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Research Article

Effects of Seed Maturity and Storage on Storability and Germinability of Terap (*Artocarpus odoratissimus* Blanco)

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Abstract

Background and Objective: *Artocarpus odoratissimus* Blanco (Terap) seeds are recalcitrant by existence and seed germination is hampered by the loss of vitality in a short period during storage. Therefore, the present study aims to determine the best storability for *A. odoratissimus* seeds to prolong their viability and germinability. **Materials and Methods:** The experiment consisted of a Randomized Complete Block Design (RCBD) in a factorial arrangement with four temperatures×two containers×nine storage periods. The seed viability and germination percentage were determined based on the storage period to detect the optimum conditions and maximum germination percentage. The final weight of the seed was recorded after the completion of the storage period, i.e., 10, 20, 30, 40, 50, 60, 70, 80 and 90 days. **Results:** A significantly higher germination percentage (83.33±3.33%) was observed in T_2 where, seeds were kept under a transparent container at 20°C for 90 days with a minimum water loss of 16.84±0.18%. This also has been explained by the quadratic equation given as $\hat{Y}_{Ger}\% = -0.0055x^2+0.4247x+90.167$ with R^2 value 0.80. However, seeds stored in a dark container at 25°C (T_5) and 20°C (T_6) germinated during storage and showed rapid moisture loss recorded a lower percentage of germination at 56.66±3.33-66.67±0.33%, respectively. The moisture loss of 55.83±0.13% constituted a critical moisture level beyond which germination could not proceed. **Conclusion:** The storage condition with a transparent container at 20°C was the most promising technique for prolonging the shelf life of *Artocarpus odoratissimus* seeds.

Key words: *Artocarpus*, germination, recalcitrant, seed longevity, seed storage, shelf life

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Artocarpus odoratissimus, also known as Terap is an indigenous fruit species that belongs to the Moraceae family and is mainly found in Borneo Island, including Sarawak, Sabah, Brunei and Kalimantan[1]. Terap fruits have a strong aroma and are popular for their sweet and juicy flesh, suitable for being eaten raw or making flitters[2]. It also has been discovered that Terap fruits are high in nutritional and phenolic compounds, which may have an enormous health benefit[3]. The *A. odoratissimus* is always propagated by seeds. The seeds can germinate in around 2 weeks and the trees become fertile within 4-6 years. The initial moisture content of the seed was 49.25% on a fresh weight basis, resulting in average germination of 92% on the 7th day of sowing. Seeds of the *A. odoratissimus* are recalcitrant, sensitive to desiccation and have a shorter lifetime, thus enabling storing them for long-term in large quantities.

Seed quality is an essential factor in producing good seedlings. Seed quality is measured as both genetic and physical purity, followed by proper post harvest management techniques for improving the quality and extending shelf life during seed processing[4,5]. These two elements impact seed germination and the production of high-quality seedlings. Seeds can be kept fresh by controlling storage conditions and storing them for the shortest possible time to avoid physiological deterioration. From harvest until transplanting, seed management is meant to preserve high seed germination and viability. According to Ren *et al.*[6] the vitality of stored seeds is influenced by seed moisture content and storage temperature.

Seed degeneration is accelerated by unfavourable storage conditions, particularly those related to storage temperature and humidity[7,8]. The loss of viability with certain storage conditions implies that normal seed ageing occurs over an extended time. Natural ageing includes those involving chemical changes resulting in seed deterioration. Seed storage requires specific care to ensure that the quality of the seeds is maintained during storage[9]. Storing seed for longer than the recommended time might impair germination viability, percentage and maximum seed production[10]. However, seeds can be stored for more extended periods when considering seed quality, moisture content and temperature control during storage. Besides, some recalcitrant seeds of tropical origin are prone to a condition known as 'chilling damage', in which the moist seeds die at temperatures considerably above zero, often in the range of 10-15°C[11].

Additionally, light has been defined as a crucial abiotic component affecting the germination process of small seeds and it can do so by varying the degree, quality or period of the light exposure[12,13]. The lack of internal resources in small seeds makes the light very necessary for the survival and viability of seedlings grown in their initial few days of existence. A recent study by Gawankar *et al.*[14] discovered that the red light accelerates germination 24 hrs after imbibition in the dark condition. The researchers believed that these responses are mediated by phytochrome perception of the light environment.

Based on the literature search, a dearth of information is available on the optimum storage conditions to prolong the shelf-life of *A. odoratissimus* seeds. Therefore, this study aims to identify the most effective method of preserving *A. odoratissimus* seeds to prolong their germination viability. Because of the rapid deterioration of *A. odoratissimus* seed caused by its recalcitrance nature, it is critical to determine the most appropriate storage conditions to ensure the availability of high-quality planting materials for successful seedling production.

MATERIALS AND METHODS

Study area and sample collection: The fruits of *A. odoratissimus* were collected from the commercial fruit farm located in Kampung Penan Muslim Batu 10 (3°10'13.8"N, 113°2'25.8"E), Bintulu, Sarawak. The chosen fruits were healthy and free from disease and pests. The fruits were brought to the laboratory and promptly examined and cleansed with distilled water before sample preparation. The present study was carried out in Horticulture Laboratory at Universiti Putra Malaysia Bintulu (3°12'51.84"N and 113°4'56.28"E), Sarawak from January to June, 2020.

Sample preparation: *Artocarpus odoratissimus* fruits were cut into two and the seeds were separated from fleshly sheaths that enclose the seeds. The seeds were then thoroughly washed with distilled water to remove any remaining pulp or sugary residue. Selected seeds were treated with carbendazim (50% WP or 2 g L^{-1}) for 5 min and kept under shade for 3 hrs at ambient room temperature for surface drying. Initial moisture content was determined for seeds before storage.

Seed storage treatments: The seeds of *A. odoratissimus* were stored at four different temperatures, respectively ambient 25, 20, 15 and 10°C, under two types of storage conditions, i.e., transparent and dark containers. The design for the test on the tray was based on the three factors in Randomized Complete Block Design (RCBD), including four ranges of temperatures×two types of containers in all possible combinations×storage period. For each treatment, 250 seeds were stored simultaneously and 25 seeds were taken out for seed germination every 10 days at intervals for 90 days of observation.

Observation and data collection: The seed viability and germination percentage were determined based on the storage period to detect the optimum storage conditions and maximum germination percentage. The final weight of the seed was recorded after the completion of the storage period (i.e., 0 (control), 10, 20, 30, 40, 50, 60, 70, 80 and 90 days). The seeds subjected to different treatments were sown in a germination tray containing soil+sand in 2:1 proportion. Germination trays were kept in the net house for germination and raising of the seedlings, watering was performed accordingly. The observation of moisture content, loss of seed weight and percentage of germination was recorded from time to time and were calculated as follows:

$$\text{Seed moisture content (\%)} = \frac{\text{Fresh weight (g)} - \text{Oven dry weight (g)}}{\text{Oven dry weight}} \times 100$$

$$\text{Seed weight loss (\%)} = \frac{\text{Fresh weight during storage (g)} - \text{Final weight after storage(g)}}{\text{Fresh weight during storage}} \times 100$$

$$\text{Germination (\%)} = \frac{\text{Number of germinated seed (n)}}{\text{Total number of sown seeds}} \times 100$$

Statistical analysis: The notable contrast between studied treatments was identified through the Analysis of Variance (ANOVA). A Tukey's test (p<0.05) was performed for the comparison between the means of the treatments through Statistical Analysis System (SAS) version 9.4. Before analysis, the values in percentage were transformed to arcsine values using SAS software. An in-depth investigation was conducted on the analysis outcomes through two-way ANOVA and factor analysis to identify the association between the factors.

RESULTS AND DISCUSSION

Effect of different seed maturation on germination percentage: The seed development stage and maturation strongly influence the rate and percentage of germination. Early harvest may reduce seed germination and vigour, whereas late harvest may increase losses due to degradation[15,16]. The effect of different seed maturation in *A. odoratissimus* on the moisture content, germination percentage and days of germination are presented in Table 1. The moisture content and germination percentage of several seed maturation phases found in this study, i.e., naturally full ripen seeds, artificially ripen seeds and overripe seeds, differed significantly at p<0.05. Germination was shown to be higher in naturally full ripened seeds at 92.50±0.82%. The maximum germination percentage in *A. odoratissimus* seeds was obtained when the moisture content of the seeds was 49.25±0.35%. The seeds reached physiological maturity during this stage and produced a high proportion of successful germination. This was following Wesley-Smith *et al.*[17], in jackfruit, where 80% of the seeds can germinate from freshly harvested ripened fruit, which is ascribed to early germination to accelerated maturity resistant seeds.

Artificially ripened seeds showed a second higher germination percentage, at 80.25±0.36%. Early harvesting may induce seed dormancy, influencing seed desiccation and prechilling after harvest[18]. Researchers claimed that seed desiccation was required for matured seed germination, while others stated that fresh seeds germinate without seed desiccation[15,19]. The least germination percentage was recorded in the overripe seeds with 69.45±0.72%. The lower germination percentage was due to the reduced moisture content at 34.87±0.69%. Recalcitrant seeds are susceptible to desiccation due to their high moisture content[20]. Lower germination percentages could also cause by a decrease in moisture content below a specific critical value or a general decline in physiological condition over time[21].

Fully matured seeds accelerated and increased the percentage of germination in *A. odoratissimus*. This discovery was consistent with the findings by Samarah and Mullen[15], where fully matured *Shorea robusta* seeds resulted in higher germination with early sprouting than seeds of lower maturity stages. Findings showed that, naturally, ripened seeds of *A. odoratissimus* were at their optimum physiological maturity during fruit ripening, which accelerated radicle emergence earlier at 6.50±0.64 days after sowing. Overripe seeds can be sprouted around day 10.90±0.90 after sowing, while artificially ripened seeds take a more extended period to germinate, which was at 14.80±0.44 days.

Critical moisture level for seed viability in *A. odoratissimus*: Recalcitrant seeds require moisture levels above a certain threshold. If the moisture content falls below that level, the seeds become unviable and lose their germination potential. According to Berjak and Pammenter[22], Obroucheva *et al.*[23] and Costa *et al.*[24], the recalcitrant seed needs a high-water content to maintain the cell component in contrast to orthodox seeds, where, a decrease in moisture content does not affect their viability because germination occurs during the imbibition

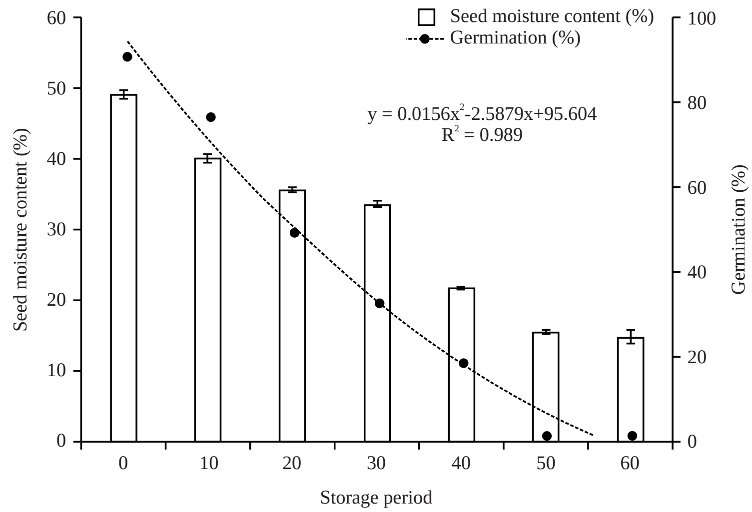

Fig. 1: Seed moisture content (%) and germination (%) against storage period at ambient temperature in *A. odoratissimus* seed

Table 1: Different seed maturation on moisture content (%), germination percentage and germination speed (days)

Seed maturity stages	Naturally full ripen seeds	Artificially ripen seeds	Overripe seeds
Germination (%)	92.50±0.82[a]	80.25±0.36[b]	69.45±0.72[c]
Moisture content (%)	49.25±0.35[a]	40.12±0.11[a]	34.87±0.69[b]
Germination speed (days)	6.50±0.64[c]	14.80±0.44[a]	10.90±0.90[b]

Different superscript alphabets in the same row indicate differences at p<0.05 (ANOVA, Tukey's test), value is given as Means±Standard error

Table 2: Seed moisture content, moisture loss and germination (%) observed under different storage periods at ambient temperature

Storage method	Storage period (days)	Seed moisture content (%)	Moisture loss (%)	Germination (%)
Ambient temperature	0	49.25±0.35	Na	92.00±0.04
	10	40.17±0.57	11.12±0.17	77.13±0.55
	20	35.67±0.38	18.43±0.24	49.27±0.11
	30	33.75±0.45	27.57±0.12	32.10±0.24
	40	21.75±0.26	31.47±0.43	17.50±0.11
	50	15.54±0.34	55.83±0.13	0.00±0.00
	60	14.86±0.92	68.44±0.29	0.00±0.00

Value is given as Mean+Standard error and Na: Not available

process and will not damage protein structure if exposed to drying. In the present study, the seeds of *A. odoratissimus* were subjected to six different storage periods from day 10-60, resulting in varying moisture loss. The finding makes it possible to determine the threshold degree of seed moisture content beyond which a seed's viability is compromised. Data on seed moisture content (%) observed at different storage periods at ambient temperature and observations on germination percentage are presented in Table 2 and depicted in Fig. 1.

When seeds were stored at room temperature for 10 days, it indicated a lower germination percentage at 77.13±0.55%, with a moisture content of 40.17±0.57%. Seed moisture content was further dropped to 35.67±0.38% at 20 days of the storage period, resulting in a 49.27±0.11% germination percentage. On day 40, seed moisture content was recorded at 21.75±0.26% yielding 17.50±0.11% of germination percentage. The germination ability was utterly lost as the storage period extended for up to 60 days, mainly due to moisture content loss. This occurrence was entirely foreseeable. This means that when the moisture content in seeds drops to 15.54±0.34%, the germination of *A. odoratissimus* seeds is entirely halted and the seed is completely losing viability. Thus, according to the present findings, a moisture loss rate of 55.83±0.13% was the crucial amount beyond which germination cannot occur. Gawankar *et al.*[25], reported that seeds of *A. heterophyllus* kept at ambient room temperature resulted in rapid deterioration in germinability. The water loss of 43.68% in *A. heterophyllus* seeds was identified as the critical moisture loss beyond which germination does not perform. The critical water content status represented the lack of free-bound water, which led to reduced cell metabolism, resulting in the regulation of seed degradation and viability rates[25]. Additionally, seed moisture content of 60% was shown to be the most prominent moisture

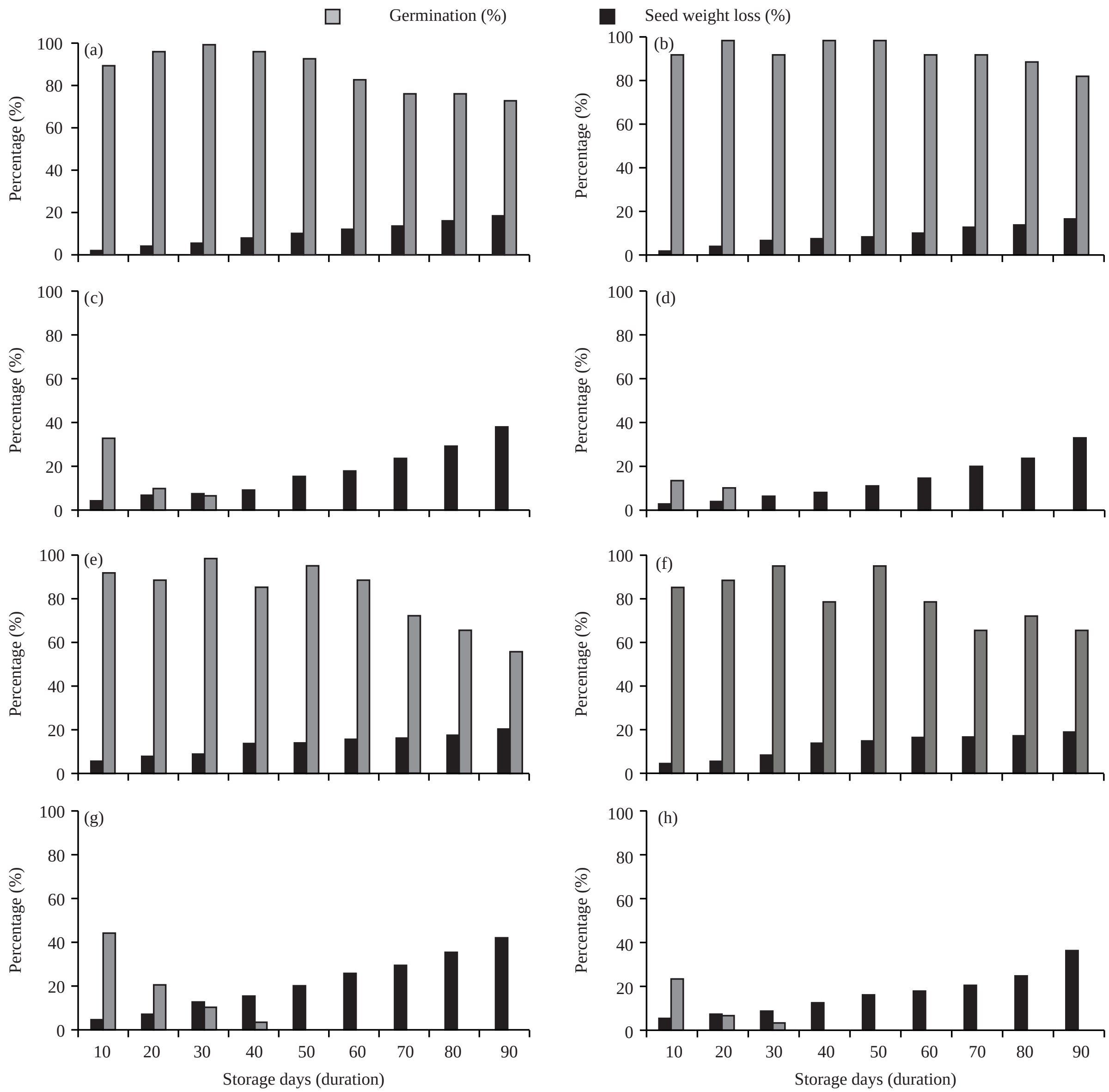

Fig. 2(a-h): Seed moisture and germination percentage against storage period following the treatments, (a) T_1: Transparent at 25°C, (b) T_2: Transparent at 20°C, (c) T_3: Transparent at 15°C, (d) T_4: Transparent at 10°C, (e) T_5: Dark at 25°C, (f) T_6: Dark at 20°C, (g) T_7: Dark at 15°C and (h) T_8: Dark at 10°C

level for ensuring successful germination percentage (99.10%) and successive reductions in seed moisture content resulted in a considerable loss of viability, demonstrating the resistant seed storage behaviour of jaman seeds[26].

Effect of seed storage conditions on seed weight loss (%) and germination percentage: Recalcitrant seeds, including *A. odoratissimus* are generally spread from the main plant with a high-water content and remain sensitive to desiccation, starting to lose survivability as they lose water, posing a problem for successful seedling establishment due to the relationship between high moisture content and having a specific critical value for survival[27]. Obtaining high-quality planting material for effective propagation is becoming increasingly difficult because of this situation. The effect of seed storage conditions on seed weight loss and germination percentage is presented in Table 3 and 4, respectively. These finding showed that the seeds of *A. odoratissimus* lost moisture and the germination percentage were highly influenced by the storage condition, temperature and period (Fig. 2a-h).

Table 3: Seed weight loss (%) under different storage conditions based on the storage period

	Storage periods								
Treatments	10	20	30	40	50	60	70	80	90
T_1	2.10±0.12^{e} (0.02)	4.21±0.03^{d} (0.04)	5.64±0.09^{e} (0.05)	8.11±0.06^{f} (0.08)	10.30±0.29^{d} (0.10)	12.21±0.06^{d} (0.12)	13.77±0.22^{e} (0.13)	16.21±0.06^{e} (0.16)	18.64±0.22^{f} (0.18)
T_2	1.84±0.06^{e} (0.02)	4.02±0.06^{e} (0.04)	6.75±0.25^{d} (0.07)	7.54±0.06^{d} (0.07)	8.43±0.09^{e} (0.08)	10.20±0.06^{e} (0.10)	12.93±0.22^{f} (0.13)	14.02±0.09^{f} (0.14)	16.84±0.18^{f} (0.17)
T_3	4.34±0.03^{c} (0.04)	6.93±0.06^{c} (0.07)	7.60±0.06^{c} (0.07)	9.36±0.06^{e} (0.09)	15.65±0.06^{c} (0.15)	18.22±0.07^{b} (0.18)	24.04±0.09^{b} (0.24)	29.73±0.22^{b} (0.30)	38.63±0.12^{b} (0.39)
T_4	2.82±0.06^{d} (0.03)	3.94±0.03^{e} (0.04)	6.30±0.06^{d} (0.06)	8.06±0.03^{f} (0.08)	10.90±0.06^{d} (0.11)	14.42±0.09^{d} (0.14)	19.71±0.09^{c} (0.20)	23.42±0.15^{c} (0.23)	32.63±0.43^{d} (0.32)
T_5	5.70±0.03^{a} (0.06)	7.95±0.03^{a} (0.08)	8.99±0.06^{b} (0.86)	13.88±0.19^{c} (0.13)	14.21±0.06^{c} (0.14)	15.86±0.06^{c} (0.16)	16.43±0.06^{d} (0.06)	17.81±0.18^{d} (0.17)	20.64±0.18^{e} (0.20)
T_6	4.55±0.06^{c} (0.04)	5.61±0.06^{d} (0.06)	8.50±0.09^{b} (0.83)	14.04±0.06^{b} (0.14)	15.06±0.03^{c} (0.15)	16.75±0.22^{c} (0.16)	16.94±0.03^{d} (0.17)	17.49±0.06^{d} (0.17)	19.27±0.12^{f} (0.19)
T_7	4.48±0.03^{c} (0.04)	6.92±0.06^{c} (0.07)	12.42±0.06^{a} (0.12)	15.02±0.06^{a} (0.15)	19.57±0.09^{a} (0.19)	25.14±0.09^{a} (0.25)	28.65±0.16^{a} (0.29)	34.46±0.09^{a} (0.35)	40.89±0.09^{a} (0.41)
T_8	5.39±0.07^{b} (0.06)	7.30±0.06^{b} (0.07)	8.70±0.06^{b} (0.85)	12.51±0.09^{d} (0.12)	16.07±0.12^{b} (0.16)	17.83±0.09^{b} (0.18)	20.38±0.03^{c} (0.20)	24.67±0.21^{c} (0.24)	36.13±0.06^{c} (0.37)

Different superscript alphabets in the same column indicate differences at $p<0.05$ (ANOVA, Tukey's test) and values are given as Means+Standard error and values in parenthesis are the arc sin conversion values

Table 4: Seed germination (%) under different storage conditions based on the storage period

	Storage periods								
Treatments	10	20	30	40	50	60	70	80	90
T_1	90.00±0.00 (1.11)	96.67±3.33 (1.42)	100.00±0.00 (1.57)	96.67±3.33 (1.42)	93.33±3.33 (1.27)	83.33±3.33 (0.99)	76.67±3.33 (0.88)	76.67±6.66 (0.87)	73.33±0.33 (0.83)
T_2	93.33±0.66 (1.35)	100.00±0.00 (1.42)	93.33±3.33 (1.27)	100.00±5.77 (1.20)	100.00±0.00 (1.57)	93.33±3.33 (1.27)	93.33±0.00 (1.27)	90.00±3.33 (1.11)	83.33±3.33 (0.99)
T_3	33.33±0.33 (0.34)	10.00±0.00 (0.10)	6.66±0.33 (0.06)	0	0	0	0	0	0
T_4	13.33±0.33 (0.13)	10.00±0.00 (0.10)	0	0	0	0	0	0	0
T_5	93.33±3.33 (1.27)	90.00±5.77 (1.20)	100.00±0.00 (1.57)	86.67±6.66 (1.14)	96.67±3.33 (1.42)	90.00±0.00 (1.11)	73.33±3.33 (0.82)	66.67±6.66 (0.73)	56.66±3.33 (0.60)
T_6	86.67±3.33 (1.05)	90.00±5.77 (1.20)	96.67±3.33 (1.42)	80.00±5.77 (0.94)	96.67±3.33 (1.42)	80.00±5.77 (0.94)	66.67±6.66 (0.73)	73.33±0.33 (0.82)	66.67±0.33 (0.73)
T_7	43.00±3.33 (0.44)	20.00±0.00 (0.20)	10.00±5.77 (0.10)	3.33±3.33 (0.03)	0	0	0	0	0
T_8	23.33±3.33 (0.23)	6.67±3.33 (0.06)	3.33±3.33 (0.03)	0	0	0	0	0	0

Values are given as means+standard error and values in parenthesis are the arc sin conversion values

Table 5: Polynomials for germination percentage ($\hat{Y}_{Ger}$ %) against the period of storage for *Artocarpus odoratissimus* seeds

Storage methods	Temperature (°C)	Treatments	Polynomial equations for germination (%)	R^2
Transparent container	25	T_1	$\hat{Y}_{Ger}$ % = -0.315x+102.750	0.71
			$\hat{Y}_{Ger}$ % = -0.0059x^2+0.2727x+91.976	0.84
			$\hat{Y}_{Ger}$ % = 0.0003x^3-0.0477x^2+2.0335x+73.587	0.97
	20	T_2	$\hat{Y}_{Ger}$ % = -0.1283x+100.310	0.39
			$\hat{Y}_{Ger}$ % = -0.0055x^2+0.4247x+90.167	0.80
			$\hat{Y}_{Ger}$ % = -6E-06x^3-0.0046x^2+0.3875x+90.556	0.79
Dark container	25	T_5	$\hat{Y}_{Ger}$ % = -0.45x+105.830	0.68
			$\hat{Y}_{Ger}$ % = -0.0112x^2+0.6669x+85.357	0.89
			$\hat{Y}_{Ger}$ % = -3E-05x^3-0.0067x^2+0.4807x+87.302	0.89
	20	T_6	$\hat{Y}_{Ger}$ % = -0.3183x+97.361	0.56
			$\hat{Y}_{Ger}$ % = -0.0058x^2+0.265x+86.667	0.66
			$\hat{Y}_{Ger}$ % = 0.0002x^3-0.0347x^2+1.4832x+73.944	0.71

Among the treatments, seeds placed in a dark container lost high moisture than seeds stored in a transparent container. When it comes to different storage temperatures, the seeds stored at 15 and 10°C have significantly higher seed moisture loss, which causes the seed to deteriorate more rapidly and yield a lower percentage of germination. Recalcitrant seeds were distributed with high-water content and less than 20% of dehydration causes mortality by desiccation[28]. Seeds stored in T_2 (Transparent at 20°C) and T_1 (Transparent at 25°C) containers were recorded to have the least percentage of moisture loss after 90 days of the storage period, which were 16.84±0.18 and 18.64±0.22%, respectively. Similarly, a higher germination rate was observed in the seeds stored at T_2 conditions (transparent at 20°C), 100% from day 10-50 of the storage periods and gradually fell to 83.33±3.33% after 90 days of storage (Fig. 2b). This was followed by T_1, where, 73.33±0.33% of the seed were germinated after 90 days of storage (Fig. 2a).

It is necessary to have moisture levels above a specific value for recalcitrant seeds, including seeds of *Artocarpus*[14,25]. Water content that falls below makes the seeds nonviable and prevents them from germinating. According to Walters *et al.*[29], the deterioration of seed viability could be induced by a fall in moisture content below a specific minimal value or it may just be caused by the development of appropriate metabolic deterioration over a long period. Notably, seeds with a soft coat kept for too long tend to deteriorate more rapidly and sustain more mechanical damage during storage[30].

Besides, seeds stored in dark containers at 25 (T_5) and 20°C (T_6) exhibited a higher percentage of germination 93.33±3.33 and 86.67±3.33%, respectively at the early storage store of day 10. However, rapid moisture loss under T_5 (Fig. 2e) and T_6 (Fig. 2f) storage conditions resulted in a reduction in the percentage of germination (T_5: 56.66±3.33 and T_6: 66.67±0.33%, respectively) at 90 days of storage. According to Doijode[31] and Heschel *et al.*[32], phytochrome activities are responsible for most of the control over the germination process throughout the plant. Pearl tissue contains pigment, which allows the plants to engage in a variety of photobiological activities as a result. The action of phytochromes is thought to be responsible for the germination process in certain plants. According to Dhyani *et al.*[33] and Gawankar *et al.*[25], the effects of darkness and humidity are crucial in preventing moisture loss during initial storage. Nevertheless as the seeds approached the end of 90 days of the storage period, they lost moisture fast due to the increased humidity levels that had triggered seed germination inside the container. This was contradicted by the screw cap transparent container that can prevent water loss and light has an inhibitory effect[34], thus prolonging the viability of *A. odoratissimus* seeds.

Artocarpus odoratissimus seed stored in T_3 (Fig. 2c) and T_4 (Fig. 2d) conditions demonstrated a lower germination rate at 33.33±033 and 13.33±033% at the initial storage period of 10 days no germination was recorded from the storage period of day 40-90. A similar trend was obtained under T_7 (Fig. 2g) and T_8 (Fig. 2h) conditions, where lower germination was recorded at the beginning of the storage period and no seeds germinated after days 40 and 30, respectively. Because of their nature as recalcitrant seeds sensitive to drying and chilling injuries that preserve survivability of storage, *A. odoratissimus* seeds are not suitable to be stored below 15°C. These observations are consistent with Adegbaju *et al.*[35], who found that temperatures between 10 and 15°C resulted in a considerably lower germination rate for *Celosia argentea* seeds. The effect of storage conditions on the germination percentage of *A. odoratissimus* seeds over the storage period is illustrated to fit different polynomial graphs (Fig. 3a-d). This loss in germination percentage is predictably explained by polynomials such linear, quadratic and cubic equations generated for T_1, T_2, T_5 and T_6 (Table 5). Meanwhile, T_3, T_4, T_7 and T_8 storage were not conducive for

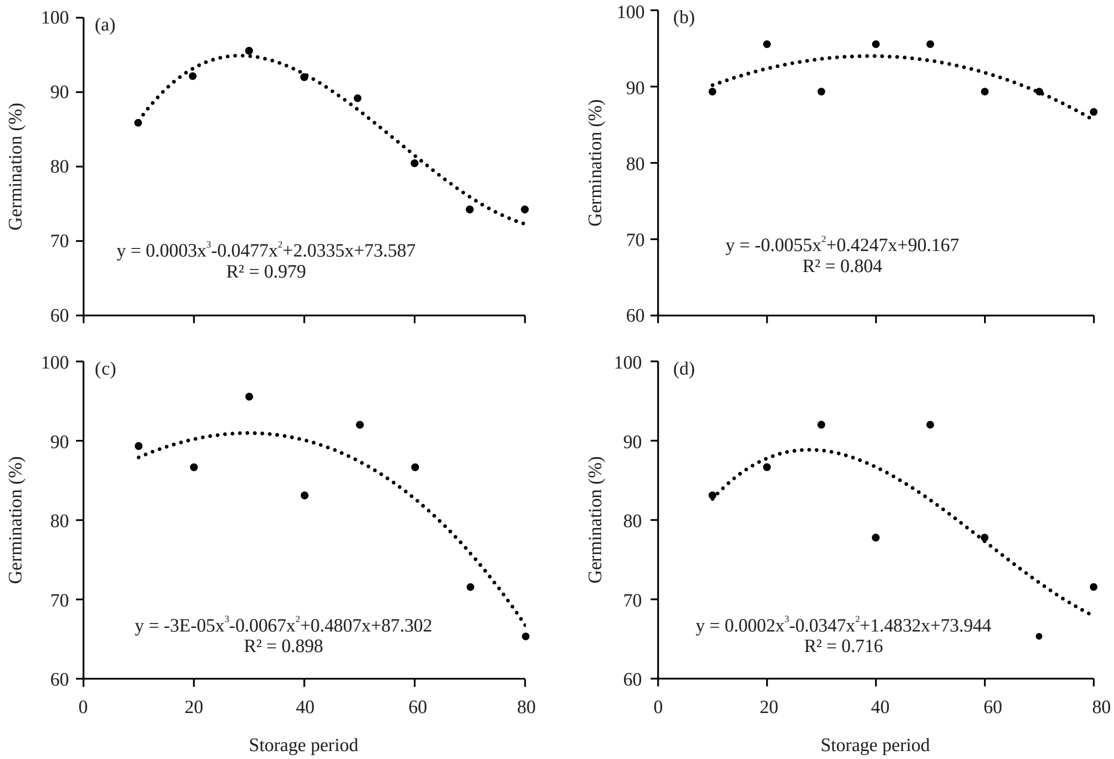

Fig. 3(a-d): Polynomial observed on germination percentage of *Artocarpus odoratissimus* seeds against the storage period based on treatments, (a) T_1: Transparent at 25°C, (b) T_2: Transparent at 20°C, (c) T_5: Dark at 25°C and (d) T_6: Dark at 20°C

Table 6: Significance levels of diverse elements and interactions

Sources	Seed weight loss (%)	Germination (%)
Storage condition (C)	p<0.01**	p<0.01**
Temperature (T)	p<0.01**	p<0.01**
Storage period (P)	p<0.01**	p<0.01**
Interaction		
C×T	p<0.01**	p<0.01**
C×P	p<0.01**	p<0.01**
T×P	p<0.01**	p<0.01**
C×T×P	p<0.01**	p = 0.139^{ns}

**Notable difference was observed at p<0.01 and ns: Insignificant

seed storage of *A. odoratissimus* and no polynomial curves were generated. Storing the seeds in the transparent container at ambient temperature (25°C) (T_1) resulted in successful germination during the early storage period. However, slightly higher losses of moisture were recorded at 90 days of storage and this has been explained by the cubic Eq.:

$$\hat{Y}_{Ger}\,\% = 0.0003x^3 - 0.0477x^2 + 2.0335x + 73.587$$

with R^2 value = 0.97 (Fig. 3a). This value is comparable with the seeds stored in a transparent container at a temperature of 20°C (T_2), resulting in a higher percentage of germination with lower moisture loss, which was explained by the quadratic equation given:

$$\hat{Y}_{Ger}\,\% = -0.0055x^2 + 0.4247x + 90.167$$

with an R^2 value of 0.80 (Fig. 3b). Seed storage condition in a transparent container at 20°C indicates an appropriate technique for *A. odoratissimus* seeds storage to prolong their shelf-life and viability. The present findings follow the study by Macchia *et al.*[36], where, the ideal temperature for the germination of stevia seeds was 20°C and the seeds germinated more successfully in light than in darkness. Iloh *et al.*[37], reported that the cereal crops of rice, sorghum and maize resulted in a decrease in germination rate as temperature regimes increased. High temperatures may increase lipid autooxidation, resulting in free fatty acid production during the storage period, which can link to the deterioration of seeds of oil plants[38,39]. The germinability of *A. odoratissimus* seeds in a dark container (T_5) with ambient temperature also has been explained by the cubic equation given:

$$\hat{Y}_{Ger}\,\% = -3E\text{-}05x^3 - 0.0067x^2 + 0.4807x + 87.302$$

with an R^2 value of 0.89 (Fig. 3c) suggesting faster seed deterioration under this condition. The loss in germinability also can be highly predicted in the T_6 condition explained by the cubic equation given:

$$\hat{Y}_{Ger}\ \% = 0.0002x^3 - 0.0347x^2 + 1.4832x + 73.944$$

with an R^2 value of 0.71 (Fig. 3d). Unfavourable environmental conditions accelerate the seed deterioration process. Seed deterioration reduces the germination rate and the viability of the seed, resulting in seed mortality. Deteriorated seeds produce poor seedlings.

Storage conditions and temperature highly influence seed germination, 15 and 10°C showed that *A. odoratissimus* seeds have difficulty germinating under this storage condition due to *A. odoratissimus* seeds being susceptible to chilling injury. The chilling injury is related to moisture content. As stated by Walters *et al.*[40], a combination of genetic and environmental factors such as storage temperature and seed moisture content significantly affect storage duration. Rajjou and Debeaujon[41], also mentioned when seeds deteriorate during storage, they lose vitality, become more sensitive to stress during germination and eventually become difficult to germinate. Based on the present studies, it was clear that storing seeds in transparent containers at an appropriate temperature is one of the most effective methods for achieving good and effective preserving seeds over time. Storing the seeds in a dark container exposed to darkness and temperature control also increased seed germination.

Interaction effect of storage condition, temperature and period: A more in-depth investigation of the data was carried out using two-way ANOVA followed by factorial analysis (Table 6). Three factors are involved in this phase, i.e., (1) Two types of conditions, (2) Different ranges of temperature and (3) Storage period. It was indicated through the seed weight loss and germination percentage of *A. odoratissimus* seeds that a notable significant interaction ($p<0.01$) was observed between the three factors. The interaction was observed for all parameters except germination percentage for storage condition × temperature × storage period. It concludes convincingly that the storage condition highly affects the seed viability and germination percentage, which declines with increasing storage duration irrespective of storage condition. A similar trend was observed in seeds of *Swertia chirayita* reported by Pradhan and Badola[42]. During storage, seed germination reduced, with a higher decline as storage temperature increased. Temperature and moisture conditions regulate the ageing of seeds, which may be related to various chemical reactions and enzymatic modifications. According to Saha and Sultana[43], the percentage of seed germination and field emergence rate reduced with increasing seed age in soybean varieties but the electrical conductivity of seed leachate increased. When these elements (storage conditions, storage period and temperature) are combined, they affect germinability by decreasing the ability of *A. odoratissimus* seeds to germinate. The most significant factors influencing seed germinability were temperature and storage duration. Storage temperature highly affected the seed germination percentage, which declined with the increasing storage period. de Jesus Souza *et al.*[44], revealed that storage duration and temperature significantly affected quinoa seed content.

CONCLUSION

Based on the findings, *A. odoratissimus* seeds could be effectively stored for 90 days in the transparent container at a temperature (20°C) has been explained by the quadratic equation given:

$$\hat{Y}_{Ger}\ \% = -0.0055x^2 + 0.4247x + 90.167$$

with R^2 value = 0.80. Under this storage condition, the maximum germination percentage of 83.33±3.33% was obtained with a minimum water loss of 16.84±0.18%. The transparent screw container that can prevent water loss and light has an inhibitory effect, thus prolonging the viability of *A. odoratissimus* seeds. The germination of *A. odoratissimus* seeds was completely lost if the water loss in the seed exceeds 55.83±0.13%.

SIGNIFICANCE STATEMENT

The increasing popularity of *A. odoratissimus* in Borneo's local markets is due to its nutraceutical properties and health benefits, which provide income opportunities for local farmers. Since this species is seasonal, the plants produce fruits at certain months, knowledge of methods of seeds preservation was deemed important and determination on how soon the seeds would lose their viability. This study discovered the appropriate simple storage techniques to prolong longevity and ensure successful germination. This study will help the farmers to preserve the *A. odoratissimus* seeds to obtain high-quality planting material for effective propagation.

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