Vegetable Science (2020) 47(2): 224-229

Effect of ultra-drying on storability and vigour of onion seeds

Vishwanath Rohidas Yalamalle*, Yogesh Khade and Major Singh

Received: November 2020/ Accepted: December 2020

Abstract

Onion seeds are poor storers they have one of the lowest storability among cultivated crops. Seed moisture is one of the critical factors which determines the seed storability. The effect of ultra-drying of onion seeds on seed storability and seed vigour was studied. Seeds of three onion varieties Bhima Dark Red, Bhima Shakti and Bhima Safed were dried in 2:1 beads to seed ratio (w/w) for 96 hours and packed and stored in moisture impervious pack for 12 months under ambient conditions. The initial moisture of seeds was 8.46% - 5.25%, which reduced to 3.48 - 2.91% at after 96 hours. The ultra-dried seeds had higher seed viability and vigour in comparison to control (undried seeds). At the end of 12 months of storage, the average seed germination in ultra-dried seeds was 81% whereas in control it was 52%. In comparison to control at the end of 12 months, the ultra-dried seeds had 23.82%, 33.80%, 83.12% and 98.60% higher seedling length, seedling dry weight, vigour index-I and vigour index-II. The ultra-dried seeds also recorded lower electrical conductivity indicating lower membrane degradation during storage. Thus, drying of onion seed in 2:1 beads to seed ratio for 96 hours is beneficial in enhancing the storability of onion seeds.

Keywords: Onion seed, drying beads, germination, storage, vigour

Introduction

Onion seeds have one of the lowest storability among cultivate crops (Yalamalle et al. 2020, Yalamalle and Kuchlan 2016). Seed ageing is associated with ROS induced degradation of cellular components including DNA, RNA, and proteins. The peroxidation of lipids leads to membrane degradation and leakage of solute from the cells (Bailly 2004, Kurek et al. 2019). Orthodox seeds have adapted to survive the desiccation, wherein the metabolic activity is lower, and the accumulation of oxidative stress is minimal. The rate of seed degradation can be slowed by reducing the seed moisture (Mukhopadhyay et al. 2013) and thus enhancing the storability of seeds.

According to Harrington thumb rule (Harrington 1960), the storability of seeds doubles for every 1% reduction in the seed moisture or every 5 ^{0}C reduction in the storage temperature. The reduction in the storage temperature requires setting up of cold storage facility, which is not only capital intensive but also involves recurring cost. Since > 80 % of the onion seed are produced by farmers (Gupta and Sharma 2014), there is a need to establish technology for on-farm storage of onion seeds.

Onion seeds are harvested and processed in May. During this time high temperature and high RH pose challenges in drying seeds. High RH during storage enhances the seed moisture and increases the incidence of fungi and insect pest, leading to faster seed deterioration (Santos et al. 2016). Seed moisture is the most critical factor contributing to seed ageing and post-harvest losses (Guzzon et al. 2020). The seeds can be dried using seed dryer machines, which is capital intensive and not economical for the farmers as well as to the small seed companies. Desiccants like silica gel, aluminium silicates, lithium chloride, and calcium chloride are being used for drying seeds. These desiccants when kept in a closed container, reduce the RH of the air and seeds lose moisture until it comes to equilibrium with storage atmosphere (Hay et al. 2012). The quantity of moisture absorbed and the rate of absorption depends on the desiccant used and the quantity of desiccant used (Hay et al. 2012). Drying beads ®/ zeolite beads are made of aluminium silicate. They have a high affinity to water and can absorb moisture up to 20-25% of their dry weight. Unlike silica gels, aluminium silicates has a high affinity to water and works well even in low RH (Hay et al. 2012). It reduces the moisture quickly, is non-toxic and can be regenerated by heating at > 200 ^{0}C for 3-4

ICAR-Directorate of Onion and Garlic Research, Pune- 410505, Maharashtra

*Corresponding author, Email: vishwanath_yal@yahoo.com

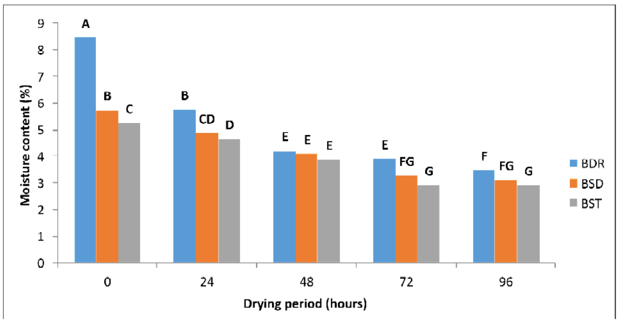

Figure 1: Effect of zeolite beads on onion seed moisture during different drying periods

hours. Zeolite beads are being used for seed conservations in seed banks, community seed banks in resource-poor regions (Guzzon et al. 2020). Since in India onion seeds are produced by small and marginal farmers, there is a need to provide on-farm onion seed storage method.

Material and Methods

Experimental material: Freshly harvested seeds of three onion varieties - Bhima Dark Red hereafter

Table 1: Effect of ultra-drying on seed germination in three onion varieties stored for different durations.

Storage period	Germination (%)							
	Beads drying				Control			
	BDR	BST	BSD	Mean	BDR	BST	BSD	Mean
Initial	86 (68.06)	84 (66.44)	86 (68.30)	85 (67.06)^{a}	86 (68.06)	84 (66.45)	86 (68.30)	85 (67.60)^{a}
6 m	76 (60.68)	85 (66.96)	80 (63.49)	80 (63.71)^{b}	75 (59.91)	83 (66.14)	77 (61.17)	78 (62.41)^{b}
12 m	82 (64.92)	79 (62.53)	81 (64.17)	81(63.87)^{b}	33 (34.84)	64 (53.13)	59 (50.00)	52 (45.99)^{c}
Mean	81 (64.55)$^{a\wedge\$}$	82 (65.31)^{a}	82 (65.32)^{a}		64 (54.27)^{c}	77 (61.91)^{a}	74 (59.67)^{b}	
			Mean A_1	82.04 (65.06)^{a}			Mean A_2	71.78 (58.67)^{b}

BDR-Bhima Dark Red, BST-Bhima Shakti, BSR-Bhima Super, BSD-Bhima Safed. ^ Values with same letters in a column/ row are not statistically significant. $- Values in the parenthesis are arcsine transformed values. m- Months. A_1- Beads, A_2- Control.

Table 2: Effect of ultra-drying on seedling length in three onion varieties stored for different durations.

Storage period	Seedling length (cm)							
	Beads drying				Control			
	BDR	BST	BSD	Mean	BDR	BST	BSD	Mean
Initial	10.77	11.65	10.51	10.98^{a}	10.77	11.65	10.51	10.98^{a}
6 m	10.85	9.71	10.88	10.48^{a}	9.83	8.66	10.53	9.67^{b}
12 m	6.07	8.20	7.85	7.38^{b}	4.57	6.44	6.99	6.00^{c}
Mean	9.23^{b}	9.85^{a}	9.75^{a}		8.39^{b}	8.92^{a}	9.34^{a}	
			Mean A_1	9.61^{a}			Mean A_2	8.88^{b}

BDR - Bhima Dark Red, BST-Bhima Shakti, BSR-Bhima Super, BSD- Bhima Safed. ^ Values with same letters in a column/ row are not statistically. m- Months. A_1- Beads, A_2- Control

Table 3: Effect of ultra-drying on seedling dry weight in three onion varieties stored for different durations

Storage period	Dry weight (mg seedling^{-1})							
	Beads drying				Control			
	BDR	BST	BSD	Mean	BDR	BST	BSD	Mean
Initial	2.03	2.20	2.37	2.20^{a}	2.03	2.20	2.37	2.20^{a}
6 m	1.60	1.40	1.80	1.60^{c}	1.65	1.19	1.71	1.52^{b}
12 m	1.86	2.00	1.96	1.94^{b}	1.13	1.85	1.39	1.45^{b}
Mean	1.83$^{b\wedge}$	1.87^{b}	2.04^{a}		1.60^{b}	1.74^{a}	1.82^{a}	
			Mean A_1	1.91^{a}			Mean A_2	1.72^{b}

BDR - Bhima Dark Red, BST-Bhima Shakti, BSR-Bhima Super, BSD- Bhima Safed. ^ Values with same letters in a column/ row are not statistically. m- Months. A_1- Beads, A_2- Control

Table 4: Effect of ultra-drying on vigour index-I in three onion varieties stored for different durations

Storage period	Vigour index-I							
	Beads drying				Control			
	BDR	BST	BSD	Mean	BDR	BST	BSD	Mean
Initial	926.07	979.24	904.90	936.74^{a}	926.07	979.24	904.90	936.74^{a}
6 m	823.88	821.84	871.19	838.97^{b}	734.94	721.45	809.38	755.26^{b}
12 m	498.41	643.97	636.83	593.07^{c}	148.56	411.63	411.39	323.86^{c}
Mean	749.46^{b} ^	815.01^{a}	804.31^{a}		603.19^{b}	704.10^{a}	708.55^{a}	
			Mean A_1	789.59^{a}			Mean A_2	671.95^{b}

BDR-Bhima Dark Red, BST-Bhima Shakti, BSR-Bhima Super, BSD-Bhima Safed. ^ Values with same letters in a column/ row are not statistically significant. m- Months. A_1- Beads, A_2- Control

Table 5: Effect of ultra-drying on vigour index-II in three onion varieties stored for different durations

Storage period	Vigour index-II							
	Beads drying				Control			
	BDR	BST	BSD	Mean	BDR	BST	BSD	Mean
Initial	175.00	185.20	203.93	188.04^{a}	175.00	185.20	203.93	188.04^{a}
6 m	121.43	118.42	144.26	128.04^{c}	122.95	98.75	131.64	117.78^{b}
12 m	152.39	157.25	159.02	156.22^{b}	37.04	118.12	80.83	78.66^{c}
Mean	149.61^{b} ^	153.62^{b}	169.07^{a}		111.66^{b}	134.02^{a}	138.80^{a}	
			Mean A_1	157.43^{a}			Mean A_2	128.16^{b}

BDR-Bhima Dark Red, BST-Bhima Shakti, BSR-Bhima Super, BSD- Bhima Safed. ^ Values with same letters in a column/ row are not statistically. m- Months. A_1- Beads, A_2- Control

Table 6: Effect of ultra-drying on electrical conductivity in three onion varieties stored for different durations.

Storage period	Electrical Conductivity (µS cm^{-1} g^{-1})							
	Beads drying				Control			
	BDR	BST	BSD	Mean	BDR	BST	BSD	Mean
Initial	93.77	104.93	100.83	99.84^{c}	93.77	104.93	100.83	99.84^{c}
6 m	96.73	99.30	116.66	104.23^{b}	120.04	124.81	142.74	129.19^{b}
12 m	118.09	117.44	109.80	115.11^{a}	163.27	131.33	139.28	144.62^{a}
Mean	102.86^{a}	107.22^{a}	109.10^{a}		125.69^{ab}	120.36^{b}	127.62^{a}	
			Mean A_1	106.39^{a}			Mean A_2	124.55^{b}

BDR - Bhima Dark Red, BST-Bhima Shakti, BSR-Bhima Super, BSD- Bhima Safed. ^ Values with same letters in a column/ row are not statistically. m- Months. A_1- Beads, A_2- Control

Table 7: Summary of three-way ANOVA for the effect of drying methods (beads and control) on seed storability (initial, 6 months and 12 months) and quality in three onion varieties (Bhima Dark Red, Bhima Shakti and Bhima Safed).

Factors	d.f	G %	SL	DW	VI-I	VI-II	EC
A[1]	1	1.41**	0.42**	0.09**	37.93**	7.81**	5.43**
B[2]	2	1.72**	0.51*	0.11**	46.46**	9.64**	NS
C[3]	2	1.72**	0.51**	0.11**	46.46**	9.64**	6.64**
A X B	2	2.43**	NS	NS	NS	NS	NS
A X C	2	2.43**	0.73*	0.15**	65.70**	13.63**	9.40**
B X C	4	2.98**	0.89**	0.18**	80.47**	16.70**	11.51**
A X B XC	4	4.22**	NS	0.26*	NS	23.61**	NS

[1]Drying method, [2]storage period, [3]variety. d.f- degrees of freedom. G% - germination (%), SL-Seedling length, DW-seedling dry weight, VI-I- vigour index-I, VI-II- vigour index-II, EC- electrical conductivity. **- significant at *P d”* 1%, *- significant at *P d”* 5%.

(“BRD”), Bhima Shakti (“BST”) and Bhima Safed (“BSD”) having initial germination of >80% was procured from the seed production unit, ICAR-Directorate of Onion and Garlic Research, Pune, India. The seeds (100 g of each variety) were dried in aluminium silicates or “zeolite” beads (drying beads®) in 2: 1 beads to seed ratio at ambient temperature (25-35 ^{0}C) for 96 hours at 10% RH. The dried seeds were hermetically sealed in 400-gauge poly packs and the seed quality attributes were studied at three intervals (initial, 6 months and 12 months).

Seed germination and seed vigour: In a 150 mm Petri plate, 50 seeds in three replicates were placed on moistened filter paper (Axiva, India catalogue No. 100150R). The Petri plates were kept in a seed germinator set at 20 ± 1 ^{0}C and 75% RH. On the 12th day, germination % was calculated based on the number of normal seedlings (ISTA, 2015). The seedling length was measured on 10 randomly selected normal seedlings, the same seedlings were dried in an oven (60 ^{0}C) till the dry seedlings reach constant weight. The seed vigour index-I (VI-I) and vigour index-II (VI-II) were calculated as per Abdul Baki and Anderson (1973).

Electrical conductivity: In a 50 ml beaker, 100 mg seeds were weighed in three replicates and to it, 25 mL double distilled water was added. Then the beakers were kept at 20 ± 1^{0}C for 24 hours, the leachate was collected and the electrical conductivity (EC) was recorded with the help of a digital conductivity meter along with distilled water as a control.

Statistical analysis: The data were analyzed by statistical analysis system SAS® System version 9.3 (SAS Institute, Cary, NC, USA). The data collected were subjected to a three-way ANOVA and means were separated by the least significant difference test (at *P d”* 0.05). Grouping letters on treatment means were assigned using Fishers protected LSD. Means with at least one common letter were not statistically significant.

Results and Discussion

Ultra-dry seed storage is a simple and inexpensive method to enhance the storability of seeds (Li et al. 2010). The effect of ultra-drying of onion seeds in zeolite beads on seed storability and vigour was studied.

Seed moisture: The initial seed moisture in BDR, DST and BSD were 8.46% ± 0.13 (mean ± st. dev. fresh weight basis), 5.25% ± 0.13 and 5.75% ± 0.27 respectively. This was reduced to 3.48% ± 0.06, 3.12% ± 0.08 and 2.91% ± 0.10 after 96 hours of drying in zeolite beads (Figure 1). In comparison to silica gel drying, zeolite beads have high affinity to the water molecule, particularly at low RH. It can absorb up to 20-25% of body weight in water (Hay et al. 2012). Hay et al. (2012) dried paddy seeds in 3:1 beads to seed ratio for 90-95 days storage the moisture reduced from 22.6% to 4.2 %. Nivethitha et al. (2020) also reported a rapid reduction in seed moisture in okra seeds dried in zeolite beads. In another study, Shen and Qi (1998) dried onion seeds in silica gel for 58 days and during which the moisture reduced to 1.7% from 7.4%. The difference in the results from the previous studies may because each kind and variety have different sorption and desorption properties (Moharir and Nam 1995).

Seed germination: Ultra-drying of onion seeds had a significant effect on the germination (%). From the initial 85.33%, the germination reduced to 80.55% at the end of 12 months. Whereas in control the germination reduced to 51.78% (Table 2). There was no significant difference among the varieties in ultra- dried seeds for average germination, whereas in control BST had higher average germination (77%). The interaction for various factors were significant, (*P d"* 0.01) for drying methods X variety, (*P d"* 0.01) for drying methods X storage period, (*P d"* 0.01) variety X storage period and (*P d"* 0.01) for drying methods X variety X storage period (Table 7).

Seedling length: Ultra-drying of onion seeds had a significant effect on the seedling length (Table 2). There was no significant reduction in seedling length up to six months in ultra-dried seeds, whereas seeding length reduced in case of control. After 12 months of storage, the average seedling length in ultra-dried seed was 7.38 cm, which was 23.82% higher than control. Among varieties, BST and BSD had higher seedling length in both ultra-dried seeds as well as in control. The interaction for various factors were significantly differed (*P d"* 0.05) for drying methods X storage period and (*P d"* 0.01) for variety X storage period (Table 7).

Seedling dry weight: Ultra-drying of onion seeds had a significant effect on the seedling dry weight (Table 3). There was a significant reduction in seedling dry weight during the various storage periods. In ultra-dried seeds 12 months old seeds had the highest seedling dry weight, whereas in control the seedling dry weight at 6 months and 12 months were statistically similar. Among the varieties in both ultra-dried seeds and control, BSD had higher seedling dry weight. The interaction for various factors significantly differed (*P d"* 0.01) for drying methods X storage period, (*P d"* 0.01) for variety X storage period and (*P d"* 0.01) and (*P d"* 0.05) for drying methods X variety X storage period (Table 7).

Vigour index-I: The vigour index-I declined with the storage period in both the ultra-dried seeds and control, but the highest decline in seed vigour was seen in control (Table 4). The ultra-dried seeds had 83.12% higher vigour index-I. Among the varieties, in both ultra-dried seeds and control higher vigour index-I was recorded in variety BST and BSD. The interaction for various factors significantly differed (*P d"* 0.01) for drying methods X storage period and (*P d"* 0.01) for variety X storage period (Table 7).

Vigour index-II: Like vigour index-I, the vigour index-II also declined with storage period in both ultra-dried seeds and control, but the highest decline in vigour index-II was seen in control (Table 5). In comparison to control the ultra-dried seeds had 98.60% higher vigour index-II. In both ultra-dried seeds as well as control highest vigour index-II was recorded in variety BSD. The interaction for various factors significantly differed (*P d"* 0.01) for drying methods X storage period, (*P d"* 0.01) for variety X storage period and (*P d"* 0.01) for drying methods X variety X storage period (Table 7).

Electrical conductivity: The electrical conductivity enhanced with the storage period in both the ultra-dried seeds and control, but the highest electrical conductivity was recorded in control (Table 6). In comparison to control ultra-dried seeds had 98.60% lower electrical conductivity. In both ultra-dried seeds as well as control, lowest EC was recorded in BSD. The interaction for various factors significantly differed (*P d"* 0.01) for drying methods X storage period and (*P d"* 0.01) for variety X storage period (Table 7). Seeds are hygroscopic and they absorb or lose moisture until an equilibrium is reached with the storage environment (Krishnan et al. 2004). Seeds can be dried by using high temperature in machines or under the sun. High temperature during storage cause damages to seed and may affect storability (Hartmann et al. 2016). To avoid damages to the seeds seed drying at low temperature under low humidity is recommended. In the present study, zeolite beads were used to dry the seeds to ultra-low moisture up to 2.91% moisture.

The metabolic activity is higher in seeds with high moisture, which leads to higher reactive oxygen species (ROS) generation (Yalamalle et al. 2019). The seed quality attributes like seed germination and seed vigour were higher in seeds dried in zeolite beads. Li et al. (2010) studied the storability of *Ammopiptanthus mongolicus* for 24 months and in comparison to control ultra-dried seeds had higher antioxidant activities and lower malondialdehyde. The ROS causes lipid peroxidation in the membrane and results in higher solute leakage. The electrical conductivity is used as an indicator of membrane integrity. In the present study, the EC increased with the seed age, however, the electrical conductivity of ultra-dried seeds at 12 months (115.11 μS cm^{-1} g^{-1}) was significantly (*P d"* 0.05) lower than that of control (144.62 μS cm^{-1} g^{-1}). The results are in agreement with the previous studies of Li et al. (2010) and (Li-rong and Jian-guo 2009).

Conclusion

Dry chain concept, which refers to drying seeds to safe moisture levels and storing the seeds by hermetically sealing in moisture impervious bags is recommended for storage of seeds in community seed banks and on-farm seed storage units (Bradford et al. 2018). Our results demonstrated that drying of onion seeds in zeolite beads for 96 hours can enhance the storability and vigour of onion seeds under ambient conditions.

सारांश

प्याज के बीजों का भंडारण क्षमता अन्य फसलों के तुलना में सबसे कम होता है। बीजों के भंडारण क्षमता पर बीजों में उपस्थिति नमी निर्धारित करती है। प्याज के बीज भंडारण क्षमता और बीज ओज पर बीज के अति–सुखाने के प्रभाव का अध्ययन किया गया। प्याज के 3 किस्मों जैसे–भीमा डार्क रेड, भीमा शक्ति और भीम सफेद को 2:1 (बीजः सुखानेवाले बीड्स) अनुपात में 96 घंटे सुखाया गया और परिवेशी परिस्थितियों पालीथीन की थैली में 12 महीनों के लिए संग्रहित किया गया। बीज की प्रारम्भिक नमी 8.46–5.25 प्रतिशत थी जो 96 धंटे सुखाने के बाद घटकर 3.48–2.91 प्रतिशत हो गयी। सामान्य की तुलना में अति–सूखे बीजों में भण्डारित बीज की गुणवत्ता अत्यधिक थी। भण्डारण के 12 महीनों के अंत में अल्ट्रा–सूखे बीज में औसत बीज अंकुरण 81 प्रतिशत था जबकि सामान्य में यह 52 प्रतिशत था। बारह महीनें के अंत में सामान्य की तुलना में अल्ट्रा–सूखे बीजों में 23.82 प्रतिशत, 33.80 प्रतिशत, 83.12 प्रतिशत 98.60 प्रतिशत अधिक अंकुर लंबाई, शुष्क वजन, ओज सूचकांक–I और ओज सूचकांक–II था। आल्ट्रा–सूखे बीजों में कम विद्युत प्रवाहत्त्व दर्ज की गयी, जो भण्डारण के दौरान कम कोशिका झिल्ली पतन का संकेत है। प्याज के बीज के 2:1 अनुपात में (बीजः सुखाने वाला बीड्स) 96 घंटों तक सुखाने से प्याज के बीजों का भंडार क्षमता बढ़ता है।

References

Abdul Baki AA and Anderson JD (1973) Vigor determination in soybean seed by multiple criteria 1. Crop Sci 13: 630–633.

Bailly C (2004) Active oxygen species and antioxidants in seed biology. Seed Sci Res 14: 93–107.

Bradford KJ, Dahal P, Van AJ, Kunusoth K, Bello P, Thompson J and Wu F (2018) The dry chain: Reducing postharvest losses and improving food safety in humid climates. Trends Food Sci Technol 71: 84–93.

Gupta RP and Sharma HP (2014) Onion seed production- scope, challenges and future strategy to meet the demand of quality seed. In: Brain Storming Session on Crop Improvement and Seed Production of Onion. NHRDF, Nashik, India, pp 1–12.

Guzzon F, Bello P, Bradford KJ, Guzman MM de los A and Costich DE (2020) Enhancing seed conservation in rural communities of Guatemala by implementing the dry chain concept. Biodivers Conserv 29: 3997–4017.

Harrington J (1960) Thumb rules of drying seeds. Crop Soils 13: 16–17.

Hartmann Filho CP, Goneli ALD, Masetto TE, Martins EAS and Oba GC (2016) The effect of drying temperatures and storage of seeds on the growth of soybean seedlings. J Seed Sci 38: 287–295.

Hay FR, Thavong P, Taridno P and Timple S (2012) Evaluation of zeolite seed "Drying Beads®" for drying rice seeds to low moisture content prior to long-term storage. Seed Sci Technol 40: 374–395.

ISTA (2015) ISTA rules full issue. Int Rules Seed Test 2015: 1–276.

Krishnan P, Nagarajan S and Moharir AV (2004) Thermodynamic characterisation of seed deterioration during storage under accelerated ageing conditions. Biosyst Eng 89: 425–433.

Kurek K, Plitta-Michalak B and Ratajczak E (2019) Reactive oxygen species as potential drivers of the seed aging process. Plants 8: 174.

Li-rong T and Jian-guo H (2009) Effect of ultradrying on germination and physiological and biochemical characteristics of Haloxylon persicum. African J Biotechnol 8: 626–629.

Li Y, Qu J-J, Zhang W-M, An L-Z, Xu P and Li Y-C (2010) Impact of ultra-dry storage on vigor capacity and antioxidant enzyme activities in seed of Ammopiptanthus mongolica. Bot Stud 51: 465–472.

Moharir AV and Nam P (1995) Moisture desorption and absorption isotherms of seeds of some varieties of Triticum aestivum and Triticum durum wheat. Curr Sci 68: 316–326.

Mukhopadhyay D, Chauhan JC, Parihar SS and Dadlani M (2013) Seed storage behaviour in Berberis aristata. Indian J Agric Sci 83(3): 304–309.

Nivethitha M, Bara BM, Chaurasia AK, Manimurugan C and Singh PM (2020) Standardization of ultra- seed drying of okra cv.Kashi Kranti with zeolite beads and silica gel. J Pharmacogn Phytochem 9(5): 1198-1202.

Santos F dos, Medina PF, Lourenção AL, Parisi JJD and Godoy IJde (2016) Damage caused by fungi and insects to stored peanut seeds before processing. Bragantia 75 (2): 184-192

Shen D and Qi X (1998) Short- and long-term effects of ultra-drying on germination and growth of vegetable seeds. CABI International. https://www.bioversityinternational.org/fileadmin/bioversity/publications/Web_version/243/ch10.htm. Accessed 1 November 2020.

Yalamalle VR, Ithape DM, Kumar A, Bhagat K, Ghosh S and Singh M (2020) Seed treatment with 5-azacytidine reduces ageing-induced damage in onion seeds. Seed Sci Technol 48(3): 407-412.

Yalamalle VR and Kuchlan MK (2016) Safe storage of onion (Allium cepa L) seeds under moisture impervious packets with fungicide treatment. Environ Ecol 34: 2453–2457.

Yalamalle VR, Tomar BS, Jain SK, Arora A, Kumar A and Munshi AD (2019) Spermine induced protection of onion seed vigour and viability during accelerated ageing. J Environ Biol 40: 1079–1083.