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Effect of Modified Atmosphere Storage Conditions on Seed Quality and Longevity of Kabuli Chickpea Varieties

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ABSTRACT

Background: Chickpea is an important pulse crop. The area, production and productivity of Kabuli chickpea are very low as compared to Desi type chickpea. While, worldwide chickpea production is predominated by Desi type (80%) compared to Kabuli type (20%). One of constraints limiting the Kabuli chickpea seed production is the fast seed deterioration process as, they possesses thin and fragile seed coat which makes it more susceptible to infestation of pulse beetle and storage fungi. In addition, the day by day increase in usage of chemical pesticides and increase in health awareness among the people and demand towards organic based products necessitate a new alternative method of seed storage than the routinely used storage methods. Modified atmosphere storage is an alternative method to avoid chemical fumigants, which are said to cause residual effect on seed material and development of resistance by storage pest against insecticides.

Methods: The present investigation on modified atmosphere packaging (MAP) was carried out at the Department of Processing and Food Engineering, College of Agricultural Engineering, University of Agricultural Sciences, Raichur during March 2017. Further, its storage and seed quality assessment were conducted at Seed Quality and Research Laboratory of National Seed Project (Crops), Seed Unit, University of Agricultural Sciences, Dharwad during March 2017 to May 2018.

Result: The results revealed that the Kabuli chickpea seeds stored in the gaseous atmosphere with the combination of CO_2 (80%) +N_2 (20%) + O_2 (0%) [C_2] have maintained the maximum germination (92%) followed by Vaccum Packaging [C_5] by using 700 gauge polyethylene bag for 14 months under ambient conditions above the Indian Minimum Seed Certification Standards.

Key words: CO_2, Gases, Kabuli chickpea, Modified atmosphere packaging, N_2, O_2, Organic, Storage.

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is a third most important pulse crop in the world after beans and peas, valued for its nutritive seed composition with high protein content and used increasingly as a substitute for animal protein and in the preparation of variety of snacks, sweets and condiments. Chickpea is classified based on seed size, shape and colour. In India, the two most commonly cultivated types are white seeded 'Kabuli chickpea' and brown seeded 'Desi' type. Globally and nationally the area, production and productivity of Kabuli chickpea is very low as compared to Desi type chickpea. However, world of chickpea is predominated by Desi type which accounts 80 per cent and Kabuli type only 20 per cent of production. India is the largest producer of chickpea contributing over 70 per cent of the world production with an area of 86.80 lakh hectares with a production of 80.90 lakh tonnes and with a productivity of 932 kg per hectare (Anonymous, 2017).

Seed deterioration is a natural process which is inevitable, inexorable and irreversible. Hence, seed storage and its quality maintenance becomes more challenging in Kabuli chickpea seeds as, they possesses thin and fragile seed coat which makes it as more susceptible to infestation of pulse beetle and storage fungi. The day by day increase in usage of chemical pesticides and on contrary the increase in health awareness among the people and their demand towards organic based products necessitates a new alternative method of storage that improves conditions and environments that cause quality deterioration then the routinely used storage methods. A low-oxygen atmosphere system for handling of chickpea seeds appears to have potential for improving storage practices. Many studies have showed that modified atmosphere of elevated carbon dioxide and depleted oxygen is an effective method against insect pests and microorganisms attack during storage. Modified atmosphere storage is one of the seed and food preservation method that maintains the natural quality of seeds and food products besides extending the storage life of seed by reducing the respiration rate (Moltos *et al*., 2002). Modified atmosphere storage is an alternative method to avoid chemical fumigants, which are said to cause residual effect on seed material and development

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of resistance by storage of resistance by storage pest against insecticides and pesticides which help in protection of stored seed from insect pest infestations and also to slow down the seed deterioration. Besides, alternatively high carbondioxide treatment is residue free and approved by Environmental Protection Agency, USA. Carbondioxide treated seeds are also accepted in the organic market. Hence, an attempt was made to study the effect of modified atmosphere storage conditions on seed quality and longevity of Kabuli chickpea varieties.

MATERIALS AND METHODS

The laboratory experiment was conducted in the Department of Processing and Food Engineering, College of Agricultural Engineering, University of Agricultural Sciences, Raichur using the Modified Atmosphere Packaging (MAP) Unit during March 2017 in order to assess the seed storability of Kabuli chickpea by subjecting to different modified atmospheric storage conditions with different concentrations combination of gases like carbon dioxide, nitrogen and oxygen. The experiment consisted of two varieties *viz.,* V_1 (BG1105) and V_2 (MNK-1) and five treatments *viz.,* C_1: Normal air (untreated control), C_2: CO_2 (80%) + N_2 (20 %) + O_2 (0%), C_3: CO_2 (75%) + N_2 (20 %) + O_2 (5%), C_4: CO_2 (70%) + N_2 (20%) + O_2 (10%) and C_5: Vaccum packing. The seeds exposed to these gas combinations were stored in 700 gauge polyethylene bags for 14 months (from March 2017 to May 2018) under ambient condition at Seed Unit, Dharwad. The experiment was carried out in completely randomized design with factorial concept with four replications and observations on seed quality parameters were recorded bimonthly.

Method of modified atmosphere packaging was carried out as per the procedure given by Vasudevan *et al.* (2014). However, in the present study 800 g seeds of both varieties were packed in polyethylene bag (700 gauge) with the gases like carbon dioxide, nitrogen and oxygen in different concentrations according to the treatments mentioned above.

The seeds obtained from each treatment were evaluated for the seed quality parameters in the Seed Quality and Research Laboratory, Seed Unit, University of Agricultural Sciences, Dharwad. Germination test was conducted as per procedure given by ISTA (2014). The speed of germination was calculated by using the formula given by Maguire (1962). Ten normal seedlings were selected randomly in each treatment from all the replications on 8th day. The root length was measured from the tip of the primary root to base of hypocotyl and mean root length was expressed in centimeter (cm) while, the shoot length was measured from the base of the primary leaf to the base of the hypocotyl and mean shoot length was expressed in centimeter (cm). Seedling dry weight (Evans and Bhatt, 1977) and seedling vigour index Abdul-Baki and Anderson (1973) were calculated by using the formula as suggested by Abdul-Baki and Anderson (1973), electrical conductivity of seed leachate was measured as per procedure given by Presley (1958). The data collected from the experiment were analyzed statistically by the procedure prescribed by Gomez and Gomez (2010).

RESULTS AND DISCUSSION

Influence of varieties on seed quality

Seed quality differs among the varieties in a crop. Among the varieties, significantly higher seed germination (99.10%) (Table 1), speed of germination (57.07) (Table 2), root length (22.09 cm) (Table 3), shoot length (16.33 cm) (Table 4), seedling dry weight (163 mg) (Table 5), seedling vigour index (3813) (Table 6) and lower electrical conductivity (0.299 dSm^{-1}) (Table 7) were recorded in variety V_1 (BG1105) as compared to variety MNK-1 (98.15%, 38.44, 19.35 cm, 12.95 cm, 81 mg, 3173 and 0.520 dSm^{-1}, respectively). However, there was gradual decrease in seed quality with the advancement of storage period.

Similar trend was observed throughout the storage period, whereas at the end of fourteen months of storage V_1 (BG1105) recorded significantly highest seed germination (91.40%), speed of germination (55.01), root length (16.96 cm), shoot length (10.87 cm) seedling dry weight (116 mg), seedling vigour index (2546) and lower electrical conductivity (1.068 dSm^{-1}) as compared to MNK-1 (V_2) (90.10%, 36.26, 14.60 cm, 7.57 cm, 59 mg, 2000 and 1.255 dSm^{-1}, respectively). This may be attributed to genotypic response of varieties, where V_1 (BG1105) was superior over MNK-1 (V_2). Similar varietal response was reported by Merwade (2000), Gnyandev (2009) and Sushma (2013) in chickpea.

Influence of modified gaseous on seed quality in Kabuli chickpea genotypes

The present study of modified atmospheric storage conditions exhibited significant effect on seed germination of chickpea seeds. The seeds which were stored with the gaseous combination of CO_2 (80%) + N_2 (20%) + O_2 (0%) (C_2) showed better germination throughout the storage period followed by the gaseous combination of vaccum packing (C_5) and CO_2 (75%) + N_2 (20%) + O_2 (5%) (C_3) and lowest was in control (C_1). The seed germination per cent due to concentrations of modified atmospheric gases varied significantly at all the month of storage period except for initial month. From second month of storage period significantly higher seed germination (99.88%) was recorded in C_2 (80% CO_2 + 20% N_2 + 0% O_2) treated seeds and it was followed by C_5 (vaccum treated seeds) (99.38%), while the lower (95.75%) was recorded in untreated seeds (control) (C_1). At the end of fourteen months of storage period the highest seed germination was recorded in C_2 (92.38%) and it was followed by C_5 (91.63%) and the lowest was recorded in control (C_1) (88.75%). Whereas, in the initial month numerically highest germination was recorded (99.88%) in C_2 and the lowest (96.63%) in control (C_1) (Table 1).

Modified atmosphere storage of seeds devoid of oxygen recorded higher seed viability for an appreciable period. Higher seed viability and vigour were maintained with modified atmospheric storage particularly in carbon dioxide and vacuum packaged condition. The probable reason for differences in longevity of seeds in the modified

Table 1: Influence of modified atmospheric storage conditions on germination in Kabuli chickpea varieties during storage.

Treatments	Germination (%)							
	Months after storage							
	0	2	4	6	8	10	12	14
Varieties (V)								
V_1 -BG1105	99.10	98.55	97.75	96.80	95.90	95.55	93.40	91.40
	(84.52)*	(83.05)	(81.34)	(79.66)	(78.29)	(77.79)	(75.08)	(72.92)
V_2 -MNK-1	98.15	97.95	97.00	95.75	94.75	94.45	91.75	90.10
	(82.15)	(81.74)	(79.99)	(78.07)	(76.72)	(76.34)	(73.28)	(71.63)
S.Em. ±	0.41	0.14	0.18	0.24	0.29	0.28	0.29	0.29
C.D. @ 1%	NS	0.53	0.71	0.92	1.11	1.07	1.12	1.11
Concentration of modified atmospheric gases (C)								
C_1: Normal air (Untreated control)	96.63)	95.75	94.25	94.00	93.13	92.50	90.38	88.75
	(79.39)	(78.07)	(76.10)	(75.79)	(74.77)	(74.08)	(71.90)	(70.37)
C_2: CO_2 (80%) + N_2 (20%) + O_2 (0%)	99.88	99.88	99.00	97.88	97.00	96.88	94.25	92.38
	(87.98)	(87.98)	(84.23)	(81.60)	(79.99)	(79.79)	(76.10)	(73.95)
C_3: CO_2 (75%) + N_2 (20%) + O_2 (5%)	99.00	98.63	97.88	96.50	95.63	95.38	92.88	91.00
	(84.23)	(83.24)	(81.60)	(79.19)	(77.90)	(77.56)	(74.49)	(72.51)
C_4: CO_2 (70%) + N_2 (20%) + O_2 (10%)	98.13	97.63	97.38	95.88	94.75	94.50	92.00	90.13
	(82.11)	(81.11)	(80.65)	(78.26)	(76.72)	(76.41)	(73.54)	(71.66)
C_5: Vaccum packing	99.50	99.38	98.38	97.13	96.13	95.75	93.38	91.63
	(85.91)	(85.45)	(82.65)	(80.21)	(78.62)	(78.07)	(75.06)	(73.15)
S.Em. ±	0.65	0.21	0.29	0.37	0.45	0.44	0.46	0.45
C.D. @ 1%	NS	0.83	1.12	1.45	1.75	1.69	1.77	1.76
Interaction (V × C)								
V_1C_1	98.00	96.50	94.75	93.75	94.00	93.75	91.50	89.50
	(81.84)	(79.19)	(76.72)	(75.49)	(75.79)	(75.49)	(73.02)	(71.06)
V_1C_2	100.00	100.00	99.50	98.75	97.50	97.25	95.00	93.00
	(89.96)	(89.96)	(85.91)	(83.55)	(80.87)	(80.42)	(77.05)	(74.63)
V_1C_3	99.00	98.50	98.25	97.25	96.50	96.00	94.00	92.00
	(84.23)	(82.93)	(84.23)	(80.42)	(79.19)	(78.43)	(75.79)	(73.54)
V_1C_4	98.75	98.00	97.50	96.50	95.25	95.00	92.75	90.75
	(83.55)	(81.84)	(80.87)	(79.19)	(77.38)	(77.05)	(74.35)	(72.26)
V_1C_5	99.75	99.75	98.75	97.75	96.25	95.75	93.75	91.75
	(87.10)	(87.10)	(83.55)	(81.34)	(78.80)	(78.07)	(75.49)	(73.28)
V_2C_1	95.25	95.00	93.75	94.25	92.25	91.25	89.25	88.00
	(77.38)	(77.05)	(75.49)	(76.10)	(73.81)	(72.76)	(70.83)	(69.70)
V_2C_2	99.75	99.75	98.50	97.00	96.50	96.50	93.50	91.75
	(87.10)	(87.10)	(82.93)	(79.99)	(79.19)	(79.19)	(75.20)	(73.28)
V_2C_3	99.00	98.75	97.50	95.75	94.75	94.10	91.75	90.00
	(84.23)	(83.55)	(80.87)	(78.07)	(76.72)	(75.91)	(73.28)	(71.54)
V_2C_4	97.50	97.25	97.25	95.25	94.25	94.00	91.25	89.50
	(80.87)	(80.42)	(80.42)	(77.38)	(76.10)	(75.79)	(72.76)	(71.06)
V_2C_5	99.25	99.00	98.00	96.50	96.00	95.75	93.00	91.25
	(85.00)	(84.23)	(81.84)	(79.19)	(78.43)	(78.07)	(74.63)	(72.76)
Mean	98.63	98.25	97.38	96.28	95.33	94.94	92.58	90.75
S.Em. ±	0.92	0.30	0.41	0.53	0.64	0.62	0.64	0.64
C.D. @ 1%	NS	NS	NS	NS	NS	NS	NS	NS

*Figures in the parenthesis are arcsine root transformed values. NS: Non-significant.

atmospheric storage conditions might be due to the variation in the gas concentrations, where the treatments C_2 and vaccum packing having gas combination of higher CO_2 with zero per cent of oxygen concentration *i.e.,* low oxygen atmosphere and also the seeds stored under vacuum condition showed better germination as reported by Meena *et al.* (2017). Whereas, germination was reported to decrease in peas with increase in oxygen level (Roberts and Abdalla, 1968).

In general, ageing is manifested by decrease of metabolic activity and an increase of catabolic processes. In particular, an oxidative stress might be reduced in oxygen free storage atmospheres (Justice and Bass, 1978; Benson, 1990). It should be noted that seed deterioration during storage could result in marked changes in the content and activity of enzymes capable for degrading the stored reserves (Priestley, 1986; Wilson and McDonald, 1986; Walters, 1998). The advantage of higher seed reserve utilization efficiency in seeds stored in low oxygen concentration and vacuum packing, provide energy for a faster growing rate of the seedlings. In the present study also maximum speed of germination (48.83 and 46.40) was noticed in seeds stored in C_2 (80% CO_2+ 20% N_2 + 0% O_2) and C_5 (vaccum treated seeds) (Table 2), respectively compared to control (C_1) (42.15) at the end of fourteen months of storage. The similar results were also reported by Guillaumin (1928), Rathi *et al.* (2000) and Bera *et al.* (2008).

The root length and shoot length of Kabuli chickpea seeds were decreased gradually with the advancement in storage period. However, highest root length (17.99 cm) was recorded in C_2 (80% CO_2 + 20% N_2 + 0% O_2) treated seed followed by C_5 (vaccum treated seeds) (16.53 cm), while lowest was recorded in control (C_1) (13.64 cm) at the end of fourteen months of storage period (Table 3). At the end of fourteen months of storage period, highest shoot length (9.93 cm) was recorded in C_2 (80% CO_2 + 20% N_2 + 0% O_2) followed by C_5 (vaccum treated seeds) (9.32 cm),

Table 2: Influence of modified atmospheric storage conditions on speed of germination in Kabuli chickpea seeds during storage.

Treatments	Speed of germination							
	Months of storage							
	0	2	4	6	8	10	12	14
Varieties (V)								
V_1: BG1105	57.07	56.87	56.62	56.40	56.35	55.91	55.62	55.01
V_2: MNK-1	38.44	38.24	38.06	37.80	37.57	37.47	36.81	36.26
S.Em. ±	0.89	0.30	0.25	0.14	0.12	0.09	0.09	0.06
C.D. @ 1%	3.45	1.18	0.99	0.53	0.47	0.36	0.36	0.34
Concentration of modified atmospheric gases (C)								
C_1: Normal air (Untreated control)	44.59	44.39	44.15	43.95	43.83	43.44	42.77	42.15
C_2: CO_2 (80%) + N_2 (20%) + O_2 (0%)	50.50	50.30	50.21	50.04	49.94	49.71	49.44	48.83
C_3: CO_2 (75%) + N_2 (20%) + O_2 (5%)	47.92	47.72	47.59	47.38	47.17	46.97	46.77	46.09
C_4: CO_2 (70%) + N_2 (20%) + O_2 (10%)	47.26	47.06	46.68	46.31	46.14	45.97	45.22	44.71
C_5: Vaccum packing	48.51	48.31	48.06	47.84	47.71	47.36	46.89	46.40
S.Em. ±	1.40	0.48	0.40	0.22	0.19	0.15	0.14	0.14
C.D. @ 1%	NS	1.87	1.57	0.84	0.75	0.57	0.56	0.54
Interaction (V × C)								
V_1C_1	52.66	52.46	52.66	53.00	53.02	52.67	52.13	51.46
V_1C_2	60.31	60.11	59.76	59.34	59.23	58.60	58.79	58.36
V_1C_3	57.54	57.34	57.05	56.91	57.07	56.22	56.56	55.51
V_1C_4	56.53	56.34	56.00	55.68	55.54	55.49	54.72	54.26
V_1C_5	58.33	58.13	57.62	57.08	56.88	56.59	55.91	55.49
V_2C_1	36.51	36.31	35.64	34.89	34.63	34.22	33.41	32.84
V_2C_2	40.69	40.49	40.67	40.75	40.66	40.83	40.08	39.31
V_2C_3	38.31	38.11	38.14	37.85	37.26	37.72	36.98	36.68
V_2C_4	37.99	37.79	37.37	36.93	36.75	36.45	35.72	35.16
V_2C_5	38.70	38.50	38.50	38.60	38.55	38.13	37.87	37.32
Mean	47.76	47.56	47.34	47.10	46.96	46.69	46.22	45.64
S.Em. ±	1.98	0.68	0.57	0.31	0.27	0.21	0.20	0.19
C.D. @ 1%	NS	NS	NS	NS	NS	NS	NS	NS

NS: Non-significant.

while lowest shoot length (8.72cm) was recorded in control (C_1) (Table 4). The decline in root and shoot length mightbe due to the damage caused by fungi and insects and also toxic metabolites which might have hindered the seedling growth. Similar findings were reported in onion (Shivappa, 2011) and groundnut (Shrishail, 2011). Deterioration in seed quality associated with decrease in root and shoot length with the passage of time had been confirmed by earlier workers in many crops.

In the present study, highest vigour index was recorded in C_2 (80% CO_2 + 20% N_2 + 0% O_2) treated seed (2581) followed by C_5 (vaccum treated seeds) (2367), while lowest was recorded in control (C_1) (1988) respectively (Table 6) at the end fourteen months of storage period. Gradual decline in seedling vigour index was noticed due to age induced decline in germination and decrease in seedling length.

The significant difference due to modified atmospheric storage conditions on seedling dry weight was recorded throughout the storage period. At the end of fourteen months of storage period, highest seedling dry weight was recorded in C_2 (80% CO_2 + 20% N_2 + 0% O_2) treated seed (99 mg) followed by C_5 (vaccum treated seeds) (88 mg), while lowest was recorded in control (C_1) (79 mg) (Table 5). This gradual decline in seedling dry weight may be due to deterioration of seed.

Whereas, at the end of fourteen months of storage period, lowest electrical conductivity (0.941 dSm^{-1}) of seed leachate was recorded in C_2 (80% CO_2 + 20% N_2 +0% O_2) treated seed followed by C_5 (vaccum packing) (1.096 dSm^{-1}). This might be due to the better maintenance of membrane integrity while, the highest electrical conductivity (1.427 dSm^{-1}) was recorded in control (C_1) (Table 7). Increase in electrical conductivity as the storage period advanced may be due to increased membrane permeability and decreased integrity of seed coat resulted in excess release of electrolytes which caused higher electrical conductivity. Such of these findings were also reported by Shivappa (2011) in onion and Shrishail (2011) in groundnut.

Table 3: Influence of modified atmospheric storage conditions on root length in Kabuli chickpea seeds during storage.

Treatments	Root length (cm)							
	Months of storage							
	0	2	4	6	8	10	12	14
Varieties (V)								
V_1: BG1105	22.09	21.92	21.30	20.99	19.95	18.91	18.39	16.96
V_2: MNK-1	19.35	19.12	18.51	18.11	17.58	17.20	15.44	14.60
S.Em. ±	0.34	0.23	0.27	0.24	0.29	0.37	0.22	0.32
C.D. @ 1%	1.34	0.89	1.03	0.94	1.13	1.45	0.85	1.26
Concentration of modified atmospheric gases (C)								
C_1: Normal air (Untreated control)	19.43	19.33	18.85	18.53	17.09	16.61	14.26	13.64
C_2: CO_2 (80%) + N_2 (20%) + O_2 (0%)	22.08	21.85	21.28	20.78	20.55	19.79	19.44	17.99
C_3: CO_2 (75%) + N_2 (20%) + O_2 (5%)	20.60	20.44	19.86	19.49	18.77	17.86	17.25	16.18
C_4: CO_2 (70%) + N_2 (20%) + O_2 (10%)	20.36	20.10	19.14	18.89	17.98	17.20	15.50	14.56
C_5: Vaccum packing	21.13	20.91	20.40	20.07	19.23	18.79	18.12	16.53
S.Em. ±	0.54	0.36	0.42	0.38	0.46	0.59	0.34	0.51
C.D. @ 1%	NS	1.41	1.63	1.48	1.79	2.29	1.34	2.00
Interaction (V × C)								
V_1C_1	20.99	20.96	20.49	20.65	18.61	18.08	15.24	14.95
V_1C_2	22.85	22.23	22.75	21.95	22.27	19.71	20.68	18.19
V_1C_3	21.61	21.39	21.18	20.80	19.41	18.86	19.36	17.81
V_1C_4	22.97	22.74	20.68	20.49	19.29	18.46	16.64	15.93
V_1C_5	22.39	22.26	21.33	21.07	20.18	19.43	20.02	17.93
V_2C_1	17.92	17.69	17.22	16.41	15.57	15.15	13.27	12.34
V_2C_2	21.70	21.47	19.70	19.61	19.23	19.87	18.21	17.79
V_2C_3	19.12	18.89	18.55	18.17	18.13	16.85	15.15	14.54
V_2C_4	18.23	18.00	17.60	17.28	16.67	15.95	14.37	13.20
V_2C_5	19.78	19.55	19.46	19.08	18.29	18.15	16.21	15.14
Mean	20.76	20.52	19.90	19.55	18.76	18.05	16.91	15.78
S.Em. ±	0.77	0.51	0.59	0.54	0.65	0.83	0.49	0.73
C.D. @ 1%	NS	NS	NS	NS	NS	NS	NS	NS

NS: Non-significant.

Table 4: Influence of modified atmospheric storage conditions on shoot length in Kabuli chickpea seeds during storage.

Treatments	Shoot length (cm)							
	Months of storage							
	0	2	4	6	8	10	12	14
Varieties (V)								
V_1 : BG1105	16.33	16.32	15.82	13.13	11.99	11.95	11.71	10.87
V_2 : MNK-1	12.95	12.95	12.37	9.43	9.28	9.19	8.81	7.57
S.Em. ±	0.26	0.18	0.19	0.28	0.24	0.19	0.17	0.13
C.D. @ 1%	1.01	0.71	0.72	1.09	0.93	0.74	0.71	0.52
Concentration of modified atmospheric gases (C)								
C_1: Normal air (Untreated control)	13.73	13.72	13.05	9.88	9.85	9.52	9.33	8.72
C_2: CO_2 (80%) + N_2 (20%) + O_2 (0%)	15.44	15.43	15.06	13.03	11.84	11.65	11.31	9.93
C_3: CO_2 (75%) + N_2 (20%) + O_2 (5%)	14.69	14.69	14.19	11.10	10.71	10.65	10.37	9.14
C_4: CO_2 (70%) + N_2 (20%) + O_2 (10%)	14.33	14.33	13.77	10.61	10.04	9.97	9.70	8.99
C_5: Vaccum packing	15.01	15.01	14.40	11.77	10.93	10.87	10.59	9.32
S.Em. ±	0.41	0.29	0.31	0.44	0.38	0.30	0.20	0.21
C.D. @ 1 %	NS	1.13	1.14	1.72	1.46	1.17	1.11	0.83
Interaction (V × C)								
V_1C_1	15.83	15.83	14.86	11.04	10.87	10.59	10.98	10.47
V_1C_2	16.77	16.76	16.44	14.24	13.28	12.89	12.50	11.35
V_1C_3	16.34	16.34	16.05	13.43	12.33	12.22	11.94	10.77
V_1C_4	16.12	16.11	15.59	12.96	11.31	11.20	10.93	10.73
V_1C_5	16.59	16.59	16.15	14.00	12.56	12.45	12.18	11.03
V_2C_1	11.62	11.62	11.24	8.72	8.83	8.44	7.68	6.97
V_2C_2	14.11	14.11	13.68	11.83	10.41	10.39	10.12	8.51
V_2C_3	13.05	13.04	12.33	8.77	9.10	9.08	8.80	7.50
V_2C_4	12.55	12.54	11.94	8.27	8.76	8.74	8.47	7.25
V_2C_5	13.43	13.43	12.64	9.55	9.30	9.28	9.00	7.62
Mean	14.64	14.64	14.09	11.28	10.67	10.53	10.26	9.22
S.Em. ±	0.58	0.41	0.42	0.63	0.53	0.43	0.40	0.30
C.D. @ 1%	NS	NS	NS	NS	NS	NS	NS	NS

NS: Non-significant.

Table 5: Influence of modified atmospheric storage conditions on seedling dry weight in Kabuli chickpea seeds during storage.

Treatments	Ten seedling dry weight (mg)							
	Months of storage							
	0	2	4	6	8	10	12	14
Varieties (V)								
V_1 : BG1105	163	162	160	142	141	136	124	116
V_2 : MNK-1	81	81	78	72	66	65	62	59
S.Em. ±	2	1	2	2	2	2	2	2
C.D. @ 1%	9	6	6	9	8	9	8	6
Concentration of modified atmospheric gases (C)								
C_1: Normal air (Untreated control)	115	114	112	98	94	92	80	79
C_2: CO_2 (80%) + N_2 (20%) + O_2 (0%)	130	129	126	119	117	113	108	99
C_3: CO_2 (75%) + N_2 (20%) + O_2 (5%)	122	121	118	104	103	99	94	86
C_4: CO_2 (70%) + N_2 (20%) + O_2 (10%)	119	118	119	103	100	96	85	86
C_5: Vaccum packing	125	124	121	111	105	104	98	88
S.Em. ±	4	2	3	3	3	4	3	3
C.D. @ 1%	NS	9	10	14	13	15	12	10
Interaction (V × C)								
V_1C_1	151	150	147	128	125	123	107	104
V_1C_2	176	175	170	160	164	156	146	135
V_1C_3	162	161	158	138	139	132	123	112
V_1C_4	157	155	160	138	138	131	115	115
V_1C_5	168	167	163	146	141	140	128	116
V_2C_1	79	78	76	67	63	61	53	54
V_2C_2	84	83	81	77	70	70	70	63
V_2C_3	81	81	77	71	66	65	65	60
V_2C_4	81	80	78	69	63	61	55	56
V_2C_5	82	82	79	76	69	67	68	61
Mean	122	121	119	107	104	100	93	88
S.Em. ±	5	3	4	5	5	5	4	4
C.D. @ 1%	NS	NS	NS	NS	NS	NS	NS	NS

NS: Non-significant.

Table 6: Influence of modified atmospheric storage conditions on seedling vigour index in Kabuli chickpea seeds during storage.

Treatments	Seedling vigour index							
	Months of storage							
	0	2	4	6	8	10	12	14
Varieties (V)								
V_1 : BG1105	3813	3769	3630	3306	3066	2950	2814	2546
V_2 : MNK-1	3173	3144	2997	2638	2548	2495	2229	2000
S.Em. ±	67	33	34	39	40	42	25	35
C.D. @ 1%	260	128	132	153	156	163	98	138
Concentration of modified atmospheric gases (C)								
C_1: Normal air (Untreated control)	3220	3167	3009	2670	2511	2421	2134	1988
C_2: CO_2 (80%) + N_2 (20%) + O_2 (0%)	3747	3723	3599	3311	3143	3065	2900	2581
C_3: CO_2 (75%) + N_2 (20%) + O_2 (5%)	3471	3435	3334	2954	2821	2719	2570	2306
C_4: CO_2 (70%) + N_2 (20%) + O_2 (10%)	3430	3389	3204	2830	2658	2569	2322	2125
C_5: Vaccum packing	3597	3570	3424	3096	2900	2840	2682	2367
S.Em. ±	106	52	54	62	63	66	40	56
C.D. @ 1%	NS	203	209	242	246	258	156	218
Interaction (V × C)								
V_1C_1	3627	3550	3349	2972	2772	2689	2399	2276
V_1C_2	3922	3898	3909	3574	3428	3208	3152	2749
V_1C_3	3758	3716	3658	3329	3062	2984	2942	2629
V_1C_4	3860	3808	3535	3227	2915	2818	2557	2420
V_1C_5	3898	3876	3701	3429	3151	3053	3019	2656
V_2C_1	2813	2784	2668	2368	2250	2153	1870	1699
V_2C_2	3572	3548	3289	3047	2859	2921	2649	2412
V_2C_3	3184	3153	3010	2580	2580	2455	2197	1982
V_2C_4	3000	2971	2873	2434	2400	2321	2087	1831
V_2C_5	3297	3265	3147	2762	2649	2627	2345	2077
Mean	3493	3457	3314	2972	2807	2723	2522	2273
S.Em. ±	149	74	76	88	90	94	57	79
C.D. @ 1%	NS	NS	NS	NS	NS	NS	NS	NS

NS: Non-significant.

Table 7: Influence of modified atmospheric storage conditions on electrical conductivity in Kabuli chickpea seeds during storage.

Treatments	Electrical conductivity (dSm^{-1})							
	Months of storage							
	0	2	4	6	8	10	12	14
Varieties (V)								
V_1 : BG1105	0.299	0.404	0.509	0.665	0.765	0.878	0.965	1.068
V_2 : MNK-1	0.520	0.624	0.729	0.830	0.930	1.033	1.125	1.255
S.Em. ±	0.047	0.045	0.040	0.038	0.035	0.034	0.037	0.042
C.D. @ 1%	0.181	0.174	0.155	0.148	0.137	0.132	0.144	0.165
Concentration of modified atmospheric gases (C)								
C_1: Normal air (Untreated control)	0.603	0.702	0.807	1.030	1.130	1.258	1.338	1.427
C_2: CO_2 (80%) + N_2 (20%) + O_2 (0%)	0.227	0.335	0.440	0.536	0.636	0.739	0.831	0.941
C_3: CO_2 (75%) + N_2 (20%) + O_2 (5%)	0.418	0.522	0.627	0.723	0.823	0.925	1.018	1.155
C_4: CO_2 (70%) + N_2 (20%) + O_2 (10%)	0.481	0.584	0.689	0.756	0.856	0.958	1.051	1.188
C_5: Vaccum packing	0.318	0.425	0.530	0.694	0.794	0.896	0.989	1.096
S.Em. ±	0.070	0.071	0.063	0.060	0.056	0.053	0.059	0.067
C.D. @ 1 %	NS	0.275	0.245	0.234	0.216	0.208	0.228	0.261
Interaction (V × C)								
V_1C_1	0.443	0.541	0.646	0.981	1.081	1.233	1.301	1.349
V_1C_2	0.169	0.277	0.382	0.459	0.559	0.661	0.754	0.854
V_1C_3	0.272	0.378	0.483	0.624	0.724	0.826	0.919	1.041
V_1C_4	0.371	0.475	0.580	0.678	0.778	0.880	0.973	1.106
V_1C_5	0.240	0.349	0.454	0.586	0.686	0.789	0.881	0.988
V_2C_1	0.762	0.864	0.969	1.080	1.180	1.282	1.375	1.504
V_2C_2	0.286	0.393	0.498	0.614	0.714	0.816	0.909	1.028
V_2C_3	0.564	0.667	0.772	0.822	0.922	1.025	1.117	1.269
V_2C_4	0.590	0.693	0.798	0.834	0.934	1.037	1.129	1.271
V_2C_5	0.396	0.502	0.607	0.801	0.901	1.004	1.096	1.205
Mean	0.409	0.514	0.619	0.748	0.848	0.955	1.045	1.161
S.Em. ±	0.104	0.100	0.089	0.085	0.079	0.076	0.083	0.095
C.D. @ 1 %	NS	NS	NS	NS	NS	NS	NS	NS

NS: Non-significant.

CONCLUSION

The results revealed that seeds stored in gaseous combination of CO_2 (80%)+N_2 (20%)+O_2 (0%) [C_2], followed by vaccum packing [C_5] by using 700 gauge polyethylene bags can be stored for 14 months under ambient condition by maintaining seed quality and its storability above the Indian minimum seed certification standards. Hence, these modern techniques of modified atmospheric storage can play an important role in future days as it is simple and easily adaptable and cost effective, particularly beneficial in the absence of cold storage facility whereas, vacuum packaging can help in maintenance of better seed quality for nucleus, breeder and organically produced seed and can be replaced with the laborious and hazardous fumigation process as it is eco-friendly. However, there is still large scope for depth research study with respect to biochemical and molecular basis of storability under these MAP conditions.

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Conflict of interest

All authors declare that they have no conflict of interest.

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