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RESEARCH ARTICLE

Importance of Seed Traits in Processing Germplasm Collections: A Case Study of Chickpea Genetic Resources at ICRISAT

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Seed traits like color, shape, size, weight, surface projections and texture determine the type and quality of storage containers, drying behavior, and germination testing and packaging procedures for germplasm conservation. We studied the seed traits on 65 chickpea germplasm accessions and observed significant differences across traits and association with other related parameters. Seed moisture content differed significantly with seed coat color, surface texture and shape. Large Kabuli types and seeds with smooth surface texture have better drying features; however, had deleterious effects on seed quality. Hard-seededness was strongly associated with moisture content, seed types, color and seed coat thickness. Desi type chickpeas were superior to Kabuli and intermediate types with respect to seed germination. The results provide a basis for identifying chickpea types requiring additional care during seed processing and identifying germplasm with desirable seed traits for utilization in research.

Key Words: Chickpea; Drying; Germplasm; Seed germination; Seed trait

Introduction

Management of *ex situ* germplasm collections require innovative decisions on operating conditions, seed processing and storage behavior of seeds. Several researchers have described the importance of seed traits during processing, germination testing and storage. In chickpea (*Cicer arietinum* (L.), apart from utilization point of view, parameters like the seed size, seed coat thickness, shape and surface texture are important since they influence the seed handling procedures in genebanks. The chickpeas are broadly classified into desi (angular seed), Kabuli (owl's head seed shape) and intermediate (pea shaped) types based on morpho-agronomic characteristics including seed traits. However, irrespective of these categories, an array of genotypes with varying degree of seed coat thickness and color are found because of introgression of Kabuli germplasm into desi germplasm and vice versa (Ugale and Bahl, 1983; and Gaur *et al*., 2010). Desi and Kabuli types differ in their seed coat and crude fiber contents and the seed coat thickness of desi types is approximately three times than those of Kabuli types (Singh *et al*., 1981). Kabuli seeds have a thinner seed coat due to thinner palisade and parenchyma layers of desi types which contained fewer pectic polysaccharides and less protein, while palisade layers were rigid and extensively thickened (Wood *et al*., 2011). Dark colored seeds have thick seed coat and vice versa, and the protein content is significantly correlated with seed color and seed size (Govil, 1980). Chavan *et al*. (1986) related the crude fiber content with seed coat content and reported higher fiber content in desi than Kabuli type cultivars. Seed weight and volume are positively correlated to fat and carbohydrate content and negatively correlated to fiber content of chickpea seeds (Singh *et al*., 1992).

Seeds with pigmented seed coats have a longer storage life, and chickpeas with dark seed coats store better than lighter-colored varieties (Gvozdeva and Zhukova, 1971) and pale-seeded chickpeas are shorter lived than those with thicker, harder coats (Van der Maesen, 1984). Seed length, width, thickness, geometric mean diameter, sphericity and porosity of chickpea seeds increase with increase in the moisture content and true density and bulk density reduce with increase in the moisture content (Mohsenin, 1986). Dutta *et al.* (1988) reported changes in seed surface area, shape,

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bulk density, kernel density and porosity with changing moisture contents. Smaller chickpea seeds have more surface to volume ratio and emerge better under sub-optimum seedbed moisture conditions (Padma Sri, 1998). However, majority of workers have used fewer numbers of accessions (cultivars) representing smaller diversity for seed traits.

The ICRISAT Genebank, Patancheru, India, currently conserve 20,764 accessions of chickpea from 61 countries as *ex situ* collection. These accessions are seed producing and the seeds have orthodox storage behaviour. Representative seed samples of these accessions are conserved as active collection (medium-term storage) in standard aluminum cans at 4 °C and 30% relative humidity) and as base collection (long-term storage) in vacuum packed laminated aluminum foil pouches at -20°C, and <7% seed moisture content and >90% seed viability), as per the recommended genebank standards (FAO/IPGRI, 2014). The collection represents wide diversity for important morpho-agronomic characters including seed traits and the operational procedures for managing the collection have been described (Upadhyaya and Gowda, 2009). The findings of Wood *et al*. (2011) also provide information on differences in the processing behavior between the major chickpea seed types. Grouping germplasm accessions based on seed traits assists in efficient management of the collection. Considering these factors, experiments were conducted on 65 chickpea germplasm accessions representing variation for traits related to seed and their influence on post-harvest processing and seed quality.

Materials and Methods

Sixty-five accessions representing desi, Kabuli and intermediate types from the world collection maintained in the genebank were randomly selected and used in this study (Fig. 1). Freshly harvested seed samples of the selected accessions from the 2010-11 post-rainy season at ICRISAT, Patancheru, India were hand-threshed and cleaned samples were stored under short-term storage conditions (25°C and 40% RH) to attain equilibrium moisture content (emc).

Observations on seed color, shape, surface texture and 100-seed weight were recorded following the Descriptors for Chickpea (IBPGR/ICRISAT/ICARDA, 1993). The moisture content of equilibrated seed samples was estimated on fresh weight basis (w.b.) following oven-dry method (ISTA, 1993). Sample seeds weighing exactly 200 g were kept in clean muslin cloth bags in a seed drying cabinet maintaining a constant temperature of 15°C and 15% RH (Cromarty *et al*., 1982). Seed samples were weighed at two day intervals to record changes in moisture contents and

Fig. 1. Variation for seed color, shape, surface texture and size of chickpea germplasm accessions used in the study.

seed drying continued until the sample weights in all entries stabilized indicating emc under this environment (Sastry *et al*., 2003).

Seed moisture content is an important component affecting seed quality and longevity. Under all storage conditions, the moisture content of seeds comes to equilibrium with the relative humidity of the surrounding atmosphere. Over a wide range of conditions, the longevity of seeds increases in a quantifiable way with decrease in moisture content (Roberts, 1973). The objective of drying in this study is to study the influence of seed traits on emc during drying and the impact of drying on related seed traits including viability. A seed germination test is a widely accepted and direct measure of viability. Germination tests on fresh and dry seed samples of the accessions were carried out following standard procedures (ISTA, 1993) and appropriate dormancy breaking measures (Ellis *et al*., 1985). Hard seeds identified as live and ungerminated at the end of initial testing (seven days) were scarified and the test period was extended to 14 days. Bulk density of seed was calculated by dividing the weight of seed of each sample on its volume, measured by using a graduated cylinder (Ayman *et al*., 2010). The true density was determined by using toluene solution displacement method (Mohsenin, 1986). Bulk density and true density were expressed as g/cc at given seed moisture conditions. The porosity (%) was determined as the percentage of densities of bulk seeds following the methodology of Jha (1999).

The data collected on test weight, moisture content, bulk density, true density and porosity and germination were statistically analyzed as Completely Randomized Design (CRD) using Genstat 15.1 Edition.

Results

Observations on seed traits and physical properties of fresh and dry chickpea samples of 65 accessions are summarized in Table 1. Based on morphological data (ICRISAT, 2017), the test accessions were represented by 18 seed colors. The major seed colors were brown (15), yellow brown (11), beige (9) and 15 other colors represented by 30 accessions. Out of 65 accessions, 46 were desi, 13 Kabuli and 6 intermediate types. Forty-nine accessions had rough seed surface followed by smooth (15) and tuberculated (1) accessions. Twenty different combinations for seed color, shape, surface texture and size are observed among the tested accessions. Tuberculated seed surface is represented by one accession (ICC 6098). The 100- seed weight (fresh seed) of test accessions ranged from 6.8 g (ICC 5590) to 65.0 g (ICC 11183) with a mean of 22.9 g representing wide range of diversity for this trait. There are five accessions with 100-seed weight >40 g; 21 accessions with 20 g to 40 g and 39 accessions with <20 g 100-seed weight. The mean 100-seed weight of desi, Kabuli and intermediate types was 19.3 g, 26.1 g and 22.3 g, respectively. The average 100-seed weight of small, medium, large and very large seed sizes are 12.8 g, 18.2 g, 29.2 g and 50.6 g, respectively. Forty-nine accessions had rough seed surface and medium size, 15 accessions had smooth surface and medium size and one accession had tuberculate surface with a seed weight of 15.9 g.

Seed Moisture Content

The emc of fresh seeds ranged from 10.5% to 11.9% with a mean of 11.1%. The differences in emc were significant among the accessions. Observations on seed moisture contents across seed traits, following drying, are presented in Table 1. The emc in all the accessions remained stable after 30 days of drying indicating no further drying possible in the seed samples. The emc of dry seeds ranged from 4.9% to 6.6% with a mean of 5.6%, a preferred moisture level for conserving chickpea germplasm under long-term conditions. The emc was lowest in ICC 8933, a medium sized intermediate type accession and highest in ICC 15554, a very large sized desi type accession. The 100-seed weight of dry seeds ranged from 5.7 g to 59.8 g with a mean of 19.5 g, indicating an average weight reduction of 3.4 g during drying. The mean seed moisture changes were 4.51%, 0.49%, 0.26%, 0.12% and 0.16% at the end of 6, 12, 18, 24 and 30 days of drying, respectively.

Seed Density and Porosity

Observations on bulk density, true density and porosity of fresh seed and dry chickpea seeds are summarized in Table 2. Bulk density of fresh seeds ranged from 0.62 g/cc to 0.81 g/cc with a mean of 0.71 g/cc. The highest bulk density was observed in ICC 14340 and the lowest in ICC 11883. True density of fresh seed ranged from 1.06 g/cc to 1.40 g/cc with a mean of 1.29 g/cc. Two accessions (ICC 8923 and ICC 1014) with highest true seed density were intermediate types. Porosity of fresh seeds ranged from 31.4% to 52.9% with a mean

Table 1. Summary on seed weight, moisture content and physical properties of fresh and dry seeds of chickpea accessions.

Seed Trait	No. of Acc.	Fresh seed									
		100-SWT (g)		MC (%)		Bulk density		True density		Porosity (%)	
		Range	Mean + SE	Range	Mean + SE	Range	Mean + SE	Range	Mean + SE	Range	Mean + SE
Desi	46	6.8-48.7	19.3 + 9.64	10.5-11.8	11.1 + 0.29	0.69-0.81	0.76 + 0.031	1.06-1.35	1.28 + 0.059	31.4-48.9	40.3 + 3.73
Kabuli	13	13.0-65.0	26.1+ 15.8	10.8-11.9	11.3 + 0.31	0.62-0.80	0.75 + 0.051	1.23-1.39	1.31 + 0.046	36.8-52.9	42.7 + 4.39
Intermediate	6	13.3-30.4	22.3 + 5.76	10.5-11.4	11.0 + 0.36	0.76-0.80	0.78 + 0.014	1.24-1.40	1.32 + 0.068	38.6-44.4	40.7 + 2.43
Small	24	6.8-14.9	12.8 + 2.16	10.6-11.9	11.2 + 0.31	0.70-0.81	0.77 + 0.030	1.06-1.39	1.27 + 0.073	31.4-45.9	38.9 + 3.75
Medium	23	15.0-24.0	18.2 + 3.00	10.5-11.4	11.0 + 0.24	0.69-0.80	0.76 + 0.031	1.21-1.40	1.29 + 0.051	36.3-48.9	40.7 + 3.08
Large	13	25.0-35.2	29.2 + 3.67	10.5-11.7	11.1 + 0.39	0.71-0.78	0.75 + 0.024	1.24-1.40	1.31 + 0.045	38.6-46.8	42.6 + 2.71
Very large	5	40.8-65.0	50.6 + 8.96	11.0-11.7	11.3 + 0.33	0.62-0.73	070 + 0.045	1.29-1.31	1.28 + 0.029	40.8-52.9	45.7 + 4.45
Rough	49	6.8-48.7	19.3 + 9.54	10.5-11.8	11.1 + 0.29	0.70-0.81	0.76 + 0.03	1.06-1.40	1.28 + 0.059	31.4-46.1	40.2 + 3.52
Smooth	15	13.2-65.0	26.6 + 14.21	10.5 -11.9	11.2 + 0.35	0.62-0.80	0.76 + 0.048	1.24-1.40	1.31+ 0.052	37.3-52.9	42.3 + 4.06
Tuberculated	1		15.9		11.1		0.69		1.35		48.9
Overall	65	6.8-65.0	22.9 + 12.41	10.5-11.9	11.1 + 0.31	0.62-0.81	0.71 + 0.19	1.06-1.40	1.29 + 0.059	31.4-52.9	40.8 + 3.84
						Dry seed					
Desi	46	5.7-46.3	18.0 + 9.13	4.9-6.6	5.7 + 0.36	0.72-0.92	0.81 + 0.047	1.24-1.57	1.35 + 0.057	30.1-48.4	39.4 + 3.70
Kabuli	13	11.9-59.8	24.2 + 14.65	5.1-6.0	5.4 + 0.29	0.68-0.86	0.79 + 0.049	1.29-1.49	1.35 + 0.051	35.1-49.0	41.4 + 3.73
Intermediate	6	12.5-27.7	21.0 + 5.46	5.3-5.6	5.4 + 0.11	0.80-0.84	0.82 + 0.014	1.31-1.41	1.35 + 0.034	38.3-43.0	39.7 + 1.77
Small	24	5.7-14.6	11.7 + 2.13	4.9-6.4	5.6 + 0.36	0.79-0.92	0.83 + 0.037	1.24-1.57	1.34 + 0.067	30.1-43.5	37.9 + 3.58
Medium	23	13.4-22.5	17.2 + 2.88	5.1-5.9	5.5 + 0.24	0.72-0.90	0.81 + 0.040	1.27-1.49	1.36 + 0.054	35.2-48.4	40.2 + 3.17
Large	13	22.8-33.3	27.1 + 3.31	5.2-6.3	5.7 + 0.40	0.76-0.84	0.80 + 0.028	1.32-1.39	1.35 + 0.024	38.3-44.9	41.2 + 2.35
Very large	5	38.4-46.3	47.5 + 7.76	5.1-6.6	5.6 + 0.59	0.68-0.78	0.73 + 0.038	1.30-1.33	1.32 + 0.013	39.8-49.0	44.3 + 3.33
Rough	49	5.7-46.3	18.0 + 9.02	4.9-6.6	5.6 + 0.36	0.77-0.92	0.82 + 0.044	1.24-1.57	1.34 + 0.056	30.1-45.3	39.3 + 3.45
Smooth	15	12.2-59.8	24.8 + 13.20	5.1-5.9	5.4 + 0.25	0.68-0.86	0.80 + 0.046	1.30-1.49	1.36 + 0.046	37.1-49.0	41.3 + 3.24
Tuberculated	1		14.7		5.7		0.72		1.40		48.4
Overall	65	5.7-59.8	19.5 + 10.38	4.9-6.6	5.6 + 0.35	0.68-0.92	0.81 + 0.045	1.26-1.57	1.35 + 0.054	30.1-49.0	39.9 + 3.62

Table 2. Summary on germination of fresh and dry seeds of chickpea accessions.

Seed trait	No. of accessions	Observation	Fresh seed		Dry seed		
			Germination (%)	Hard seed (%)	Initial Germination (%)	Hard seed (%)	Final Germination (%)
Desi	46	Range	88-100	0	41-100	0-58	66-100
		Mean (SE+)	97.3 (3.20)		91.3 (13.51)	4.7 (12.59)	95.8 (6.87)
Kabuli	13	Range	87-100	0	79-100	0	79-100
		Mean (SE+)	95.7 (3.97)		93.5 (6.91)	0	93.5 (6.91)
Intermediate	6	Range	77-98	0	69-100	0	69-100
		Mean (SE+)	90.3 (8.45)		88.2 (12.04)		88.2 (12.04)
Rough	49	Range	88-100	0	41-100	0-58	66-100
		Mean (SE+)	97.3 (3.11)		91.7 (13.18)	4.4 (12.25)	96.1 (6.57)
Smooth	15	Range	77-100	0	69-100	0	69-100
		Mean (SE+)	93.0 (6.48)		90.3 (9.45)	0	90.3 (9.45)
Tuberculated	1	Mean	98	0	98	0	98
Small	24	Range	89-100	0	83-100	0-5	83-100
		Mean (SE+)	98.3 (2.42)		97.4 (3.67)	0.3 (1.17)	97.8 (3.64)
Medium	23	Range	86-100	0	66-100	0-13	66-100
		Mean (SE+)	96.0 (4.36)		93.0 (8.20)	0.9 (2.93)	93.9 (8.01)
Large	13	Range	77-100	0	41-100	0-58	69-100
		Mean (SE+)	94.7 (5.92)		81.2 (20.39)	13.0 (21.46)	94.2 (8.63)
Very large	5	Range	93-99	0	73-89	0-12	73-98
		Mean (SE+)	92.8 (5.29)	0	82.2 (6.30)	3.4 (5.27)	85.6 (10.36)
Overall	65	Range	77-100	0	41-100	0-58	66-100
		Mean (SE+)	96.4 (4.46)		91.5(12.27)	3.3 (10.77)	94.7 (7.60)

of 40.8%. Drying seed samples from 11.1% to 5.6% moisture content indicated significant changes in bulk density, true density and porosity. The mean bulk density increased from 0.71 to 0.81 g/cc, true density from 1.29 g/cc to 1.35 g/cc while porosity decreased from 40.8 g/cc to 39.9%.

Fresh and dry Kabuli type accessions had a higher mean porosity of 42.7% and 41.4% respectively, compared to intermediate and desi types. Similarly, fresh and dry seeds with smooth surface had higher mean porosity of 42.3% and 44.3% respectively compared to seeds with rough surface. The highest porosity (49.0%) for dry seeds was observed in ICC 11883, a Kabuli type with largest test seed weight (65.0 g). Kabuli types with smooth seed surface are larger in seed size (both fresh and dry seeds) followed by intermediate and desi types with rough seed surfaces. Mean emc of fresh seeds ranged between 10.5 and 11.9% and emc of fresh and dry seeds was lowest in desi types. Seed bulk density was lowest among very large seeded Kabuli types compared to small seeded desi types with rough seed surface. True density was lowest in desi small seeded accessions with rough seed surface and highest in intermediate types. Porosity was lowest in small seeded accessions and highest with rough seed surfaces. The bulk density of dry seeds was highest in small seeds followed by rough seed surface and intermediate types. Highest true density was observed in desi types with medium seed size and rough seed surfaces and lowest with very large seeds. Chickpea seed types with highest bulk and true densities and porosity are depicted in Fig. 2.

Correlations among physical properties of fresh and dry seeds (data not presented) indicated no significant association between seed size and seed moisture contents. Seed size and bulk densities were negatively associated across seed moistures. However, the association was not significant for true density. Seed porosity was significantly correlated with seed size and true density negatively correlated to bulk density.

Seed Germination

The seed germination of fresh and dry chickpea accessions is presented in Table 2. Observations on germination were recorded after seven days of incubation in fresh seeds while for dry seeds initial recording was done after seven days and final recording after 14 days. Seed germination in fresh samples ranged from 77% to 100% with a mean of 96.4%. The germination was lowest in ICC 8400, a large seeded, intermediate type and smooth seed surfaced accession. Five other accessions had germination less than 90%. The germination levels in 51 accessions ranged from 95% to 100%. In dry seeds, the germination after seven days of incubation ranged from 41% to 100% with a mean of 91.5%. Seeds in several accessions remained healthy and ungerminated indicating the presence of hard seeds (0% to 58%). When the hard seeds were scarified and‒tested, the germination increased to 66% to 100% with mean of 94.7%. Lowest germination was recorded in ICC 11321 followed by ICC 8400 (69%) and eight other accessions had germination less than 90% after drying seeds to lower moisture levels.

A summary on seed germination of fresh and dry chickpea accessions across seed traits is presented in Table 2. Fresh seed germination was highest among desi types followed by Kabuli and intermediate types and seeds with rough surface had higher viability compared to seeds with smooth surfaces. A gradual reduction in mean viability was observed as the seed size of accessions increased. In case of dry seeds, the initial germination percentage of desi accessions is

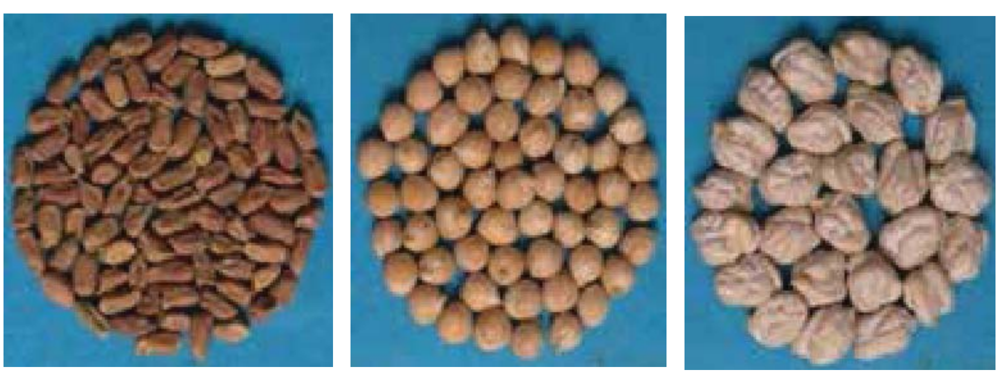

Fig. 2. Chickpea accessions with highest bulk density (left), true density (middle) and porosity (right).

less compared to Kabuli types. This is because of hard seeds occurring in several accessions of desi types (up to 58%).

Discussion

The chickpea accessions in this study represented desi, Kabuli and intermediate types differing in seed color, seed surface texture and 100-seed weight. It is assumed that the moisture content of seeds comes to equilibrium with the relative humidity of the surrounding atmosphere and a narrow range in emc is expected across seed lots in a given species. Seeds of ICC 16948 with beige color, owl's head shape and smooth seed coat recorded highest emc, whereas lowest emc was recorded in two accessions (ICC 506 and ICC 8400) with varying seed color, shape and surface texture including seed weight. The differences in emc of fresh seeds could be attributed to seed traits, especially the seed coat thickness for exchanging moisture with surrounding environment. The mean 100-seed weights (before and after drying) across seed traits were higher in large seeded Kabuli types and seeds with smooth surface, indicating better drying characteristics.

Observations on seed moisture changes (data not presented) under a constant drying environment indicated a three-phase drying of chickpea seeds. In the first phase, considered as rapid drying stage, the loss of moisture is significantly higher compared to the later phases. The mean seed moisture changes at different period indicate rapid drying in the first six days followed by normal (6 to12 days) and slow drying and stable moistures at latter stages. Similar trend was observed under controlled environment drying of different sized chickpea seeds (Sastry *et al*., 2007). Though the initial seed moisture contents remained similar in all accessions, the large seeded Kabuli types and seeds with thin and smooth surface texture lost moisture rapidly resulting in lowest emc compared to seeds with small seeded desi types.

The bulk density and true density of fresh seeds were significant among accessions. Bulk density ranged 0.62 g/cc to 0.81 g/cc with a mean of 0.76 g/cc and highest in ICC 14340 and lowest in ICC 11883, an accession with highest seed weight. Bulk density determines the way the seeds are packed and is useful in determining the size of container needed for a given weight of seed (Gürsoy and Güzel, 2010). Two accessions (ICC 8923 and ICC 1014) having highest true seed density were intermediate types. The minimum and maximum porosity (%) of fresh seeds were observed for very small and largest seeded accessions respectively, indicating strong positive correlation (r = 0.574 for fresh seed and r = 0.530 for dry seed).

Drying seed samples from 11.1% to 5.6% moisture resulted in significant changes in bulk density, true density and porosity. The bulk density and true density of seeds increased while porosity decreased. Bulk density was highest in small sized seeds with angular surface and rough seed coat while it is lowest in large seeded Kabuli type. The relative reduction in seed densities at high moisture content could be attributed to less weight gain due to added moisture in relation to the concomitant volumetric expansion of the seeds. Mohsenin (1986); Konak *et al*. (2002); Amin (2003), Gurhan *et al*. (2009), Nikobin (2009) and Ayman *et al.* (2010), made similar observations under seed moisture regimes of 5% to 35%. A similar observation in the present study even under narrower moisture regimes for fresh and dry seeds signifies the importance of diversity in chickpea seed traits and their influence on physical properties. Seed density is a component of grain yield, positively correlated to seed protein content, and hence selection for increased density could provide an efficient way to improve protein content without affecting seed yield. Measurement of seed density and weight is relatively inexpensive hence it is a low-cost way to identify promising accessions (Hongxia and Joseph, 2002) for utilization in research. Present study resulted in identifying several intermediate type accessions with higher seed densities associated with other useful traits. The ICRISAT chickpea collection is represented by 701 pea shaped accessions (3.5% of entire collection) and it would be worth screening these accessions for physical properties in association with protein content.

Relationships among Seed Size, Shape and Surface

Seed size, shape, and density are important in seed cleaning process (separating seed from undesirable materials). Seed bulk density and porosity affect the resistance to airflow of seeds and are crucial in the development of aeration and drying systems. Seed porosity has significance significant role in selection of seed containers and processing seed samples for conservation especially under vacuum storage. Highly porous seeds require more storage space during packing and chickpea seeds with higher porosity coupled with angular shape and rough seed coat surface demand additional specifications and care during sealing and storage.

Seed Drying, Germination and Hard Seeds

Fifty accessions maintained germination levels above 90% after drying, indicating good initial seed quality and the typical orthodox nature of chickpea seeds. Drying seeds for base conservation (long-term storage) resulted in development of hard seeds to the extent of 58% in 12 accessions. All these accessions are desi types with angular seed shape and rough seed coat. Large numbers of hard seeds are observed in ICC 1069 (black), ICC 8521 (brownish beige) and ICC 6306 (black) followed by different shades of brown and yellow seed coat color. Seed coat of desi types was 2.72 times and 3 to 25 times thicker than Kabuli types with normal testa and with cracked testa respectively (Yadav and Sharma, 2000). This indicated a strong association of hard-seededness in chickpea with desi types having darker seed color which were characterized by thick seed coats. Rao *et al*. (1990) observed viability loss in intermediate types having cracks on seed coats developed during seed handling and recommended a two-stage drying procedure – an initial slow drying in a cabinet at 15 ºC and 30-40% RH until moisture content reaches 9% or less, followed by drying at 15 ºC and 15% RH to reach desired moisture levels for long-term storage.

Seed coat color is an indicator of mechanical resistance of seeds due to the presence of polymerized phenol, and acts as a chemical defense against microorganisms through soluble phenolic compounds. Kabuli types have very thin seed coats and lack the phenolic compounds, as compared to desi types and are extremely susceptible to a range of seed rotting fungi. The proportion of seed coat was less in large seeded than in small seeded type and damages to seed coat such as cracks, bruises and injuries to cotyledons escape unnoticed during normal processing resulting in poor seed quality. Hard seed coats lessen or alleviate stresses during and after harvest. Weak structure and cracks in the seed coat permit fungal infection, causing seed deterioration (Davenport and Splittstoesser, 1993). Germination of fresh and dry seeds is important from post-harvest seed operations, conservation and utilization point of view. A critical observation of seeds with poor viability before and after drying revealed injuries to seeds with thin seed coat in the form of bruises and ruptures during threshing or cleaning and splitting and cracking (Fig. 3) of seed coat in smooth surface and pea shaped accessions during drying. Yadav and Sharma (1998) observed higher seed coat cracking in Kabuli type chickpeas with large seed size and thin seed coat. Physiological cracking of seed coat in Kabuli types reduces quality of seeds during storage and thin seed coat in Kabuli types opens the avenues for imbibition and pathogenic injuries (Powell *et al*., 1986; Yadav and Sharma, 1998) resulting in reduced germination. Absence of hard seeds in any of the fresh seeds is an important observation in this study and none of the Kabuli or intermediate types had hard seeds as a result of seed drying. This could be attributed to the nature of the seed coat which is considerably thinner in both Kabuli type and intermediate types, as compared to desi type chickpeas. All the accessions with hard seeds have rough seed coat and essentially represent the desi types. Among the seed sizes, hard seeds were significantly high in large sized seeds (up to 58%). Based on extended germination tests of dry seeds desi type accessions with rough seed coat and small seed sized accessions recorded highest viability and such accessions could be safely dried for long-term conservation.

Fig. 3. Chickpea accessions with seed coat injuries to fresh seed (left and middle) and dry seeds (right)

In conclusion, sorting chickpea germplasm based on seed traits results in efficient processing of large number of accessions in genebanks and desi type chickpeas could be safely processed following precautions for hard seeds during germination tests. Kabuli types were prone to seed coat related injuries during processing resulting in poor quality and viability and seeds with pea shape and smooth surface were sensitive to drying necessitating alternate measures for reducing moisture content. Knowledge on seed surface texture, density, and porosity of chickpea seeds contribute to improving processing technologies for bulk seed lots. Pea shaped chickpeas had higher true densities and recording this trait on germplasm accessions is a low-cost way for seed quality evaluation and to identify promising chickpea accessions for further utilization.

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