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The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; SP-12(9): 1724-1730

www.thepharmajournal.com
Received: 10-06-2023
Accepted: 12-07-2023

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Assessing the impact of varied storage conditions and materials on the sustained viability of acid Lime cv. Petlur Pulusu Nimma Seeds

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Abstract
This study, titled "Assessing the Impact of Varied Storage Conditions and Materials on the Sustained Viability of Acid Lime cv. Petlur Pulusu Nimma Seeds "was conducted at the Horticultural Research Station in Anantharajupeta, Annamayya district, during the 2022-2023 period. Acid lime seeds were subjected to storage at three different temperatures (4 °C, 7 °C, and room temperature) and using three types of storage containers (polythene bags, plastic containers, and aluminium foil bags) for a duration of 150 days. The experiment followed a three-factorial completely randomized design with 45 treatment combinations, each replicated three times. The results revealed that seeds stored at 4 °C in aluminum foil bags for 30 days ($T_1M_3S_1$) exhibited the highest seed moisture content at 51.06%. Maximum germination percentage (81.27%) was observed in seeds stored at 4 °C in aluminum foil bags for 30 days ($T_1M_3S_1$). Furthermore, the highest seedling vigor index-I (947.16 cm) was recorded in seeds stored at 4 °C in aluminum foil bags for 30 days ($T_1M_3S_1$), while the highest seedling vigor index-II (37.02 g) was observed under the same conditions ($T_1M_3S_1$).

Keywords: Acid lime seeds, seed germination, storage conditions, storage materials, seed viability

Introduction
Citrus aurantiifolia Swingle, commonly known as acid lime and variably referred to as 'Pati lime,' 'Mexican lime,' and 'Kagzi lime,' occupies a prominent position within the citrus family, bearing significant importance in both culinary and agricultural domains. Its extensive cultivation is driven by its versatility and strong demand in the market.

The primary method of propagating acid lime is through seeds, capitalizing on their inherent polyembryonic nature, which guarantees the development of true-to-type offspring. However, acid lime seeds pose a distinctive challenge due to their recalcitrant nature. The term 'recalcitrant' underscores the susceptibility of these seeds to desiccation, temperature fluctuations, and adverse storage conditions. Without meticulous handling and precise storage management, seed longevity and germination potential are compromised. Recognizing the strong association between high initial seed viability and improved storage potential, along with the understanding that seeds with reduced initial viability may exhibit shorter storage lifespans (Khan *et al.*, 2003) [5], this research aims to delve into the intricate domain of acid lime seed storage. Specifically, we focus on Acid Lime cv. Petlur Pulusu Nimma seeds with the objective of evaluating the impact of diverse storage conditions and materials on sustained seed viability and extending the storage period.

Materials and Methods
The research was conducted at the Horticultural Research Station, Dr. YSR Horticultural University, Anantharajupeta, Annamayya district, during the period from 2022 to 2023. Acid lime fruits were procured from the Citrus Research Station in Petlur, where they served as the primary source for seed extraction. Meticulous attention was given to the selection of fruits, prioritizing those that were freshly harvested, fully matured, healthy, and of substantial size to ensure the extraction of high-quality seeds.

The extracted seeds underwent a rigorous cleaning process, involving thorough washing under running water. Subsequently, they were evenly spread in a shaded area to eliminate excess moisture. The seeds were then subjected to storage in various materials, namely polythene bags, plastic containers, and aluminum foil bags, at temperatures of 4 °C, 7 °C, and room temperature for a duration of 150 days.

At 30-day intervals, seeds from each storage treatment were retrieved and sown in propagation trays, containing a mixture of cocopeat, vermicompost, and Trichoderma in a 2:1:1 ratio. The experimental design employed a factorial approach within a Completely Randomized Design (CRD), encompassing forty-five treatment combinations. These combinations consisted of three levels of storage temperatures (4 °C, 7 °C, and room temperature), three storage materials (Polythene bag, Plastic container, Aluminum foil bag), and five storage durations (30, 60, 90, 120, and 150 days), each with three replications.
The data collected encompassed seed moisture content, germination percentage, as well as seedling vigor index I and II across the different treatment combinations.

Results and Discussion

Seed Moisture Content (%)

The data in Table 1 presents the seed moisture content (%) of the acid lime cultivar "Petlur Pulusu Nimma." The impact of various treatments on seed moisture content was determined to be statistically significant.
Among the different storage temperatures considered, the highest seed moisture content (44.70%) was observed under T_1 conditions (4 °C), whereas the lowest seed moisture content (18.08%) was recorded for T_3 (room temperature). Similarly, in the context of various storage materials, the maximum seed moisture content (36.94%) was found when utilizing M_3 (Aluminum foil bags), while the minimum seed moisture content (33.80%) was associated with M_1 (polythene bags). Additionally, with regard to varying storage periods, the highest seed moisture content (42.83%) was noted after 30 days of storage (S_1), while the lowest seed moisture content (28.86%) was observed after 150 days after storage (S_5).
The data revealed that treatment T_1M_3 (4 °C and aluminum foil bag) recorded the highest seed moisture content (46.36%), whereas T_3M_1 (room temperature and polythene bag) showed the lowest seed moisture content (16.73%). Regarding the interaction between storage temperature and storage period, treatment T_2S_1 (7 °C and 30 days after storage) had the highest seed moisture content (50.18%), closely followed by treatment T_1S_1 (4 °C and 30 days after storage) at 50.11%. Conversely, the lowest seed moisture content (9.25%) was observed in treatment T_3S_5 (room temperature and 150 days after storage). Additionally, when considering the interaction between storage material and storage period, treatment M_3S_1 (Aluminum foil bag and 30 days after storage) exhibited the highest seed moisture content (44.02%), similar to M_2S_1 (plastic container and 30 days after storage) at 43.24%. In contrast, the lowest seed moisture content (26.02%) was recorded in treatment M_1S_5 (Polythene bag and 150 days after storage).
The interaction effects of storage temperature, storage material, and storage period revealed that the highest seed moisture content (51.06%) was observed in $T_1M_3S_1$ (4 °C in an aluminum foil bag at 30 days after storage). This was comparable to $T_2M_3S_1$, $T_2M_2S_1$, and $T_1M_2S_1$, which recorded moisture contents of 50.87%, 50.43%, and 50.15%, respectively. Conversely, the lowest moisture content (8.53%) was recorded in treatment $T_3M_1S_5$ (Room temperature in a polythene bag at 150 days after storage).
The findings of this study highlight a significant relationship between storage period and seed moisture content. Specifically, there was a statistically significant decrease in moisture content as the storage period increased. This trend aligns with results reported by Shedage *et al.* (2012) [13], where Jatropha seeds exhibited their highest moisture content (8.83%) after being stored at 10 °C in a plastic bag for 12 months. The study conducted by Muthanna *et al.* (2016) [9] on Karonda seeds further supports our observations. Initially, these seeds had a moisture content of 67%, but they retained 40% moisture after just two months of storage under refrigerated conditions in aluminum foil bags. Moreover, Meshram *et al.* (2022) [7] documented a distinct case with jambhiri seeds. When stored at 4 °C in a plastic container with juice, these seeds reached their maximum moisture content of 53.45% at 150 days after storage.
These findings underscore the critical role of moisture content in seed viability. Elevated temperatures can accelerate the loss of water from seeds, leading to the depletion of vital moisture necessary for essential biochemical functions. This excessive drying of seeds can hinder proper germination. Conversely, lower temperatures have been found to reduce the enzymatic activity of stored seeds, making them more suitable for long-term seed storage. One intriguing aspect highlighted by our study is the high moisture retention observed in seeds stored in aluminum foil bags. This can be primarily attributed to the impermeable nature of these airtight containers, effectively preventing moisture absorption from the surrounding environment. Our results align with earlier findings reported by Berjak and Pammenter (2002) [1] and Shelar *et al.* (1992) [14].

Germination percentage

The effect of storage temperature, storage material, and storage period on the germination percentage of acid lime cv. Petlur Pulusu Nimma seeds was examined, and the results are presented in Table 2, which revealed statistically significant findings.
When looking at the individual effects of the factors, it is evident that the highest germination percentage (54.75%) was observed at 4 °C (T1), followed by 7 °C (T2) at 45.02%. In contrast, there was a noticeable decrease in germination percentage as the storage temperature increased, reaching its lowest point at room temperature (T3) with only 12.05% germination. Concerning the storage materials used, the maximum germination percentage was observed when seeds were stored in aluminum foil bags (M3) at 44.13%, followed by plastic containers (M2) at 40.46%, while the lowest germination percentage was recorded for seeds stored in polythene bags (M1) at 39.14%. Regarding storage duration, the highest germination percentage occurred at 30 days after storage (S1) with 61.52%, followed by a gradual decline as the storage period extended, reaching a minimum of 23.46% at 150 days after storage (S5).
In terms of the interaction between storage period and temperature, no germination was observed at 120 and 150 days after storage at room temperature. When examining the interaction between temperature and storage material, higher germination percentages were observed in aluminum foil bags (T1M3) at 4 °C with 61.75%, followed by plastic containers (T1M2) at 4 °C with 58.74%. Conversely, the lowest germination percentage was recorded in plastic containers (T3M2) stored at room temperature with only 15.34%. Regarding the interaction between storage material and storage period, M1S1 (polythene bag and 30 DAS) recorded the highest germination percentage at 66.28%, while M1S5 (Polythene bag and 150 DAS) reported the lowest germination percentage at 17.25%.

Table 1: Influence of storage temperature, storage material, and storage period on seed moisture content of acid lime cv. Petlur Pulusu Nimma

T	M	S_1	S_2	S_3	S_4	S_5	Mean (TXM)	Mean (T)
T_1	M_1	49.14	47.80	42.24	38.82	35.48	42.70	44.70
	M_2	50.15	47.81	45.35	42.31	39.64	45.05	
	M_3	51.06	48.22	46.40	44.58	41.54	46.36	
	Mean (TXS)	50.11	47.94	44.66	41.90	38.89		
T_2	M_1	49.23	48.16	41.09	37.35	34.06	41.98	44.08
	M_2	50.43	48.34	44.51	40.34	40.33	44.79	
	M_3	50.87	48.79	45.44	41.28	40.90	45.46	
	Mean (TXS)	50.18	48.43	43.68	39.66	38.43		
T_3	M_1	25.32	21.98	15.55	12.29	8.53	16.73	18.08
	M_2	29.15	24.27	17.21	12.27	9.67	18.51	
	M_3	30.14	24.34	17.84	13.10	9.56	19.00	
	Mean (TXS)	28.21	23.53	16.87	12.55	9.25		
Interaction Mean of Storage Material (M) and Storage Period (S)								
Mean (MXS)		S_1	S_2	S_3	S_4	S_5	Mean (M)	
M_1		41.23	39.31	32.96	29.49	26.02	33.80	
M_2		43.24	40.14	35.69	31.64	29.88	36.12	
M_3		44.02	40.45	36.56	32.99	30.67	36.94	
Mean(S)		42.83	39.97	35.07	31.37	28.86		
Factors			C.D. at 5%			SE (m)±		
Factor (T)			0.41			0.15		
Factor (M)			0.41			0.15		
Interaction (T X M)			0.72			0.26		
Factor(S)			0.54			0.19		
Interaction (T X S)			0.93			0.33		
Interaction (M X S)			0.93			0.33		
Interaction (T X M X S)			1.60			0.57		

Storage Temperature (T)	**Storage Material (M)**	**Storage period (S)**
T_1 – 4 ℃	M_1 - Polythene bag	S_1 - 30 days after storage
T_2 – 7 ℃	M_2 - Plastic container	S_2 - 60 days after storage
T_3 - Room temperature	M_3 - Aluminum foil bag	S_3 - 90 days after storage
		S_4 - 120 days after storage
		S_5 - 150 days after storage

The interaction response of storage temperature, storage material, and storage period revealed that the maximum germination percentage was recorded in T1M3S1 (4°C in aluminum foil bag at 30 DAS) at 81.27%, which was comparable to T1M2S1 at 78.68%. Conversely, T3M2S3 (room temperature, plastic container at 90 DAS) exhibited the lowest germination percentage at 12.47%.

It's particularly noteworthy that regardless of the storage material used, seeds stored at room temperature did not germinate after 120 and 150 days of storage. This highlights a critical interaction effect where the combination of higher storage temperature, extended storage period, and certain storage materials significantly hampers the germination capacity of acid lime seeds.

The recalcitrant nature of acid lime seeds, combined with elevated storage temperatures, can cause moisture loss and a loss of viability. Longer storage periods under these conditions significantly decrease germination rates, emphasizing the need for meticulous seed storage practices. Higher temperatures boost metabolic activity, aiding germination, while lower temperatures can hinder it. Shorter storage periods result in higher germination, while extended storage leads to declining viability. These findings align with prior research by Yadav *et al*. (2021) [17] in acid lime, Khopkar *et al*. (2014) [6] in pumelo, Meshram *et al*. (2022) [7] in jambhiri, and Muthanna *et al*. (2016) [9] in karonda seeds.

Vigour index-I (cm)

The effect of storage temperature, storage material, and storage period on the vigour index-I (cm) of acid lime cv. Petlur Pulusu Nimma seeds was analyzed, and the findings are presented in Table 3. Significant differences were observed among the storage temperature, storage material, storage period, and their interactions up to 150 days of storage.

In terms of storage temperature, the highest seedling vigour index-I (523.17 cm) was found at T_1 (4 ℃), while the lowest seedling vigour index-I (200.15 cm) was observed at T_3 (room temperature). Among the different storage materials, the highest seedling vigour index-I (410.89 cm) was recorded with M_3 (Aluminum foil bag), and the lowest seedling vigour index-I (366.38 cm) was associated with M_1 (polythene bag). Regarding storage duration, the highest seedling vigour index-I (700.09 cm) was recorded at S_1 (30 DAS), while the lowest seedling vigour index-I (95.58 cm) was obtained from S_5 (150 DAS).

Examining the interaction effect of storage temperature, storage material, and storage period, seeds stored at 4 ℃ in an aluminum foil bag (T_1M_3) exhibited the highest seedling vigour index-I (573.12 cm), whereas the lowest seedling vigour index-I (157.26 cm) was recorded at room temperature with a plastic container (T_3M_2). The combined effect of 4 ℃ at 30 days after storage (T_1S_1) recorded the highest seedling vigour index-I (913.16 cm), while the lowest seedling vigour index-I was recorded in T_3S_3 (113.19 cm). Among the interactions, the polythene bag at 30 days after storage (M_1S_1) recorded the highest seedling vigour index-I (746.71 cm), and the lowest seedling vigour index-I was observed in the polythene bag at 150 days after storage (M_1S_5) (68.12 cm).

Table 2: Influence of storage temperature, storage material, and storage period on seed germination percentage of acid lime cv. Petlur Pulusu Nimma

T	M	S_1 30 DAS	S_2 60 DAS	S_3 90 DAS	S_4 120 DAS	S_5 150 DAS	Mean (T×M)	Mean (T)
T_1 (4 ^{0}C)	M_1	76.48(60.98)	62.07(51.97)	46.08(42.73)	38.19(38.15)	26.38(30.84)	49.84(44.93)	54.75(49.13)
	M_2	78.68(62.49)	68.60(55.91)	58.66(49.98)	46.44(42.94)	41.31(39.97)	58.74(50.26)	
	M_3	81.27(64.37)	76.55(61.07)	61.90(51.88)	45.59(42.45)	43.45(41.21)	61.75(52.19)	
	Mean (T×S)	78.81(62.61)	69.08(56.32)	55.55(48.20)	43.41(41.18)	37.04(37.34)		
T_2 (7 ^{0}C)	M_1	56.58(48.76)	53.60(47.05)	41.38(40.01)	43.49(41.23)	25.38(30.20)	44.08(41.45)	45.02(43.51)
	M_2	58.77(50.04)	55.24(48.00)	45.62(42.47)	41.19(39.31)	35.73(36.69)	47.31(43.42)	
	M_3	61.08(51.38)	60.63(51.15)	52.67(46.51)	42.54(40.69)	38.93(38.59)	51.17(45.66)	
	Mean (T×S)	58.81(50.06)	56.49(48.73)	46.56(43.00)	42.40(40.61)	33.35(35.16)		
T_3 (Room temperature)	M_1	65.78(54.19)	33.19(35.13)	18.57(25.49)	0.00(2.98)	0.00(2.98)	23.51(24.15)	12.05(21.67)
	M_2	31.80(34.30)	32.42(34.66)	12.47(20.63)	0.00(2.98)	0.00(2.98)	15.34(19.11)	
	M_3	43.29(41.12)	37.58(37.84)	16.38(23.84)	00.0(2.98)	0.00(2.98)	19.45(21.74)	
	Mean (T×S)	46.96(43.21)	34.40(35.85)	15.81(23.32)	0.00(2.98)	0.00(2.98)		
Interaction Mean of Storage Material (M) and Storage Period (S)								
Mean (M×S)		S_1	S_2	S_3	S_4	S_5	Mean (M)	
M_1 (Polythene bag)		66.28(54.65)	49.62(44.72)	35.34(36.08)	27.23(27.45)	17.25(21.34)	39.14(36.85)	
M_2 (Plastic container)		56.42(48.94)	52.09(46.19)	38.92(37.69)	29.21(28.61)	25.68(26.55)	40.46(37.59)	
M_3(Aluminum foil bag)		61.88(52.29)	58.25(50.00)	43.65(40.74)	29.38(28.71)	27.46(27.59)	44.13(39.87)	
Mean(S)		61.52(51.96)	53.32(46.97)	39.30(38.17)	28.60(28.26)	23.46(25.16)		
Factors			C.D. at 5%			SE (m) ±		
Factor (T)			0.77			0.28		
Factor (M)			0.77			0.28		
Interaction (T×M)			1.34			0.48		
Factor(S)			1.00			0.36		
Interaction (T×S)			1.73			0.62		
Interaction (M×S)			1.73			0.62		
Interaction (T×M×S)			2.99			1.06		

(Figures in parenthesis are in arc sign value)

The interaction response of storage temperature, storage material, and storage period showed that the highest seedling vigour index-I (947.16 cm) was recorded in $T_1M_3S_1$ (4 °C, aluminum foil bag, 30 days after storage), which was on par with $T_1M_2S_1$ (912.25 cm). In contrast, $T_3M_2S_3$ (room temperature, plastic container at 90 days after storage) exhibited the lowest seedling vigour index-I (89.99 cm).

Consistently throughout the storage period, there was a decrease in seedling vigour index-I. Seeds stored at 4 °C in aluminum foil bags exhibited the highest vigour index-I compared to those stored at room temperature over the 5-month storage period. This outcome can be attributed to the superior quality of seeds stored under these conditions, characterized by minimal moisture content reduction, ample reserved compositions, and reduced enzymatic activity, all of which contributed to higher vigour index-I. Consequently, seeds stored at 4 °C maintained higher vigour index-I throughout the storage period.

In contrast, seeds stored at room temperature exhibited poor seed viability due to rapid moisture loss and increased enzymatic activities. This study underscores the pivotal role of storage temperature and material in preserving seed vigor. These findings are consistent with previous research by Tiwari *et al.* (2017) [15] in coriander, Mohammed and Krishna (2020) [8] in jamun, and Pavithra *et al.* (2020) in Surinam cherry. Similar results were noticed by Muthanna *et al*. (2016) [9] in karonda seeds stored in refrigerated conditions in aluminum foil-coated pouches, Bhavya *et al.* (2017) [3] in karonda seeds treated with Trichoderma harzianum and stored in poly bags in refrigerated conditions (4-5 °C), and Sai Santhosh and Patil (2018) [14] in onion seeds stored in aluminum pouches with 5% moisture content. These studies collectively emphasize the importance of appropriate storage conditions in maintaining seed vigor and viability over extended storage periods.

Vigour index-II (g)

The impact of storage temperature, storage material, and storage period on the vigour index-II (g) of acid lime cv. Petlur Pulusu Nimma seeds was investigated, and the findings are presented in Table 4. Significant differences were observed in both individual means and the combined effects of storage temperature, storage material, and storage period.

Looking at the storage temperature means, the highest seedling vigour index-II (15.13 g) was found at T_1 (4 °C), while the lowest seedling vigour index-II (6.46 g) was observed at T_3 (Room temperature). Among the different storage materials, the highest seedling vigour index-II (12.22 g) was recorded with M_3 (aluminum foil bag), and the lowest seedling vigour index-II (10.42 g) was associated with M_1 (Polythene bag). Regarding the storage period, the seedling vigour index-II (25.93 g) was highest at S_1 (30 DAS), whereas the lowest seedling vigour index-II (0.58 g) was obtained from S_5 (150 DAS).

Examining the interaction effect of storage temperature, storage material, and storage period, it was found that among the interactions, 4 °C with an aluminum foil bag (T_1M_3) recorded the highest seedling vigour index-II (17.47 g), and the lowest seedling vigour index-II (5.09 g) was recorded at room temperature with a plastic container (T_3M_2). The combined effect of 4 °C at 30 days after storage (T_1S_1) recorded the highest seedling vigour index-II (34.27 g), while the lowest seedling vigour index-II was recorded in T_2S_5 (0.78 g). Among the interactions, an aluminum foil bag at 30 days after storage (M_3S_1) recorded the highest seedling vigour index-II (27.23 g), and the lowest seedling vigour index-II was observed in M_1S_5 (0.39 g).

Table 3: Influence of storage temperature, storage material, and storage period on seedling vigour index –I of acid lime cv. Petlur Pulusu Nimma

T	M	S_1	S_2	S_3	S_4	S_5	Mean (TXM)	Mean (T)
T_1	M_1	880.08	662.29	401.89	249.29	113.42	461.39	523.17
	M_2	912.25	749.89	554.98	280.00	177.84	534.99	
	M_3	947.16	831.10	601.52	299.66	186.17	573.12	
	Mean (TXS)	913.16	747.76	519.46	276.32	159.14		
T_2	M_1	649.70	608.48	367.83	280.65	90.95	399.52	421.75
	M_2	635.94	606.79	434.62	244.60	133.85	411.16	
	M_3	699.36	681.79	461.27	272.46	157.97	454.57	
	Mean (TXS)	661.66	632.35	421.24	265.91	127.59		
T_3	M_1	710.37	348.21	132.54	0.00	0.00	238.22	200.15
	M_2	362.56	333.73	89.99	0.00	0.00	157.26	
	M_3	503.36	404.52	117.05	0.00	0.00	204.99	
	Mean (TXS)	525.43	362.15	113.19	0.00	0.00		
Interaction Mean of Storage Material (M) and Storage Period (S)								
Mean (MXS)		S_1	S_2	S_3	S_4	S_5	Mean (M)	
M_1		746.71	539.66	300.75	176.65	68.12	366.38	
M_2		636.92	563.47	359.86	174.87	103.90	367.80	
M_3		716.63	639.14	393.28	190.71	114.71	410.89	
Mean(S)		700.09	580.76	351.30	180.74	95.58		
Factors			C.D. at 5%			SE (m)±		
Factor (T)			12.62			4.49		
Factor (M)			12.62			4.49		
Interaction (T X M)			21.86			7.78		
Factor(S)			16.30			5.80		
Interaction (T X S)			28.22			10.04		
Interaction (M X S)			28.22			10.04		
Interaction (T X M X S)			48.89			17.40		

Storage Temperature (T)	Storage Material (M)	Storage period (S)
T_1 – 4 ^{0}C	M_1 - Polythene bag	S_1 - 30 days after storage
T_2 – 7 ^{0}C	M_2 - Plastic container	S_2 - 60 days after storage
T_3 - Room temperature	M_3 - Aluminum foil bag	S_3 - 90 days after storage
		S_4 - 120 days after storage
		S_5 - 150 days after storage

Table 4: Influence of storage temperature, storage material, and storage period on seedling vigour index-II of acid lime cv. Petlur Pulusu Nimma

T	M	S_1	S_2	S_3	S_4	S_5	Mean (TXM)	Mean (T)
T_1	M_1	31.09	22.14	8.14	1.83	0.63	12.76	15.13
	M_2	34.70	26.15	10.69	3.19	1.04	15.15	
	M_3	37.02	32.40	13.34	3.44	1.15	17.47	
	Mean (TXS)	34.27	26.90	10.72	2.82	0.94		
T_2	M_1	21.92	20.02	8.85	2.31	0.53	10.73	11.64
	M_2	24.59	21.65	8.48	1.97	0.93	11.52	
	M_3	26.65	24.90	8.84	2.08	0.90	12.67	
	Mean (TXS)	24.39	22.19	8.72	2.12	0.78		
T_3	M_1	26.32	10.72	1.79	0.00	0.00	7.76	6.46
	M_2	13.03	10.99	1.42	0.00	0.00	5.09	
	M_3	18.02	12.82	1.75	0.00	0.00	6.52	
	Mean (TXS)	19.12	11.51	1.65	0.00	0.00		
Interaction Mean of Storage Material (M) and Storage Period (S)								
Mean (MXS)		S_1	S_2	S_3	S_4	S_5	Mean (M)	
M_1		26.44	17.62	6.26	1.38	0.39	10.42	
M_2		24.10	19.60	6.86	1.72	0.66	10.59	
M_3		27.23	23.37	7.98	1.84	0.68	12.22	
Mean(S)		25.93	20.20	7.03	1.65	0.58		
Factors			C.D. at 5%			SE (m)±		
Factor (T)			0.41			0.15		
Factor (M)			0.41			0.15		
Interaction (T X M)			0.71			0.25		
Factor(S)			0.53			0.19		
Interaction (T X S)			0.91			0.32		
Interaction (M X S)			0.91			0.32		
Interaction (T X M X S)			1.58			0.56		

Storage Temperature (T)	Storage Material (M)	Storage period (S)
$T_1 - 4\ ^0C$	M_1 - Polythene bag	S_1 - 30 days after storage
$T_2 - 7\ ^0C$	M_2 - Plastic container	S_2 - 60 days after storage
T_3 - Room temperature	M_3 - Aluminum foil bag	S_3 - 90 days after storage
		S_4 - 120 days after storage
		S_5 - 150 days after storage

The results of the interaction analysis involving storage temperature, storage material, and storage period showed that the highest seedling vigour index-II (37.02 g) was recorded in $T_1M_3S_1$ (4 °C, aluminum foil bag, 30 DAS). In contrast, $T_2M_1S_5$ (7 °C, polythene bag at 150 DAS) exhibited the lowest seedling vigour index-II (0.53 g).

Consistently throughout the storage period, there was a decrease in the seedling vigour index-II. These findings are in line with similar results reported by Pavithra *et al.* (2020), where Surinam cherry seeds sown on the day of extraction showed the maximum seedling vigour index-II. Additionally, Sai Santhosh and Patil (2018) [14] reported higher seedling vigour index-II after twenty months of storage of onion seeds; the highest was found in seeds stored in an aluminum pouch at 5% moisture content followed by a polythene bag (700 gauge). According to Muthanna *et al.* (2016) [9], karonda seeds placed in an aluminum foil-coated pouch in a refrigerator after 150 days of sowing maintained the highest vigour index-II.

In conclusion, this study highlights the significant impact of storage temperature, storage material, and storage period on the vigour index-II of acid lime seeds. It underscores the importance of appropriate storage conditions to maintain seed vigour and highlights the gradual decrease in vigour index-II over an extended storage period.

Conclusion

In conclusion, this study has identified the optimal storage conditions for Acid lime cv. Petlur Pulusu Nimma seeds. Storing the seeds at 4 °C in aluminum foil bags, especially for up to 30 days after storage ($T_1M_3S_1$), exhibited the best seed quality characteristics. This storage regimen resulted in the highest seed moisture content (51.06%), maximum germination percentage (81.27%), and superior seedling vigour indices (I: 947.16 cm, II: 37.02 g). These findings underscore the critical importance of maintaining controlled storage environments, particularly regarding temperature and storage material, to ensure the preservation of seed quality and the promotion of robust germination and healthy seedling growth.

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