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INFLUENCE OF NUT STORAGE AND PRE-SOWING TREATMENTS ON GERMINATION AND HAUSTORIUM DEVELOPMENT IN COCONUT (*Cocos nucifera* L.)

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ABSTRACT

An experiment was conducted at the College of Agriculture, Vellanikkara, Kerala Agricultural University, to study the effects of storage period and pre-sowing treatments on seed germination and haustorium development in coconut. The experiment was laid out in a two factor factorial completely randomized design with three replications. Four storage periods and four pre-sowing treatments involving water soaking, with or without punching, were evaluated. Storage period and pre-sowing treatments significantly influenced germination and haustorium development. Seeds stored for one month (S_2) recorded the highest germination percentage (92.67%) and shortest period to attain 50 per cent germination (104.25 days). Among the pre-sowing treatments, water soaking with punching for two weeks (P_3) resulted in the highest germination percentage (91.33%) and the shortest period to 50 per cent germination (107.25 days). The interaction effect of one-month seed storage and water soaking with punching for two weeks (S_2P_3) exhibited the greatest germination percentage (94.67%) and superior haustorium characteristics, including total haustorium weight (168.55 g), white portion weight (137.79 g), longitudinal diameter (32.41 cm), and transverse diameter (30.31 cm). The results indicated that storage of coconut seeds for one month followed by water soaking and punching for two weeks (S_2P_3) was the most effective treatment combination for enhancing germination and promoting desirable haustorium development.

***Key words*:** Coconut haustorium, storage duration, pre-sowing treatment, germination, haustorium development

Introduction

Coconut (*Cocos nucifera* L.) is an important perennial plantation crop of tropical and subtropical regions, with diverse applications in food, nutrition, domestic and industries. Apart from the conventional products derived from the fruit, the germinated coconut seed produces an edible, spongy cotyledonary structure known as the haustorium or coconut apple, which is traditionally consumed in several coconut producing regions. As coconut is propagated through seed, successful germination and establishment of healthy seedlings are essential for sustaining coconut production. Germination behaviour varies among coconut varieties with respect to both germination percentage and duration, owing partly to differences in fruit characteristics and varietal traits (Harries, 2012; Beveridge *et al*., 2022; Odufale *et al*., 2025).

The formation of the haustorium arises from the distal region of the embryo and increases in size during germination within the cavity of the endosperm. It plays

an important role in mobilising and transferring nutrients from the endosperm to the developing embryo and seedling (Foale, 1968; Sugimura and Murakami, 1990). Considerable changes in the size, weight, and biochemical composition of the haustorium occur during germination and development (Balasubramaniam *et al*., 1973; Li *et al*., 2019).

The haustorium has gained increasing attention as an edible food resource owing to its nutritional and bioactive components, including carbohydrates, sugars, proteins, dietary fibre, minerals, phenolics, and antioxidants (Manivannan *et al*., 2018). Its nutritional and value-added potential has been further demonstrated through its incorporation into processed food products (Kannaian *et al*., 2020; Raja Rajeshwari *et al*., 2024; Arivalagan *et al*., 2018). Since haustorium development is closely linked to the utilisation of endosperm reserves, variations in its size and weight serve as important indicators of development and harvestability (Child and Nathanael, 1964; Li *et al*., 2019). Variations in longitudinal and transverse dimensions during development have also been associated with variations in its nutritional characteristics (Sudha *et al*., 2021).

Physiological condition of the seed nut prior to planting is an important factor influencing coconut germination and subsequent seedling development. Nuts of coconut have limited storability, and prolonged storage may result in moisture loss and reduced germination potential. The influence of storage duration and conditions on germination performance and weight loss of coconut seed nuts has been reported by Shareefa *et al*., (2018) and Odufale *et al*., (2025). Pre-sowing treatments may also influence germination by improving seed hydration and facilitating water uptake. Water soaking promotes hydration of the seed nut, while punching may facilitate water penetration and accelerate germination. Improved germination and seedling growth following water soaking and punching of coconut seed nuts have been reported by Beveridge *et al*., (2022) and Kumar (2011).

Although several studies have examined the effects of storage and pre-sowing treatments on coconut germination and seedling establishment, information on their combined influence on haustorium development and quality is limited. In particular, the effects of different combinations of storage duration and pre-sowing treatments on haustorium weight, size, firmness and recovery remain insufficiently documented. Therefore, the present study was undertaken to evaluate the effects of storage duration and pre-sowing treatments on germination and haustorium development in coconut, with the objective of identifying an effective treatment combination for the production of good-quality edible coconut haustorium.

Materials and Methods

Experiment was conducted at the Plantation Farm, Dept. of Plantation, Spices, Medicinal and Aromatic Crops, College of Agriculture, Vellanikkara, to assess the effects of nut storage period and pre-sowing treatments on germination and haustorium development in coconut. Mature seed nuts of West Coast Tall (WCT) were sourced from selected mother palms maintained at the Plantation Farm.

The experiment was conducted in a Factorial Completely Randomised Design (CRD) comprising 16 treatment combinations involving four storage periods and four pre-sowing treatments, with two replications. The storage treatments included fresh seed nuts (S_1) and nuts stored for one (S_2), two (S_3), and three months (S_4). The nuts were stored under shade with the stalk end positioned upwards. Following the storage periods, the nuts were subjected to pre-sowing treatments as described in Table 1.

The pre-sowing treatments comprised untreated control (P_1), punching of seed nuts (P_2), water soaking combined with punching for two weeks (P_3), and water

Table 1: Treatment combinations of nut storage and pre-sowing treatments.

S_1P_1	Freshly harvested nuts + Absolute control
S_1P_2	Freshly harvested nuts + Seed nuts with punching
S_1P_3	Freshly harvested nuts + Water soaking of seed nuts with punching for two weeks
S_1P_4	Freshly harvested nuts + Water soaking of seed nuts without punching for two weeks
S_2P_1	Stored nuts (1 month) + Absolute control
S_2P_2	Stored nuts (1 month) + Seed nuts with punching
S_2P_3	Stored nuts (1 month) + Water soaking of seed nuts with punching for two weeks
S_2P_4	Stored nuts (1 month) + Water soaking of seed nuts without punching for two weeks
S_3P_1	Stored nuts (2 months) + Absolute control
S_3P_2	Stored nuts (2 months) + Seed nuts with punching
S_3P_3	Stored nuts (2 months) + Water soaking of seed nuts with punching for two weeks
S_3P_4	Stored nuts (2 months) + Water soaking of seed nuts without punching for two weeks
S_4P_1	Stored nuts (3 months) + Absolute control
S_4P_2	Stored nuts (3 months) + Seed nuts with punching
S_4P_3	Stored nuts (3 months) + Water soaking of seed nuts with punching for two weeks
S_4P_4	Stored nuts (3 months) + Water soaking of seed nuts without punching for two weeks

soaking without punching for two weeks (P_4). For the punching treatment, four to six evenly distributed holes were made on the husk using a knife, with small portions of the husk removed to facilitate water penetration. For the soaking treatments, seed nuts were immersed in water-filled tanks for two weeks before planting.

The treated seed nuts were planted vertically in trenches at a depth of 25-30 cm with a spacing of 30 cm × 30 cm. The nursery beds measuring 1m × 3m were prepared and raised to a height of 10-20 cm, with a spacing of 75 cm between adjacent beds. Lime was uniformly applied to the nursery beds, followed by drenching with 0.05 per cent chlorpyrifos before sowing. After planting, the nursery beds were mulched with coconut leaves for one and a half months to conserve moisture and facilitate sprouting. Weeding was carried out periodically.

The germinated seed nuts were harvested at one-leaf stage. The nuts were carefully removed from the nursery, dehusked and deshelled, and the haustorium was separated using a wooden knife to avoid tissue damage. Observations were recorded on germination and the physical characteristics of the seedling, kernel, and haustorium for each treatment and replication using five samples per replication.

Observations and measurements

Observations on germination and physical characters of seedling, kernel, and haustorium were recorded for each treatment and replication. Germination was assessed in terms of germination percentage and time required for 50 per cent germination. Seed nut germination was recorded at regular intervals for six months after sowing, with emergence of the plumule considered as the criterion for germination. Final germination percentage was calculated as the ratio of the number of germinated seed nuts to the total number of seed nuts sown, expressed as a percentage. The time required for 50 per cent of the seed nuts to germinate was recorded in days.

Shoot length was measured from the point of emergence from the nut to the tip of the longest leaf, while seedling length was measured from the base of the nut to the tip of the longest leaf and expressed in cm. Seedling fresh weight was recorded using an electronic balance and expressed in g. Kernel characteristics were assessed before and after storage of the seed nuts. Kernel thickness was measured after removal of the haustorium and expressed in cm, while kernel weight was recorded using an electronic balance and expressed in g. Kernel oil content was estimated by the centrifugation method of Ndife *et al*., (2019). The kernel was separated from the haustorium, crushed, and blended with water at a 1:1 ratio to extract coconut milk. The extract was centrifuged at 4000 rpm for 30 min at room temperature, followed by a second centrifugation to separate the oil-cream and aqueous fractions. The separated oil layer was collected by decantation and expressed as a percentage of the sample weight. Kernel moisture content was determined by the oven-drying method. A known weight of kernel sample was dried to constant weight, and moisture content was calculated as:

$$\text{Moisture content (\%)} = \frac{\text{Initial weight (g) - Final weight (g)}}{\text{Initial weight (g)}} \times 100$$

Physical characteristics of the haustorium were evaluated at the one leaf stage. Total haustorium weight, yellow portion weight and white portion weight were recorded using an electronic weighing balance and expressed in grams. Haustorium firmness was measured using a fruit pressure tester (penetrometer) and expressed as kg cm^{-2}. Longitudinal diameter was measured along the longest axis, while transverse diameter was measured at the widest portion perpendicular to the longitudinal axis, using a measuring scale and expressed in centimetres.

The recorded data were subjected to Analysis of Variance (ANOVA) using GRAPES (General R-shiny based Analysis Platform Empowered by Statistics) software to determine the statistical significance of the treatment effects (Gopinath *et al*., 2020).

Results and Discussion

Storage duration and pre-sowing treatments significantly affected germination percentage, whereas their interaction was non-significant (Table 2). Among the storage treatments, seed nuts stored for one month (S_2) recorded the highest germination percentage (92.67%), which was significantly superior to fresh seed nuts (S_1) and nuts stored for two months (S_3; 88.67%) and four months (S_4; 85.33%). With respect to pre-sowing treatments, water soaking of punched nuts for two weeks (P_3) resulted in the highest germination (91.33%). Punching alone (P_2) and water soaking of unpunched nuts for two weeks (P_4) recorded 89.33% germination and were statistically comparable. The untreated control (P_1) exhibited the lowest germination (85.33%). A similar pattern was observed for the time required to attain 50 per cent germination (Table 2). Seed nuts stored for one month (S_2) reached 50 per cent germination in the shortest period (104.25 days), whereas those stored for four months (S_4) required the longest period (131.25 days). Among the pre-sowing treatments, P_3 resulted in the earliest attainment of 50 per cent germination (107.25 days), while the untreated control (P_1) required the longest

Table 2: Effect of storage and pre-sowing treatments on germination percentage and time to 50 per cent germination of coconut.

Treatments	Germination percentage (%)					Time to 50 per cent germination (days)				
	P_1	P_2	P_3	P_4	Mean	P_1	P_2	P_3	P_4	Mean
S_1	85.33	89.33	90.67	89.33	88.67^{b}	128.00	120.00	107.00	112.00	116.75^{b}
S_2	89.33	93.33	94.67	93.33	92.67^{a}	114.00	105.00	96.00	102.00	104.25^{d}
S_3	85.33	89.33	90.67	89.33	88.67^{b}	126.00	118.00	105.00	110.00	114.75^{c}
S_4	81.33	85.33	89.33	85.33	85.33^{c}	142.00	134.00	121.00	128.00	131.25^{a}
Mean	85.33^{c}	89.33^{b}	91.33^{a}	89.33^{b}		127.50^{a}	119.25^{b}	107.25^{d}	113.00^{c}	
	S	P				S	P			
SE(m)	0.66	0.66				0.57	0.57			
CD(0.05)	2.60	2.60				1.71	1.71			

period (127.50 days). The non-significant interaction between storage duration and pre-sowing treatment indicated that their effects on germination percentage and germination rate were largely independent.

The better germination recorded in one-month-stored seed nuts may be associated with the maintenance of adequate moisture and physiological viability during a moderate storage period. In contrast, prolonged storage may accelerate deterioration of seed quality through progressive moisture loss and depletion of physiological reserves, thereby reducing germination potential and delaying germination. Shareefa *et al.*, (2018) reported that storage duration and storage conditions significantly affected germination of coconut seed nuts and observed a decline in germination with increasing moisture loss during storage. Similarly, Odufale *et al.*, (2025) reported considerable variation in coconut germination and emergence under different storage durations and storage conditions.

The superior performance of P_3 may be attributed to the combined effect of punching and water soaking, which could facilitate water entry into the nut and improve hydration of the embryo and surrounding tissues. Adequate water availability is essential for the initiation of germination and subsequent metabolic activation, and improved hydration can favour embryo activation and seedling emergence (Beveridge *et al.*, 2022). Kumar (2011) also reported that soaking coconut seed nuts in water for 15 days following punching promoted early germination and seedling growth. The present findings therefore indicate that a moderate storage period combined with an effective pre-sowing treatment can favour both higher germination and faster germination of coconut seed nuts.

Significant differences were observed in seedling growth characteristics as influenced by storage duration and pre-sowing treatments (Table 3). Storage duration had a marked effect on shoot length, with S_2 recording the maximum shoot length (63.49 cm), followed by S_4(46.42 cm). Among the pre-sowing treatments, P_2(48.48 cm) and P_3(48.42 cm) recorded the highest shoot length, while P_4 recorded the lowest value (45.20 cm). The interaction between storage duration and pre-sowing treatment was also significant, with the maximum shoot length recorded in S_2P_3(68.32 cm) and the minimum in S_3P_4(37.38 cm).

Seedling length was highest in S_2(83.97 cm), followed by S_1(69.20 cm) and S_4(69.07 cm), while S_3 recorded the lowest value (65.38 cm). Among the pre-sowing

Table 3: Effect of storage and pre-sowing treatments on physical characters of coconut seedlings.

Shoot length (cm)					
	P_1	P_2	P_3	P_4	Mean
S_1	27.50^{o}	39.58^{l}	32.92^{n}	40.09^{k}	35.02^{d}
S_2	59.72^{d}	64.67^{b}	68.32^{a}	61.27^{c}	63.49^{a}
S_3	44.12^{h}	45.08^{g}	51.22^{f}	37.38^{m}	44.45^{c}
S_4	57.81^{e}	44.58^{h}	41.21^{j}	42.08^{i}	46.42^{b}
Mean	47.29^{b}	48.48^{a}	48.42^{a}	45.20^{c}	
	S	P	S × P		
SE(m)	0.08	0.08	0.16		
CD(0.05)	0.24	0.24	0.48		
Seedling length (cm)					
S_1	61.92^{l}	63.07^{k}	77.24^{f}	74.57^{g}	69.20^{b}
S_2	79.53^{e}	80.26^{de}	89.73^{a}	86.36^{b}	83.97^{a}
S_3	72.43^{h}	80.71^{d}	43.51^{m}	64.87^{j}	65.38^{c}
S_4	82.12^{c}	66.17^{i}	62.42^{kl}	65.57^{ij}	69.07^{b}
Mean	74.00^{a}	72.55^{b}	68.22^{c}	72.84^{b}	
	S	P	S × P		
SE(m)	0.12	0.12	0.25		
CD(0.05)	0.37	0.37	0.74		
Seedling weight (g)					
S_1	1424.40^{c}	1460.40^{b}	1586.70^{a}	1297.50^{e}	1442.30^{a}
S_2	1156.46^{g}	1253.41^{f}	1344.45^{d}	286.48^{e}	1260.20^{b}
S_3	578.27^{o}	907.70^{l}	1028.41^{i}	1127.47^{h}	910.46^{d}
S_4	894.30^{m}	866.65^{n}	948.44^{k}	997.67^{j}	926.76^{c}
Mean	1013.30^{d}	1122.04^{c}	1227.01^{a}	1177.30^{b}	
	S	P	S × P		
SE(m)	2.02	2.02	2.02		
CD(0.05)	5.83	5.83	5.83		

treatments, P_1 recorded the highest seedling length (74.00 cm), followed by P_4(72.84 cm) and P_2(72.55 cm), whereas P_3 recorded the lowest value (68.22 cm). Seedling weight was highest in S_1(1442.30 g), followed by S_2(1260.20 g) and S_4(926.76 g), while S_3recorded the minimum value (910.46 g). Among the pre-sowing treatments, P_3 resulted in the highest seedling weight (1227.01 g), followed by P_4(1177.30 g) and P_2(1122.04 g), whereas P_1 recorded the lowest weight (1013.30 g). At the interaction level, S_1P_3 recorded the maximum seedling weight (1586.70 g).

The variation in shoot length, seedling length and seedling weight may be related to differences in the physiological status of the seed nuts and the availability and mobilisation of stored reserves. The comparatively better shoot growth observed under S_2 suggests that a moderate storage period may provide favourable conditions for subsequent seedling establishment, whereas prolonged storage could adversely affect seedling vigour. Shareefa *et al.*, (2018) reported reductions in seed nut length and weight with increasing storage duration, which were primarily associated with moisture loss. Kumar (2011) similarly observed improved coconut seedling growth following suitable resting and pre-sowing treatments. The relatively higher seedling weight under P_3 may therefore be associated with improved hydration and more effective mobilisation of stored reserves during germination and early seedling establishment.

Storage duration and pre-sowing treatments influenced the physical and biochemical attributes of the kernel, including thickness, weight, oil content and moisture content (Table 4). Kernel thickness was highest in S_2(1.06 cm), which was significantly superior to S_1 and S_3(0.92 cm), while S_4 recorded the lowest value (0.88 cm). Among the pre-sowing treatments, kernel thickness increased from 0.90 cm in P_1 to 0.99 cm in P_4. The maximum interaction value was recorded in S_2P_3(1.20 cm), whereas S_4P_1 recorded the minimum (0.70 cm). Prior to storage, kernel thickness in S_1, S_2, S_3 and S_4 was 0.92, 1.06, 0.92 and 0.88 cm, respectively. Following storage and subsequent seedling development up to the one-leaf stage, these values declined slightly to 0.88, 1.01, 0.87 and 0.82 cm, respectively. The reduction in kernel thickness during seedling development suggests the utilisation of endosperm reserves in support of haustorium and seedling growth. Mahayothee *et al.*, (2016) reported kernel thickness values ranging from 3.67 to 5.97 mm at different developmental stages, while Sudha *et al.* (2021) reported values ranging from 0.9 to 1.4 cm, with a mean of 1.23 cm.

Kernel weight was highest under P_4 (144.66 g), followed by P_3(143.80 g), P_1(140.95 g) and P_2(139.24 g). At the interaction level, S_2P_3 recorded the highest kernel weight (189.06 g), whereas S_1P_1 recorded the lowest (71.02 g). Before storage, kernel weights of S_1, S_2, S_3 and S_4 were 95.45, 182.91, 155.30 and 135.00 g, respectively, which declined to 90.80, 174.20, 146.90 and 125.80 g, respectively, following storage and seedling development. The reduction in kernel weight is indicative of the mobilisation of stored endosperm reserves towards developing haustorial and seedling tissues. Li *et al.*, (2019) reported that kernel weight remained relatively stable during the early stages of germination but declined considerably during later stages of seedling development.

Table 4: Effect of storage and pre-sowing treatments on physical characters of coconut kernel.

	P_1	P_2	P_3	P_4	Mean
Kernel thickness (cm)					
S_1	0.90^{e}	0.99^{c}	0.80^{g}	0.98^{c}	0.92^{b}
S_2	1.00^{c}	0.94^{d}	1.20^{a}	1.09^{b}	1.06^{a}
S_3	1.00^{c}	0.79^{g}	1.00^{c}	0.89^{e}	0.92^{b}
S_4	0.70^{h}	0.99^{c}	0.85^{f}	0.99^{c}	0.88^{c}
Mean	0.90^{d}	0.93^{c}	0.96^{b}	0.99^{a}	
	S	P	S × P		
SE(m)	0.003	0.003	0.007		
CD(0.05)	0.01	0.01	0.02		
Kernel weight (g)					
S_1	71.02^{m}	97.16^{l}	108.05^{j}	105.56^{k}	95.45^{d}
S_2	179.47^{c}	181.91^{b}	189.06^{a}	181.22^{b}	182.91^{a}
S_3	169.27^{e}	149.95^{f}	128.05^{h}	173.91^{d}	155.30^{b}
S_4	144.04^{g}	127.94^{h}	150.07^{f}	117.96^{i}	135.00^{c}
Mean	140.95^{c}	139.24^{d}	143.80^{b}	144.66^{a}	
	S	P	S × P		
SE(m)	0.26	0.26	0.51		
CD(0.05)	0.74	0.74	1.49		
Oil content (%)					
S_1	7.62	7.47	7.47	8.30	7.88^{c}
S_2	7.86	7.73	7.73	8.55	8.14^{a}
S_3	7.71	7.58	7.58	8.33	7.95^{b}
S_4	7.48	7.57	7.57	8.20	7.77^{d}
Mean	7.67^{c}	7.53^{d}	7.53^{b}	8.35^{a}	
	S	P	S × P		
SE(m)	0.01	0.01	0.02		
CD(0.05)	0.03	0.03	0.03		
Moisture content (%)					
S_1	47.18^{j}	47.45^{g}	47.39^{gh}	48.01^{b}	47.51^{b}
S_2	47.62^{e}	47.70^{d}	47.84^{c}	48.26^{a}	47.86^{a}
S_3	47.21^{j}	47.37^{hi}	47.55^{f}	47.85^{c}	47.50^{b}
S_4	47.02^{k}	46.89^{l}	47.32^{i}	47.67^{de}	47.23^{c}
Mean	47.26^{d}	47.35^{c}	47.52^{b}	47.95^{a}	
	S	P	S × P		
SE(m)	0.01	0.08	0.02		
CD(0.05)	0.03	0.03	0.06		

Similarly, Rakesh *et al*., (2021) observed a significant reduction in kernel weight between 60 and 120 days after sowing in both COD and WCT, suggesting the utilisation of stored reserves for haustorium and seedling development.

Oil content was highest in S_2(8.14%), followed by S_3(7.95%) and S_1(7.88%), while S_4 recorded the lowest value (7.77%). Among the pre-sowing treatments, P_4 recorded the highest oil content (8.35%), whereas P_2 and P_3 recorded the lowest values (7.53% each). Prior to storage, the seed nuts exhibited only marginal differences in oil content across the storage treatments, with values of 37.21% in S_1, 37.18% in S_2, 37.24% in S_3, and 37.20% in S_4. However, oil content declined progressively with increasing storage duration, decreasing from 37.21% in S_1 to 36.83%, 36.50% and 36.15% in S_2, S_3 and S_4, respectively. The decline in oil content during seedling development may be associated with the utilisation of lipids as an energy source for germination and early seedling growth. Child and Nathanael (1964) reported that kernel oil content remained relatively stable during the initial 18 weeks following germination and subsequently declined. Sugimura and Murakami (1990) also observed a gradual reduction in oil droplets in kernel tissues, which disappeared with further development of the haustorium.

Kernel moisture content was highest in S_2(47.86%), followed by S_1(47.51%) and S_3(47.50%), while S_4recorded the lowest value (47.23%). Among the pre-sowing treatments, P_4 recorded the highest moisture content (47.95%) and P_1 the lowest (47.26%). At the interaction level, S_2P_4 recorded the highest moisture content (48.26%), whereas S_4P_2 recorded the lowest (46.89%). The moisture content of the seed nuts before storage showed slight variation among the different storage periods with values, 48.05% in S_1, 48.10% in S_2, 47.95% in S_3 and 47.85% in S_4. Following storage, a gradual decline was observed with increasing storage duration, with values of 47.95 per cent after one month (S_2), 47.60 per cent after two months (S_3), and 47.05 per cent after three months (S_4). Mahayothee *et al*., (2016) reported a kernel moisture content of 55.2 ± 4.02 per cent in coconut. The reduction in moisture content observed in the present study may reflect the progressive utilisation and redistribution of water and stored reserves during haustorium and seedling development.

Overall, the reductions in kernel thickness, weight, oil content and moisture content during seedling development provide evidence of the mobilisation of endosperm reserves towards the developing haustorium and seedling. In coconut, the kernel serves as an important reserve tissue, while the haustorium functions as an absorptive organ that facilitates the mobilisation and transfer of nutrients to the developing embryo and seedling. Balasubramaniam *et al*., (1973) identified the haustorium as an important structure involved in nutrient mobilisation during coconut germination. Li *et al*., (2019) further demonstrated that haustorium development is accompanied by progressive depletion of liquid and solid endosperm reserves and changes in the accumulation and utilisation of soluble sugars. Thus, the changes in kernel characteristics observed in the present study are consistent with the physiological role of the endosperm as a source of reserves during early coconut seedling establishment.

Table 5: Effect of storage and pre-sowing treatments on physical characters of coconut haustorium.

Haustorium total weight (g)					
	P_1	**P_2**	**P_3**	**P_4**	**Mean**
S_1	103.28^{j}	110.25^{i}	97.49^{k}	89.67^{m}	100.17^{d}
S_2	160.76^{b}	161.42^{b}	168.55^{a}	154.23^{c}	161.24^{a}
S_3	141.36^{e}	122.47^{h}	152.06^{d}	133.93^{f}	137.46^{b}
S_4	98.03^{k}	123.95^{g}	94.04^{l}	87.97^{n}	100.99^{c}
Mean	125.86^{c}	129.52^{a}	128.03^{b}	116.45^{d}	
	S	P	S × P		
SE(m)	0.22	0.22	0.45		
CD(0.05)	0.65	0.65	1.29		
Yellow portion weight of haustorium (g)					
S_1	29.22^{e}	26.43^{h}	23.81^{i}	27.29^{g}	26.69^{c}
S_2	29.77^{d}	31.28^{b}	33.99^{a}	30.38^{c}	31.35^{a}
S_3	26.66^{h}	29.91^{d}	24.01^{i}	27.98^{f}	27.14^{b}
S_4	20.00^{j}	23.99^{i}	16.00^{l}	17.99^{k}	19.50^{d}
Mean	26.41^{b}	27.90^{a}	24.45^{d}	25.91^{c}	
	S	P	S × P		
SE(m)	0.046	0.046	0.092		
CD(0.05)	0.133	0.133	0.266		
White portion weight of haustorium (g)					
S_1	72.13^{i}	84.42^{i}	64.03^{l}	62.12^{m}	70.67^{d}
S_2	129.45^{c}	133.69^{b}	137.79^{a}	130.34^{c}	132.82^{a}
S_3	111.72^{e}	91.75^{h}	126.05^{d}	101.95^{f}	107.87^{b}
S_4	76.02^{j}	99.96^{g}	72.03^{k}	57.98^{n}	76.50^{c}
Mean	97.33^{c}	102.45^{a}	99.97^{b}	88.10^{d}	
	S	P	S × P		
SE(m)	0.178	0.178	0.356		
CD(0.05)	0.512	0.512	1.025		

Storage duration, pre-sowing treatments and their interaction significantly influenced total haustorium weight (Table 5). Seed nuts stored for one month (S_2) recorded the highest mean total haustorium weight (161.24 g), whereas freshly harvested nuts (S_1) recorded the lowest value (100.17 g). Among the pre-sowing treatments, punching alone (P_2) recorded the highest mean

haustorium weight (129.52 g), while the untreated control (P_1) recorded the lowest (125.86 g). The interaction effect showed that S_2P_3 recorded the highest total haustorium weight (168.55 g), followed by S_2P_2 (161.42 g) and S_2P_1, which were statistically comparable. The lowest value was recorded in S_4P_4 (87.97 g). The greater haustorium development observed under S_2, particularly in combination with P_3, corresponded with the superior germination performance recorded under these treatments.

The weights of the yellow and white portions of the haustorium were also significantly influenced by storage duration, pre-sowing treatment and their interaction (Table 5). The highest yellow portion weight was recorded in S_2(31.35 g), whereas S_4 recorded the lowest value (19.50 g). Among the pre-sowing treatments, P_2 recorded the highest mean yellow portion weight (27.90 g), while P_3 recorded the lowest (24.45 g). At the interaction level, S_2P_3 recorded the maximum yellow portion weight (33.99 g), whereas S_4P_3 recorded the minimum (16.00 g). Similarly, S_2 recorded the highest white portion weight (132.82 g), followed by S_3(107.87 g). Among the pre-sowing treatments, P_2 recorded the highest mean white portion weight (102.45 g). The interaction effect was most pronounced in S_2P_3, which recorded the maximum white portion weight (137.79 g), while S_4P_4 recorded the minimum (57.98 g). The greater accumulation of haustorial tissue under the more favourable storage and pre-sowing treatments may reflect better germination and more active mobilisation of endosperm reserves during early seedling development.

The haustorium plays a central role in coconut seedling establishment by facilitating the mobilisation and utilisation of endosperm reserves for the developing embryo and seedling. Balasubramaniam *et al.*, (1973) reported its importance in nutrient mobilisation during coconut germination. Li *et al.*, (2019) showed that haustorium development progresses with germination and is associated with the depletion of liquid and solid endosperm reserves. Archana (2024) reported a progressive increase in total haustorium weight from 50.33 g nut^{-1} at 10 weeks to 202.30 g nut^{-1} at 20 weeks of nut development. During the same period, the weights of the yellow and white portions increased from 13.38 to 37.75 g nut^{-1} and from 37.55 to 164.55 g nut^{-1}, respectively, with the white portion contributing substantially to the increase in total haustorium weight. The higher haustorium weight observed in the present study under favourable storage and pre-sowing treatments may therefore indicate enhanced mobilisation and utilisation of endosperm reserves during early seedling establishment.

Table 6: Effect of storage and pre-sowing treatments on physical characters of haustorium.

	P_1	P_2	P_3	P_4	Mean
Firmness of coconut haustorium (kg cm^{-2})					
S_1	0.92	0.95	0.99	0.97	0.95^{c}
S_2	0.98	1.01	1.05	1.03	1.01^{a}
S_3	0.96	0.99	1.02	1.00	0.99^{b}
S_4	0.90	0.93	0.97	0.95	0.93^{d}
Mean	0.94^{d}	0.97^{c}	1.00^{a}	0.98^{b}	
	S	P	S × P		
SE(m)	0.003	0.003	0.006		
CD(0.05)	0.008	0.008	0.016		
Longitudinal diameter of haustorium (cm)					
S_1	24.40^{k}	26.38^{fg}	26.31^{gh}	25.69^{i}	25.70^{c}
S_2	28.71^{d}	30.38^{b}	32.41^{a}	29.28^{c}	30.19^{a}
S_3	25.31^{j}	26.09^{h}	26.91^{e}	26.58^{f}	26.22^{b}
S_4	27.11^{e}	24.29^{k}	22.61^{l}	21.69^{m}	23.92^{d}
Mean	26.38^{c}	26.78^{b}	27.06^{a}	25.81^{d}	
	S	P	S × P		
SE(m)	0.04	0.04	0.09		
CD(0.05)	0.13	0.13	0.26		
Transverse diameter of haustorium (cm)					
S_1	21.80	21.29	20.81	23.19	21.77^{d}
S_2	26.21	28.38	30.31	27.48	28.09^{a}
S_3	24.61	23.59	22.70	21.89	23.20^{b}
S_4	23.10	21.59	22.41	20.59	21.92^{c}
Mean	23.93^{b}	23.71^{c}	24.06^{a}	23.29^{d}	
	S	P	S × P		
SE(m)	0.04	0.04	0.09		
CD(0.05)	0.12	0.12	0.25		

Conversely, reduced haustorium development under prolonged storage may be associated with delayed germination and lower seedling vigour.

Haustorium firmness was significantly affected by storage duration and pre-sowing treatments, whereas their interaction was non-significant (Table 6). Seed nuts stored for one month (S_2) recorded the highest firmness (1.01 kg cm^{-2}), while the lowest value was observed in S_4(0.93 kg cm^{-2}). Among the pre-sowing treatments, P_3 recorded the highest firmness (1.00 kg cm^{-2}), followed by P_4(0.98 kg cm^{-2}), whereas the untreated control (P_1) recorded the lowest value (0.94 kg cm^{-2}). The higher firmness observed under S_2 and P_3, together with the greater haustorium weight recorded under these treatments, suggests comparatively better development of haustorial tissue during the early seedling stage.

Haustorium dimensions were also significantly influenced by the treatments. Longitudinal diameter was significantly affected by storage duration, pre-sowing treatment and their interaction (Table 6). Nuts stored for one month (S_2) recorded the highest mean longitudinal

diameter (30.19 cm), followed by S_3(26.22 cm). Among the pre-sowing treatments, P_3 recorded the highest value (27.06 cm), whereas P_4 recorded the lowest (25.81 cm). At the interaction level, S_2P_3 produced the maximum longitudinal diameter (32.41 cm), while S_4P_4 recorded the minimum (21.69 cm). Transverse diameter was similarly influenced by storage duration, pre-sowing treatment and their interaction (Table 6). One-month-stored nuts (S_2) recorded the highest transverse diameter (28.09 cm), while P_3 recorded the highest mean value among the pre-sowing treatments (24.06 cm). The interaction S_2P_3 recorded the maximum transverse diameter (30.31 cm), whereas S_4P_4 recorded the minimum (20.59 cm). The consistent superiority of S_2P_3 for longitudinal and transverse haustorium dimensions, together with its higher haustorium weight, indicates favourable early haustorial development under this treatment combination.

The present study demonstrated that storage duration and pre-sowing treatment substantially influenced germination, seedling growth, kernel characteristics and early haustorium development in coconut seed nuts. One-month storage (S_2) generally resulted in better germination and haustorium development than prolonged storage, while water soaking of punched nuts for two weeks (P_3) was particularly effective in improving germination and several early growth attributes. The combined treatment S_2P_3 consistently performed well, recording high germination percentage, early attainment of 50 per cent germination, greater shoot growth, higher haustorium weight and larger haustorium dimensions.

The observed response may be associated with the maintenance of seed viability during moderate storage and improved hydration following punching and soaking, which together may favour germination and subsequent mobilisation of endosperm reserves. In contrast, prolonged storage, particularly for four months, was generally associated with delayed germination and reduced haustorium development. Therefore, storage of coconut seed nuts for one month followed by punching and water soaking for two weeks appears to be a promising pre-sowing strategy for achieving improved germination and vigorous early haustorium development up to the one-leaf stage.

Conclusion

The study demonstrated that both storage duration and pre-sowing treatment significantly influenced germination and haustorium development in coconut. Storage of seed nuts for one month resulted in higher germination and faster attainment of 50 per cent germination compared with prolonged storage. Among the pre-sowing treatments, water soaking of punched nuts for two weeks was most effective in improving germination performance. The interaction of one-month storage with water soaking of punched nuts for two weeks (S_2P_3) consistently resulted in superior haustorium development, as evidenced by higher total haustorium weight, greater white portion weight, higher firmness, and larger longitudinal and transverse dimensions. Prolonged storage, particularly when combined with less effective pre-sowing treatments, was associated with delayed germination and reduced haustorium development. Hence, storage of coconut seed nuts for one month followed by water soaking of punched nuts for two weeks can be recommended as a promising pre-planting treatment combination for achieving improved germination and vigorous haustorium development at the one-leaf stage. The treatment may also be useful for the production of good-quality edible coconut haustorium, although further studies under different coconut varieties and storage environments would be useful to validate its wider applicability.

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