hernan P.B., Lopez-Fernandez M.P., Maldonado S. (2014) Analogous reserve distribution and tissue characteristics in quinoa seeds suggest convergent evolution. *Front. Plant Sci.*, 5: 5-16. DOI: 10.3389/fpls.2014.00546.

Imelda P., Sara M., Marisa O. (1998) Seed Structure and Localization of Reserves in *Chenopodium quinoa*. *Annals Bot.*, 82: 481-488.

Jacobsen S.E., Jensen C.R., Andersen M.N. (2011) Effects of salinity and soil–drying on radiation use efficiency, water productivity and yield of quinoa (*Chenopodium quinoa* Willd.). *J Agro Crop Sci.*, 198: 173-184.

Jacobsen S.E., Monteros C., Corcuera L.J., Bravo L.A., Christiansen J.L., Mujica A. (2007) Frost resistance mechanisms in quinoa (*Chenopodium quinoa* Willd.). *Eur J Agron.*, 26: 471-475.

Jacobsen S.E., Mujica A., Jensen C.R. (2003) The resistance of quinoa (*Chenopodium quinoa* Willd.) to adverse abiotic factors. *Food Rev. Int*., 19: 99-109.

López-Fernández M.P., Maldonado S. (2013b) Quinoa ricinosomes early mark suspensor and endosperm cells destined to die during late seed development. *Annals. Bot.* 112: 1253-1262. doi: 10.1093/aob/mct184.

Martin A.C. (1946) The comparative internal morphology of seeds. *Am.midl.nat.* 36(3): 513-660.

Odum S. (1965) Germination of ancient seeds. Floristical observations and experiments with archeologically dated soil samples. *Dansk. Bot. Arkiv* 24(2): 1-70.

Rao N.K., Hirich A., Salehi M., Saadat S., Jacobsen S. E. (2019) Quinoa: A New Crop for Harsh Environments. Springer Book: © Springer Nature Switzerland AG B. Gul et al. (eds.), Sabkha Ecosystems, *Tasks for Vegetation Science*, 6: 301-333. https://doi.org/10.1007/978-3-030-04417-6_19.

Rays E. (1978) Allelopatiya. 392 p. [In Russian]

Razzaghi F., Ahmadi S.H., Jacobsen S.E., Jensen C.R., Andersen M.N. (2011) Effects of salinity and soil–drying on radiation use efficiency, water productivity and yield of quinoa (*Chenopodium quinoa* Willd.). *J Agro Crop Sci.*, 198: 173-184.

Sapankevich P.V. (1964) Rol' perikarpiya v protsesse razvitiya i prorastaniya semyan. Bioloqicheskiye osnovi povisheniya kachestva semyan selskoxozyaystvennix rasteniy, 466 p.

Schlick G., Bubenheim D. (1993) Quinoa: An Emerging "New" Crop with Potential for CELSS. Technical Paper 3422. NASA. California.

Soliz-Guerrero J.B., Rodriguez D., Rodriguez-Garcia R., Angulo-Sanchez J.L., Mendez-Padilla G. (2002) Quinoa saponins: concentration and composition analysis. In: J. Janick, A. Whipkey (eds.) Trends in New Crops and New Uses, Alexandria, Virginia: ASHS Press, pp. 110-114.

Sosa-Zuniga V., Brito V., Fuentes F., Steinfort U. (2017) Phenological growth stages of quinoa (*Chenopodium quinoa*) based on the BBCH scale. *Ann. Appl. Biol.*, 171: 117-124.

Suxorukov A.P. (2015) Karpologiya semeystva Chenopodiaceae v svyazi s problemami filogenii, sistematiki i diagnostiki yego predstaviteley. Avtoref. diss. Dokt. biol. nauk. 48 p. [In Russian]

Tapia M., Fries A.M. (2007) Guía de Campo de Cultivos Andinos. FAO y ANPE.74p.

Toderich K. 2008. Genus Salsola of the Central Asian Flora; Its structure and adaptive evolutionary trends (Chūōajia no shokubutsusō Salsola zoku no kōzō to tekiō shinka no keikō) Dr Sci Thesis, Tokyo University of Agriculture and Technology, Tokyo, Japan. 9: 196 pp.

Vega-Galvez A., Miranda M., Vergara J., Uribe E., Puente L., Martinez E.A. (2010) Nutrition facts and functional potential of quinoa (*Chenopodium quinoa* Willd.), an ancient Andean grain: a review. *J Sci. Food Agric.* 90: 2541-2547.

Zurita-Silva A., Fuentes F., Zamora P., Jacobsen S.E., Schwember A. 2014. Breeding quinoa (*Chenopodium quinoa* Willd.): potential and perspectives. *Mol Breeding*, 34: 13-30.

Zaman M., Shahid S.A., Heng L. (2018) Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques, Springer, Switzerland. https://doi.org/10.1007/978-3-319-96190-3_2

Kür-Araz ovalığında (Azərbaycan) introduksiya olunmuş kinoyanın (*Chenopodium quinoa* Willd.) yeni duza tolerant sortlarının reproduktiv biologiyası, toxum morfologiyası və anatomiyasının müqayisəli tədqiqi

Xatirə H. Qasımova
Validə M. Əli-zadə
AMEA Botanika İnstitutu, Badamdar şossesi 40, Bakı, AZ1004, Azərbaycan

Dildora M. Yusupova
Özbəkistan Respublikası Elmlər Akademiyasının Bitki və Heyvanlar Aləmi Genefondu İnstitutu, Bagışamol 232, Daşkənd, 100125, Özbəkistan

Kristina N. Toderiç
Quru Ərazilərdə Tədqiqatlar və Təhsil üzrə Beynəlxalq Platforma (QƏTTBP) 1390, Hamasaka, Tottori ş., TOTTORİ, Yaponiya 680-0001 Tottori Universiteti, Yaponiya, (İCBA-CAC) Orta Asiya və Qafqazın Şoran Torpaqlarında Əkinçiliyin İnkişafı üzrə Beynəlxalq Mərkəz

Tura Rəhimova
Özbəkistan Milli Universiteti, Universitetsky küç 4, Daşkənd, 100174, Özbəkistan

Şoranlığa davamlı yüksək səviyyəli kinoya nümunələri Kür-Araz ovalığında (Azərbaycan) yüksək gil tərkibinə, su saxlama qabiliyyətinə, evapotranspirasiya və səthi sulara malik olan quraqlığa meyilli və şoran torpaqlarda introduksiya edilib. Beş kinoya nümunəsinin tədqiq olunan bütün reproduktiv mərhələlərində (toxum dəninin məhsuldarlığı, rüşeym və meyvənin inkişaf mərhələləri) həyat və toxum əmələgətirmə qabiliyyəti öyrənilib. Bitki genotipindən asılı olaraq çiçəkləmənin başlanğıc mərhələsi çiçəkləmə, toxumun yetişməsi və quru çəkiyə görə 66-77 arası gün dəyişir. Yer və genotiplərin qarşılıqlı əlaqəsi bitki boyu və toxum məhsuldarlığı istisna olmaqla çiçəkləmə və yetişmə günləri və quru çəki baxımından əhəmiyyətli idi. Kinoyanın üç erkən-orta, gec-çiçəkləmə və erkən-orta və gec toxum yetişmə klasterləri təsvir edilib. Kinoya öz-özünə tozlayan növlərdir, lakin külək (anemofil) və ya kiçik həşəratların (entomofil) köməyi ilə çiçək içərisində tozlanma baş verir. Yeni ətraf mühitdə becərilən kinoyanın tədqiq edilmiş sortları arasında meyvə və toxum morfologiyasında əhəmiyyətli dəyişiklik yox idi. Kinoyanın meyvələri sadə, quru, açılmayan, toxumca, diametri 1.8-2.5 mm, zülali ağ və ya sarımtıl rəngli, yetkin vəziyyətdə ağ perikarplı perigoniumun qalıqları olan monospermdir. Kinoya toxumlarında perikarp çox nazikdir; nəticə olaraq toxumca kisəcik də adlandırılır. Həyat qabiliyyətinə malik olan toxum perisperm və perikarpı əhatə edən periferiya, əyri ruşeymdən ibarətdir. Bir və ya iki hüceyrə divarı qalınlığının aydın görünən mikropil endospermi (embrional olmayan bir toxuma) embrionun kök apikal meristemini əhatə edən bir konus əmələ gətirir. Kinoya mikropil endosperminin anatomiyası quruluş baxımdan taxıl bitkilərindəki koleoriza hüceyrələri ilə oxşardır. Ehtiyat qida maddələri hər iki toxumada toplanır və toxumda kökün təpə meristemini qorumaqda əsas rol oynayır və cücərmə zamanı sakitlik dövrünə nəzarət edir. Lipidlər, zülallar və mineralların saxlandığı Kinoya mikropil hüceyrə toxumasının sonrakı tədqiqi duz və quraqlığa davamlı olmaqla yüksək toxum məhsuldarlığı və qida keyfiyyətinə malik olan daha yaxşı uyğunlaşdırılmış genotipləri seçmək üçün nəzərə alınmalıdır. Endogen fizioloji tip sakitlik keçirən təzə toplanan kinoya toxumları otaq temperaturunda (24-25º C) 16 saatdan sonra yüksək cücərmə dərəcəsi (78-85%) nümayiş edir. Quraqlıq və şoranlığa məruz qalmış Kür-Araz əkin sahələrində arzu olunan genotiplərin müəyyənləşdirilməsi və məhsuldarlığı artırmaq üçün əkin təcrübəsi və toxumların saxlanılmasının optimallaşdırılması üzrə işlərlə müşaiyət olunmalıdır. Sahələrə toxum erkən səpilməlidir, belə olduqda erkən çiçəkləmə və toxumun yetişməsi isti yay mövsümündən əvvəl baş verir.

Açar sözlər: *tozcuq dənəsi, quru kisəcik meyvə, mikropil endosperm, taxıla bənzər bitki, şoranlıq, səhralaşma, Kinoya*

Сравнительные исследования репродуктивной биологии, морфологии семян и анатомии новых солеустойчивых образцов киноа (*Chenopodium quinoa* Willd.), интродуцированных в Кура-Аразской низменности (Азербайджан)

Хатира Г. Гасымова
Валида М. Али-заде
Институт Ботаники НАНА, Бадамдар 40, Баку, AZ1004,Азербайджан

Дилдора М.Юсупова
Институт Генофонда Растительного и Животного Мира АН РУз, Багишамол 232, Ташкент, 100125, Узбекистан

Кристина Н. Тодерич
Международная платформа исследований и образования засушливых земель (МПИОЗЗ), 1390 Хамасака, г.Тоттори, ТОТТОРИ, Япония 680-0001 Университет Тоттори, Япония; Международный Центр биоземледелия на засаленных почвах Центральной Азии и Закавказья (ИКБА-ЦАЗ), ул. Осие 6А, Тагкент, Узбекистан

Тура Рахимова
Национальный университет Узбекистана, ул. Университетский 4, Ташкент, 100174, Узбекистан

Исследованные солеустойчивые высоко-рейтинговые образцы киноа, интродуцированные на глинистых почвах, подверженных засухе и засолению при низком залегании грунтовых вод в Кура-Аразе (Азербайджан), прошли все онтогенетические репродуктивные стадии развития (продуктивности пыльцевого зерна, зародыша и плода) и продуцировали жизнеспособные семена. Цветение изменяется между 66 -77 днями в зависимости от генотипа, высоты растений, дней до цветения и созревания ($p> 0.05$). Описаны три ранне-средне-поздних и позднецветущих, и, следовательно ранне-средне-поздних и позднеспелых кластерах киноа. Киноа является преимущественно самоопыляющимся видом, но происходит перекрестное опыление внутри соцветия с помощью ветра (анемофильное) или при поддержке мелких насекомых (энтомофильное). Значительные различия в морфологии плодов и семян среди исследованных образцов киноа, выращенных в условиях интродукции не наблюдались. Плоды киноа простые, сухие, не растрескивающиеся, однолетние, односеменные, с белым околоплодником в зрелом состоянии с остатками перигония.

Семена белого или желтоватого цвета диаметром 1.8-2.5 мм. У семян киноа околоплодник очень тонкий из-за чего семя также упоминается как мешочек. Жизнеспособные семена содержат периферический изогнутый зародыш, окруженный периспермом и перикарпием. Выраженный одно- или двухслойный микропилярный эндосперм (неэмбриональная ткань) образует конус, окружающий корневую апикальную меристему зародыша. Анатомия микропиллярного эндосперма киноа по структуре выявила сходство с клетками колеорезы у злаков. Обе ткани предназначены для накопления питательных веществ и играют жизненно важную роль, защищая корневую апикальную меристему в покоящемся семени и контролируя покой во время прорастания.

Дальнейшее исследование микропиллярной ткани киноа, где хранятся запасы жиров, белков и минералов, должны рассматриваться для отбора генотипов, сочетающих высокий выход качественных семян и соле- и засухоустойчивостью. Свежеотобранные семена киноа показали высокую скорость прорастания (78-85 %) через 16 часов при комнатной температуре (24-25 ºС) кроме Q2.

Идентификация наилучших генотипов должна сопровождаться работой по оптимизации технологии выращивания и хранения семян, чтобы максимизировать продуктивность в засушливых землях Кура-Араза, подверженных засолению. Ранний срок посева семян наиболее оптимальный, так как цветение и созревание семян происходят задолго до наступления летней жары.

Ключевые слова: *пыльцевое зерно, односемянный плод, микропилярный эндосперм, псевдозлаковое растение, засоленность, опустынивание, Киноа*