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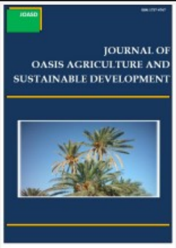

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Effect of planting material and pre-planting storage method on rhizome sprouting, crop stand, and seed rhizome yield of turmeric (*Curcuma longa* L.) at Teppi, Southwestern Ethiopia

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Abstract

A two-year study experiment was conducted from January 2021 to December 2022 at the Teppi Agricultural Research Center (TARC) with the aim of identifying suitable planting material and an appropriate pre-planting storage method that can enhance turmeric seed quality and yield under rain-fed conditions. The experiment consisted of three planting materials (mother rhizomes, finger rhizomes, and mixed rhizomes) and five pre-planting storage methods (cemented floor, under tree shade, raised mesh-wired bed, pit with grass cover, and pit with soil cover). These factors were factorially arranged using a randomized complete block design with three replications. The results from the analysis of variance revealed that the seed quality, growth, and seed rhizome yield of turmeric were significantly ($p<0.05$) influenced by the main effect of both planting material and storage method. However, their interaction did not significantly affect these attributes ($p>0.05$). The highest clean and sprouted seed rhizomes, as well as total sprouts, were recorded in mother seed rhizomes and seed rhizomes stored under tree shade. Conversely, storing mother seed rhizomes on cemented floors resulted in the highest seed weight losses. Finger seed rhizomes stored in soil-covered pits produced the highest percentages of non-sprouted and decayed seed rhizomes. Regarding growth attributes, mother seed rhizomes led to the highest plant stands, plant height, stem girth, leaf growth, and tiller number. Storing seed rhizomes under tree shade performed the best across these growth attributes. Turmeric plants grown from mother seed rhizomes yielded a higher number of mother and finger rhizomes per plant and the highest fresh rhizome yield. Likewise, storing seed rhizomes under tree shade resulted in the highest fresh rhizome yield. In general, utilizing mother seed rhizomes and storing them under tree shade improved turmeric seed quality, growth, and seed rhizome yield. Therefore, farmers in the area are recommended to adopt these practices, but further research is needed to assess their economic feasibility.

1. INTRODUCTION

Turmeric (*Curcuma longa* Linn. syn. *C. domestica* Val.) is a perennial herb that belongs to the family Zingiberaceae. According to Purseglove *et al.* (1981), the genus *Curcuma* is believed to have originated in the Indo-Malayan region. Turmeric is one of the most ancient spices in the world, as noted by Jose and Joy in 2008. It is valued for its underground orange-colored rhizome, which is used as a natural coloring agent for food, beverages, cosmetics, and dye production. This crop is extensively cultivated throughout the world, predominantly in southern and Southeast Asia; India is the largest producer country. In Ethiopia, the cultivation of turmeric commenced in 1972 after two genotypes were introduced from India and China for breeding purposes (Edossa, 1998; Habetewold *et al.*, 2018). Currently, the crop is widely cultivated in the hot and humid lowland agro-ecologies of the southwestern region of Ethiopia, particularly in the vicinity of Teppi (Edossa, 1998; Girma *et al.*, 2008).

Turmeric is propagated vegetatively through rhizomes, with both the mother and finger (daughter) rhizomes being used for planting (Nair, 2019; Prasath et al., 2019). The choice of planting materials, along with the type and weight of seed rhizomes, plays a significant role in determining the plant`s vigor, final crop yield, and overall production costs (Hossain *et al*., 2005; Hailemichael & Zakir, 2021). Moreover, the limited availability of high-quality seed rhizomes is also a major constraint for turmeric production (Hailemichael *et al*., 2016). Usually, turmeric is planted between late March and mid-April, coinciding with the onset of the rainy season, and is ready for harvest 7-8 months after planting. Typically, the farmers harvest the crop when the leaves begin to dry out, and the field exudes the typical pleasant smell of turmeric (Peethambaran *et al.*, 2016).

Preserving the seed rhizomes is a critical aspect of turmeric cultivation, and it plays a pivotal role in ensuring a successful crop establishment on the field. Usually, the local farmers retain a significant amount of their harvested turmeric rhizomes as seed or planting material for the next growing season. The reserved seed rhizomes are typically kept from the time of harvesting in January until planting in April, spanning about 90 to 120 days. Nevertheless, the turmeric seed rhizomes are perishable and susceptible to deterioration and quality losses during storage through weight loss, decay, insect pests, and disease damage (Nandini *et al*., 2014; Dodamani *et al*., 2017).

In the turmeric growing area, there was limited information available regarding suitable storage methods for turmeric seed rhizomes. Furthermore, these methods had not been studied in detail, and the most appropriate storage approach had not been identified. Farmers and growers in the area employ different storage practices, such as heaping under shade, spreading on the ground, or burying in pits. Unfortunately, these practices expose the seed rhizomes to the risk of weight loss, drying, deterioration, rot, and damage from insects, ultimately reducing the quality of the seed and its availability. Therefore, it needs to establish proper storage methods for seed rhizomes to promote sprouting and germination, and prevent storage losses like shriveling, decay, and dehydration until the time of planting. This, in turn, will contribute to enhanced field establishment, growth, yield, and overall quality of the turmeric crop. Based on the aforementioned facts, the present study was conducted with the aim of identifying a simple and appropriate pre-planting storage method that can enhance the viability, sprouting, crop stand, growth, and seed rhizome yields of turmeric at Teppi, Southwestern Ethiopia.

2. MATERIALS AND METHODS

2.1. Description of the study site

The study was conducted at the Teppi Agricultural Research Center (TARC) during the main cropping season from January 2021 to December 2022. The center is in the Southwestern Ethiopian Peoples Regional State, Sheka administrative zone, at Teppi town. It is located about 611 kilometers away from Addis Ababa, the capital city of Ethiopia. The geographical coordinates of the center are 7°10' N latitude and 35°25' E longitude, with an altitude of 1,200 meters above sea level. The climatic condition of the area is characterized by high temperatures and high humidity, as documented by Girma *et al*. (2008). Detailed meteorological data, including monthly total rainfall and average minimum and maximum temperatures for 2021 and 2022, were collected from the Teppi Agricultural Research Center Climate, Geospatial, and Biometrics Research Process and presented in the appendices. The soil type in this area is classified as Nitisol, which is dominated by a loam texture with a pH range of 5.6 to 6.0 (Abayneh & Ashenafi, 2005).

2.2. Experimental Materials, Design and Procedures

The experiment contained two main factors: firstly, the three types of planting materials to be stored, viz., mother rhizomes, finger rhizomes, and a mixture of both mother and finger rhizomes (Fig. 1). Secondly, it involved five different storage methods: spreading the seed rhizomes on a cemented floor within constructed warehouse; heaping the seed rhizomes under a tree shade and covered with grass; spreading the seed rhizomes on a one-meter raised mesh-wire bed within constructed warehouse; burying the seed rhizomes in a 0.5 × 0.5 × 0.5 meter pit and covered with grass under thatched roof shelters; and burying the seed rhizomes in a 0.5 × 0.5 × 0.5 meter pit and covered with soil under thatched roof shelters. These treatments were arranged factorially in a randomized complete block design and replicated three times.

Fig. 1. Types of turmeric planting material

A widely adapted turmeric variety known as "Dame" was used. The sample seed rhizomes were harvested during the 2020 cropping season and thoroughly cleaned, washed, and drained. The finger seed rhizomes were carefully separated from their mother seed rhizomes and then categorized into three groups: mother rhizomes, finger rhizomes, and mixtures of both rhizomes, before being stored. Fifteen kilograms of clean and uniformly sized seed rhizomes of each planting material type were allotted for each storage method and replicated three times. These stored seed rhizomes were preserved for 75 and 80 days during the 2021 and 2022 cropping seasons, respectively.

Subsequently, for further evaluation of growth and yield performance, the mother, finger, and mixture of both seed rhizomes from each storage method were transplanted into the field on April 1 and 16 in the 2021 and 2022 cropping seasons, respectively. For field evaluation, the experimental field was divided into three blocks; each block consisted of fifteen experimental plots. Within each plot, the stored mother, finger, and mixture of both seed rhizomes were randomly allocated and planted separately. In this study, a total of 45 experimental units with a size of 3m by 3m were used, and a planting space of 30 cm between rows and 15 cm between plants was maintained (Girma *et al.*, 2008).

Nitrogen fertilizer with a rate of 115 kg ha^{-1} was applied in three equal splits: one-third at emergence, one-third at the lag growth stage, and one-third at the tillering stage, as stated by Mekonnen & Garedew (2019). The phosphorus fertilizer was applied once during planting, following standard recommendations. Nitrogen was sourced from both urea and NPS fertilizers, while phosphorus was sourced from NPS fertilizer alone. The first weeding was manually done about one and a half months after planting (Girma *et al.*, 2008) and continued until the crop canopy closed. All other recommended agronomic practices were uniformly applied to all experimental plots. The crops were manually harvested at the stage of physiological maturity, recognized by the yellowing and drying of plant leaves, as outlined by Mekonnen & Garedew (2019).

2.3. Data Collection

The quality parameters of the seed rhizome, including final seed rhizome weight (kg), seed weight loss (%), number of clean seed rhizomes, sprouted seed rhizomes, total sprouts, decayed seed rhizomes, and damaged seed rhizomes, were recorded at the end of the storage period. Regarding growth parameters, the plant height (cm), total stand per plot, tiller number per plant, leaf number per plant, average leaf length and breadth (cm), and stem girth (cm) were measured for plants residing in the middle rows at the end of the sixth month of planting. According to Ravindran *et al.* (2007) and Kandiannan & Chandragiri (2008), the dry matter accumulation of the root and shoot of the turmeric plant progressively increased up to 150 days after emergence and subsequently decreased until maturity. On the other hand, the dry matter accumulation on the rhizomes steadily increased until the time of maturity. During the harvesting process, the yield and related parameters such as the number of mother rhizomes per plant, finger rhizomes per plant, girth of finger rhizomes (mm), weight of mother rhizomes per plant (g), weight of finger rhizomes per plant (g), and fresh rhizomes yield per plot (kg) were recorded. Subsequently, the rhizome yield was converted to kilograms per hectare.

2.4. Statistical Analysis

The data collected in this study were subjected to a statistical analysis. The analysis of variance (ANOVA) was carried out using SAS version 9.2 (SAS, 2008) after checking that all the assumptions for ANOVA were met by the data sets. Significant differences between treatment means were delineated by least significant differences (LSD) at the 5% probability level.

3. RESULTS AND DISCUSSION

3.1. Effect of planting material and storage method on seed rhizome quality parameters

The results of the analysis of variance revealed that the quality parameters of seed rhizomes, including the percentage of clean seed rhizomes, sprouted seed rhizomes, and total sprouts, were significantly ($p<0.05$) influenced by the main effects of both planting material and storage method. Similarly, the main effects of both planting material and storage method had a significant ($p<0.05$) effect on seed weight loss and the percentage of non-sprouted and decayed seed rhizomes, as depicted in Table 1 and 2.

Table 1. Effects of planting material and storage method on seed rhizome quality attributes of turmeric (mean of two seasons, 2021 & 2022).

Planting Materials	**Percentage of Clean Seed Rhizomes (%)**	**Percentage of Sprouted Seed Rhizomes (%)**	**Percentage of Total Sprouts (%)**
Mother Rhizomes	98.89^{a}	86.53^{a}	91.36^{a}
Finger Rhizomes	53.18^{c}	51.93^{c}	50.08^{c}
Mixture of Mother and Finger Rhizomes	83.54^{b}	75.08^{b}	81.93^{b}
LSD$_{(0.05)}$	*	*	*
Storage Types			
Cemented Floor	72.33^{c}	69.22^{bc}	76.34^{bc}
Under Tree Shade	91.00^{a}	92.96^{a}	94.31^{a}
Mesh Wire Bed	74.18^{bc}	61.78^{cd}	67.28^{c}
Grass-Covered Pit	81.99^{ab}	77.22^{b}	79.46^{b}
Soil-Covered Pit	70.94^{c}	54.72^{d}	54.91^{d}
LSD$_{(0.05)}$	*	*	*
CV (%)	12.58	14.02	13.21

*NB: Means within a column followed by the same letter are not significantly different at the 5% level of the LSD test, * = p<0.05, NS = Non-Significant*

Table 2. Effects of planting material and storage method on seed rhizome quality attributes of turmeric (mean of two seasons, 2021 & 2022).

Planting Materials	**Loss of Weight (%)**	**Percentage of Non-sprouted Seed Rhizomes (%)**	**Percentage of Decayed Seed Rhizomes (%)**
Mother Rhizomes	38.27^{a}	12.07^{c}	5.50^{c}
Finger Rhizomes	31.73^{b}	32.12^{a}	42.31^{a}
Mixture of Mother and Finger Rhizomes	37.27^{a}	23.98^{b}	21.61^{b}
LSD$_{(0.05)}$	*	*	*
Storage Types			
Cemented Floor	51.40^{a}	17.57^{b}	26.41^{b}
Under Tree Shade	32.87^{c}	8.17^{c}	12.65^{c}
Mesh Wire Bed	37.53^{b}	27.33^{a}	25.52^{b}
Grass-Covered Pit	28.87^{d}	30.00^{a}	14.35^{c}
Soil-Covered Pit	28.13^{d}	30.54^{a}	31.78^{a}
LSD$_{(0.05)}$	*	*	*
CV (%)	3.97	24.09	20.46

*NB: Means within a column followed by the same letter are not significantly different at the 5% level of the LSD test, * = p<0.05, NS = Non-Significant*

Nevertheless, the interaction effects between planting material and storage method did not have a significant ($p>0.05$) influence on these aforementioned quality parameters of turmeric seed rhizome.

3.1.1. Effect of planting material on seed rhizome quality parameters

The main effect of planting material on different quality parameters, such as percentage of clean seed rhizomes, sprouted seed rhizomes, total sprouts, seed weight loss, as well as non-sprouted and decayed seed rhizomes, is displayed in Table 1 and 2. With regards to these parameters, the mother seed rhizome type exhibited a significant difference when compared to the finger seed rhizome and the mother and finger mixed seed rhizome types, except for the percentage of non-sprouted and decayed seed rhizomes. Consequently, the highest percentages of clean seed rhizomes (98.89%), sprouted seed rhizomes (86.53%), and total sprouts (91.36%) were found in the mother seed rhizome type. Similarly, this seed rhizome type also showed the maximum percentage of seed weight loss (38.27%), followed by the mother and finger mixed seed rhizomes with 37.27% of seed weight loss. In contrast, the finger seed rhizome type resulted in lower percentages for clean seed rhizomes, sprouted seed rhizomes, total sprouts, and seed weight loss, as presented in Table 1 and 2.

A higher proportion of clean and sprouted seed rhizomes, as well as the overall sprout count originating from the mother seed rhizomes, can be attributed to their characteristic feature of having numerous auxiliary bud eyes with a larger diameter. This specific characteristic of the mother seed rhizomes contributes significantly to their consistent sprouting when compared to the finger seed rhizomes. Furthermore, the sufficient food reserves present in the mother seed rhizomes also play a vital role in promoting sprout initiation and overall sprouting. This is because the mother rhizomes act as a stronger source of nutrients in comparison with the finger rhizomes. Moreover, sprouts that emerge from the mother seed rhizomes tend to show vigorous growth, exhibiting greater length and thickness. This is mainly due to the higher proportion of meristematic cells and larger buds found in the mother seed rhizomes (Ravindran et al., 2007; Olojede et al., 2009). The result agrees with the findings of Angami et al. (2017), Patel et al. (2018), and Masreshaw (2020), who found the maximum sprouting from mother seed rhizomes compared with finger seed rhizomes. Conversely, the lower percentage of clean and sprouted seed rhizomes, as well as the total sprouts counted in finger seed rhizomes, can be due to their lower number of axillary bud eyes and reduced stored material, resulting in weakened growth potential compared to the mother rhizomes. This result is consistent with the findings of Ravindran et al. (2007) and Kadam et al. (2016), who also observed fewer and weaker sprouts emerging from finger seed rhizomes. Comparable results have also been reported in studies conducted by Alam et al. (2003), Kumar & Gill (2010), and Padmadevi et al. (2012).

Similarly, the substantial reduction in seed weight observed in the mother seed rhizomes could be associated with a higher respiration and transpiration process. This physiological progression is mainly attributed to the improved initiation and growth of sprouts during storage. Similarly, Xizhen et al. (2005), Lv et al. (2021), and Prakhongsil et al. (2022) reported an increased weight loss in stored rhizomes due to higher respiration and transpiration resulting from enhanced sprouting in ginger and turmeric rhizomes. On the contrary, the minimal weight loss observed in finger seed rhizomes may be attributed to the reduced sprouting in these rhizomes. Similar observations have also been reported previously by Indriyani (2017) in Zingiberaceae plants.

On the other hand, the finger seed rhizome type showed significantly higher percentages of non-sprouted and decayed seed rhizomes when compared to the other seed rhizome types. Specifically, we observed that 32.12% of the finger seed rhizomes did not sprout, and 42.31% of them decayed. In contrast, the mother seed rhizome type displayed lower percentages, with only 12.07% failing to sprout and 5.50% decaying (Table 2). This disparity in non-sprouted and decayed seed rhizome percentages between the finger and mother seed rhizome types can be due to differences in the number of auxiliary bud eyes and their girth size. Moreover, the higher percentage of decayed seed rhizomes observed in the finger seed rhizome type could be linked to reduced moisture loss and favorable environmental conditions, including temperature and air moisture levels, contributing to rhizome decay or rot. Khurdiya (1995), as cited in Thankamani et al. (2016), emphasizes the significant influence of surrounding air temperature and moisture on the decay of stored rhizomes. In addition, the finger rhizomes are also more susceptible to diseases and insect infestations, particularly in both field and storage conditions, as indicated by Nair (2019). This agrees with the findings of Masreshaw (2020), who also reported higher percentages of non-sprout and decayed rhizomes in finger seed rhizomes in comparison to mother seed rhizomes.

3.1.2. Effect of storage methods on seed rhizome quality parameters

Tables 1 and 2 illustrate the main effects of the storage method on the percentage of clean seed rhizomes, sprouted seed rhizomes, total sprouts, seed weight loss, and non-sprouted and decayed seed rhizomes. Notably, the seed rhizomes that were heaped and kept under a tree shade covered with grass exhibited significant differences in clean and sprouted seed rhizome percentages, as well as total sprout percentages. The highest percentages of clean seed rhizomes (91.00%), sprouted seed rhizomes (92.96%), and total sprouts (94.31%) were recorded from seed rhizomes that were heaped and stored under a tree shade covered with grass. Conversely, the seed rhizomes that were stored in pits covered with soil produced the lowest percentages for clean seed rhizomes, sprouted seed rhizomes, and total sprouts, as depicted in Table 1.

Increased percentages of clean and sprouted seed rhizomes and the total sprouts from seed rhizomes heaped and stored under trees can be attributed to the prevailing conditions of limited aeration and relative humidity, along with the ambient temperature during the storage process. Lee *et al.* (2020) and Retana-Cordero *et al.* (2021) also observed improvements in sprout growth in turmeric when the seed rhizomes are kept at an ambient temperature ranging between 16 and 32 ^{o}C. Similar reports have also been reported by Kaushal *et al.* (2017) in ginger, which belongs to the same Zingiberaceae family as turmeric. Furthermore, the improved initiation of sprouts and a greater number of sprouts observed in seed rhizomes stored under tree shade can be attributed to the exposure of the stored seed rhizomes to optimal morning and late afternoon light conditions. According to Zuniega and Esguerra (2019), turmeric seed rhizomes exposed to light during the storage period exhibited numerous and robust sprouts compared to seed rhizomes stored away from light. Our findings are consistent with the results reported by Hailemichael & Seyoum (2016) and Masreshaw (2020), who observed that storing ginger and turmeric seed rhizomes under tree shade resulted in a higher percentage of sprouts, respectively.

On the contrary, a lower percentage of clean and sprouted seed rhizomes, as well as the total sprouts from seed rhizomes stored in pits covered with soil, could be attributed to the reduced storage temperature and the absence of light during the period. This correlation between lower storage temperature and weakened rhizome sprouting has been documented in the research conducted by Olusoga *et al.* (2016), Lee *et al.* (2020), and Retana-Cordero *et al.* (2021). These studies have confirmed that as the storage temperature decreases, the sprouting of stored rhizomes either decreases or remains in a dormant state. Similar storage practices have also been suggested by Ravindran *et al.* (2007), Babu *et al.* (2013), and Mirjanaik & Vishwanath (2020) for small-scale farmers to store their turmeric and ginger seed rhizomes.

On the other hand, the method of storing seed rhizomes on a cemented floor exhibited a significant differences in terms of weight loss compared to other storage methods. Thus, the highest percentage of seed weight loss (51.40%) was recorded in seed rhizomes stored on a cemented floor within a constructed warehouse, followed by 37.53% in seed rhizomes stored on a one-meter raised mesh-weir bed. Conversely, the seed rhizomes that were stored in pits covered with soil had the lowest percentage of seed weight loss (28.13%), followed by the seed rhizomes stored in pits covered with grass under thatched roof shelters (28.87%) (Table 2). The increased weight loss of seed rhizomes stored on a cemented floor can be attributed to the higher rate of transpiration and moisture losses facilitated by the high storage temperature and reduced aeration and relative humidity within the storage structure.

These storage conditions ultimately lead to the desiccation and deterioration of seed rhizomes, resulting in significant weight loss. This result agreed with Kumar *et al.* (2006), Thankamani *et al.* (2016), and Masreshaw (2020), who observed the highest levels of dehydration and shrinkage in turmeric and ginger seed rhizomes when stored in constructed warehouses. These studies also demonstrated that the observed weight loss in these warehouses was primarily attributed to the higher rate of transpiration and moisture losses during the storage period. On the contrary, the lowest weight loss observed in seed rhizomes that were stored in pits covered with soil can be due to the lower temperature of the storage method. This resulted in reduced rates of transpiration, respiration, and moisture loss, ultimately this led to lower weight losses in the stored seed rhizomes. This finding is consistent with previous studies conducted by Hailemichael & Seyoum (2016) and Umogbai (2013), who observed the lowest weight loss in ginger and yam seeds when stored in pits. Similar results have also been reported in various studies, including those by Onyishi & Agwu (2007) on potato tubers, and Chowdhury & Hassan (2013) on onion bulbs, all of which found that storage in pits resulted in the lowest weight losses.

The storage method involving pits covered with soil showed a significant difference when compared to other storage methods in terms of the percentages of non-sprouted and decayed seed rhizomes. Accordingly, the seed rhizomes stored in pits with soil cover under thatched roof shelters exhibited the highest percentages of non-sprouted seed rhizomes (30.54%) and decayed seed rhizomes (31.78%) (Table 2). In contrast, the seed rhizomes heaped and stored under tree shade produced the lowest percentages of non-sprouted seed rhizomes and decayed seed rhizomes. The increased percentage of non-sprouted seed rhizomes in the pit storage with soil cover can be attributed to the lower storage temperature, which inhibits sprout initiation and growth. Furthermore, the absence of light also plays a significant role in preventing rhizome sprouting. This result aligns with previous studies by Olusoga *et al.* (2016), Lee *et al.* (2020), and Retana-Cordero *et al.* (2021), who found that maintaining storage temperatures below 15 ^{o}C noticeably reduces sprouting in turmeric and ginger seed rhizomes. Moreover, the increased moisture within the storage pits contributes to the higher percentage of decayed seed rhizomes. This could be due to the increased turgidity in the cell membranes of stored rhizomes, which makes them more susceptible to fungal infections. In accordance with this result, Karuppaiyan *et al.* (2008) and Hailemichael & Seyoum (2016) also reported the highest percentage of decayed ginger seed rhizomes in the pit storage method.

3.2. Effect of planting material and storage method on growth parameters

The analysis of variance revealed that the growth attributes of turmeric, including plant height, leaf length, leaf breadth, stem girth, and tiller number, were significantly ($p<0.05$) affected by the main effects of both planting material and storage method. Nevertheless, the main effects of the storage method did not show a significant influence on the plant stand count (Tables 3 and 4). Furthermore, the interaction between planting material and storage method also did not exert a significant ($p>0.05$) effect on the aforementioned growth attributes of turmeric.

3.2.1. Effect of planting materials on growth parameters

The main effect of planting materials on the growth attributes of turmeric, including plant stand count, plant height, leaf length, leaf breadth, stem girth, and tiller number, is presented in Tables 3 and 4. Particularly, plants that were grown from the mother seed rhizome type exhibited significantly higher results in terms of plant stand count, plant height, leaf length, and stem girth

Table 3. Effects of planting material and storage method on growth attributes of turmeric (mean of two seasons, 2021 and 2022).

Planting Materials	Stand Count (plants ha^{-1})	Plant Height (cm)	Stem Girth (mm)
Mother Rhizomes	248,300^{a}	90.48^{a}	15.94^{a}
Finger Rhizomes	169,444^{b}	72.67^{c}	12.61^{c}
Mixture of Mother and Finger Rhizomes	182,367^{b}	83.08^{b}	14.78^{b}
LSD(0.05)	*	*	*
Storage Types			
Cemented Floor	194,322a	82.50^{b}	15.18^{b}
Under Tree Shade	198,522a	92.45^{a}	17.40^{a}
Mesh Wire Bed	203,700a	73.06^{d}	11.43^{d}
Grass-Covered Pit	206,044a	85.25^{b}	15.47^{b}
Soil-Covered Pit	197,589a	77.11^{c}	12.71^{c}
LSD(0.05)	ns	*	*
CV (%)	35.90	3.49	8.86

*NB: Means within a column followed by the same letter are not significantly different at the 5% level of the LSD test, * = p<0.05, NS = Non-Significant*

Table 4. Effects of planting material and storage method on growth attributes of turmeric (mean of two seasons, 2021 and 2022).

Planting Materials	Leaf Length (cm)	Leaf Breadth (cm)	Number of Tillers
Mother Rhizomes	44.62^{a}	15.85^{a}	2.66^{a}
Finger Rhizomes	36.87^{c}	13.03^{b}	2.49^{b}
Mixture of Mother and Finger Rhizomes	42.25^{b}	15.54^{a}	2.50^{ab}
LSD(0.05)	*	*	*
Storage Types			
Cemented Floor	41.61^{b}	15.06^{b}	2.55^{c}
Under Tree Shade	45.68^{a}	16.15^{a}	3.23^{a}
Mesh Wire Bed	37.31^{d}	13.27^{d}	1.89^{e}
Grass-Covered Pit	42.62^{b}	15.24^{b}	2.86^{b}
Soil-Covered Pit	39.00^{c}	14.32^{c}	2.23^{d}
LSD(0.05)	*	*	*
CV (%)	3.61	4.06	8.93

*NB: Means within a column followed by the same letter are not significantly different at the 5% level of the LSD test, * = p<0.05, NS = Non-Significant*

when compared to other planting material types. However, the measurements for leaf breadth and tiller number in plants grown from mother seed rhizomes were statistically at par to those observed in plants grown from a mixture of mother and finger seed rhizomes. Thus, the highest values for plant stand count (248,300 ha^{-1}), plant height (90.48 cm), leaf length (44.62 cm), leaf breadth (15.85 cm), stem girth (15.94 mm), and tiller number (2.66 $plant^{-1}$) were measured in plants grown from the mother seed rhizomes. Conversely, the lowest values for these growth attributes were observed in turmeric plants grown from finger seed rhizomes (Tables 3 and 4).

The mother seed rhizome type exhibited significant seedling growth when grown in field conditions. This enhanced growth manifested in plant stands, plant height, stem girth, tiller number, and leaf growth can be attributed to the early sprouting and emergence of seedlings from the mother seed rhizomes. This can be mainly due to the presence of sufficient food reserves and a higher number of auxiliary bud eyes on the mother seed rhizomes when compared to those on finger seed rhizomes. Moreover, the larger diameter of the rhizome and the size of its auxiliary bud also played a vital role in promoting the growth of turmeric seedlings, as noted in previous studies by Hossain *et al.*

(2005) and Padmadevi *et al.* (2012). On the other hand, the reduced emergence and subsequent growth of turmeric seedlings grown from finger seed rhizomes could be linked to the fewer auxiliary bud eyes and lower reserves of food within these seed rhizomes. This is in conformity with the findings of Padmadevi *et al.* (2012), Hailemichael & Seyoum (2016), and Angami *et al.* (2017), who observed improved emergence and growth of turmeric and ginger seedlings when using the mother seed rhizomes for planting. Similar results have also been reported by Alam *et al.* (2003), Hossain *et al.* (2005), Ravindran *et al.* (2007), and Kadam *et al.* (2016).

3.2.2. Effect of storage methods on growth parameters

The growth attributes of seed rhizomes stored under tree shade and covered with grass exhibited significantly higher improvements compared to other storage methods. Accordingly, the seed rhizomes stored in this method showed the highest plant height (92.45 cm) and stem girth (17.40 mm), as indicated in Table 3. Similarly, this storage method resulted in the highest tiller number (3.23 plant^{-1}), leaf length (45.68 cm), and leaf breadth (16.15 cm) for the turmeric plant, as presented in Table 4. Conversely, the lowest measurements for plant height, stem girth, tiller number, leaf length, and leaf breadth were observed in seed rhizomes stored on a raised mesh wired bed within a constructed warehouse (Tables 3 and 4). The increased growth of turmeric plants observed in seed rhizomes stored under a tree shade covered with grass can be attributed to improved sprout initiation and growth during the storage period. This enhanced growth is likely due to the optimal temperature, sunlight, and improved aeration provided by this storage method. The present result agreed with that reported by Masreshaw (2020), who observed increased growth of turmeric plant when seed rhizomes were stored under a tree shade covered with grass. Hailemichael & Seyoum (2016) also support these results, as they observed similar effects on ginger.

3.3. Effect of planting material and storage method on yield parameters

The results of the analysis of variance indicate that the yield attributes of turmeric, including the number of mother rhizomes, finger rhizomes, rhizome girth, mother rhizome weight, and finger rhizome weight per plant, were significantly ($p<0.05$) influenced by the main effects of both planting material and storage method (Tables 5 and 6). Similarly, the main effects of planting material as well as the storage method had a significant ($p<0.05$) effect on fresh rhizome yield of turmeric, as presented in Table 6. Nevertheless, the interaction effects of planting material and storage method had a non-significant ($p>0.05$) influence on the aforementioned yield attributes of turmeric.

3.3.1. Effect of planting materials on yield parameters

The results in Tables 5 and 6 demonstrate the significant influence of different planting materials on yield attributes, including the number and weight of mother and finger rhizomes per plant, rhizome girth, and fresh rhizome yield. Notably, the mother seed rhizome type exhibited significant differences when compared to other planting materials in terms of the aforementioned parameters. Specifically, plants emerged from mother seed rhizomes demonstrated the highest values for mother rhizome number (2.6 plant^{-1}), finger rhizome number (14.03 plant^{-1}), and rhizome girth (18.31 mm), as indicated in Table 5. Similarly, in Table 6, it is evident that plants grown from mother seed rhizomes also yielded the maximum mother rhizome weight (96.12 g plant^{-1}), finger rhizome weight (303.73 g plant^{-1}), and fresh rhizome yield (29.57 t ha^{-1}). On the contrary, the lowest values for mother and finger rhizome numbers, rhizome weights per plant, rhizome girth, and fresh rhizome yield per hectare were observed in plants grown from finger seed rhizomes (Tables 5 and 6).

Table 5. Effects of planting material and storage method on yield attributes of turmeric (mean of two seasons, 2021 & 2022).

Planting Materials	No. of Mother Rhizomes	No. of Finger	Average Rhizome
Mother Rhizomes	2.58[a]	14.03[a]	18.31[a]
Finger Rhizomes	2.22[c]	11.73[c]	16.74[c]
Mixture of Mother and Finger Rhizomes	2.39[b]	13.20[b]	17.68[b]
$LSD_{(0.05)}$	*	*	*
Storage Types			
Cemented Floor	2.49[c]	13.26[c]	17.66[bc]
Under Tree Shade	2.90[a]	16.86[a]	18.73[a]
Mesh Wire Bed	1.82[e]	9.56[e]	16.37[d]
Grass-Covered Pit	2.65[b]	14.34[b]	17.96[b]
Soil-Covered Pit	2.14[d]	11.10[d]	17.17[c]
$LSD_{(0.05)}$	*	*	*
CV (%)	5.71	8.54	3.27

*NB: Means within a column followed by the same letter are not significantly different at the 5% level of the LSD test, * = p<0.05, NS = Non-Significant*

Table 6. Effects of planting material and storage method on yield attributes of turmeric (mean of two seasons, 2021 & 2022).

Planting Materials	Weight of Mother	Weight of Finger	Fresh Rhizome
Mother Rhizomes	96.12[a]	303.73[a]	29.57[a]
Finger Rhizomes	72.09[c]	192.34[c]	19.91[c]
Mixture of Mother and	78.52[b]	243.96[b]	23.12[b]
$LSD_{(0.05)}$	*	*	*
Storage Types			
Cemented Floor	82.19[c]	249.73[b]	24.61[b]
Under Tree Shade	105.38[a]	318.48[a]	33.50[a]
Mesh Wire Bed	56.80[e]	183.49[d]	16.60[c]
Grass-Covered Pit	96.03[b]	269.69[b]	26.87[b]
Soil-Covered Pit	70.81[d]	211.99[c]	19.42[c]
$LSD_{(0.05)}$	*	*	*
CV (%)	5.88	9.54	14.03

*NB: Means within a column followed by the same letter are not significantly different at the 5% level of the LSD test, * = p<0.05, NS = Non-Significant*

The increased rhizome number and rhizome girth in turmeric plants grown from mother seed rhizomes can be due to the sufficient stored nutrients available in the mother seed rhizomes for new growth. This in turn led to improved sprouting, emergence, and subsequent growth of turmeric plants, ultimately resulting in enhanced assimilation and translocation of photosynthetic materials into the rhizome sink. This finding aligns with the insights provided by Rosita *et al*. (2001) and Addai & Scott (2011), who have also discussed the pivotal role of reserved nutrients in facilitating the early vegetative growth of plants. Conversely, the lower food reserves in finger seed rhizomes could be a possible cause for the diminution of sprouting and subsequent growth of turmeric plants, ultimately contributing to reduced rhizome yield. Our results are in line with the findings of Olojede *et al*. (2009), Angami *et al*. (2017), Patel *et al*. (2018), and Adi & Mulyaningsih (2019), all of whom reported that turmeric plants grown from mother seed rhizomes yielded a higher number of rhizomes per plant. Similar findings have also been documented by Alam *et al*. (2003), Hossain *et al*. (2005), Padmadevi *et al*. (2012), and Kadam *et al*. (2016).

The enhanced rhizome weight per individual plant and the increased rhizome yield per hectare obtained when growing turmeric plants using a mother seed rhizome type can be attributed to the greater number of rhizomes produced by each plant. This phenomenon mainly results from improved plant growth as well as enhanced absorption and transport of photosynthetic materials into the rhizomes. This observation aligns with the findings of Edossa (1998) and Masreshaw (2020), who reported that turmeric plants grown from mother seed rhizomes yielded the highest fresh rhizome output at 14.8 t ha^{-1} and 38.2 t ha^{-1}, respectively. Conversely, the lower rhizome yield found in plants grown from finger seed rhizomes could be related to the reduced vegetative and reproductive growth of these plants. This result is attributed to low food reserves in finger seed rhizomes, resulting in reduced sprouting and emergence. These findings are in accordance with the results reported by Olojede et al. (2009) and Angami et al. (2017), who also observed the lowest fresh rhizome yield in turmeric plants grown from finger seed rhizomes. Similar results have also been documented by Padmadevi et al. (2012), Kadam et al. (2016), and Adi & Mulyaningsih (2019).

3.3.2. Effect of storage methods on yield parameters

The main effect of different storage methods on yield attributes, including the number and weight of mother and finger rhizomes per plant, rhizome girth, and fresh rhizome yield, is presented in Tables 5 and 6. Notably, seed rhizomes stored under a tree shade covered with grass exhibited a significant differences in yield attributes compared to seed rhizomes stored using different methods. Specifically, the storage method involving seed rhizomes under a tree shade covered with grass resulted in the highest values for mother rhizome number (2.9 plant^{-1}), finger rhizome number (16.86 plant^{-1}), and rhizome girth (18.73 mm), as detailed in Table 5. Similarly, this storage method also yielded the maximum mother rhizome weight (105.38 g plant^{-1}), finger rhizome weight (318.48 g plant^{-1}), and fresh rhizome yield (33.50 t ha^{-1}) (Table 6). On the contrary, the lowest values for mother and finger rhizome number and weight per plant, rhizome girth, and fresh rhizome yield were obtained from seed rhizomes stored on a one-meter raised mesh-wired bed under a constructed warehouse, as depicted in both Tables 5 and 6.

The increased number of both mother and finger rhizomes with larger diameters growing from the seed rhizomes stored under tree shade can be due to improved plant growth and enhanced photosynthetic assimilation. This improvement may be caused by better sprouting of the stored seed rhizomes, leading to enhanced emergence and growth of seedlings. These findings align with the observations of Masreshaw (2020), who noted that seed rhizomes stored in shaded areas produced more finger rhizomes (averaging 5.1 per plant) with a larger diameter (19 mm). On the other hand, the reduced number of both mother and finger rhizomes, along with the lowest rhizome girth observed in the seed rhizomes stored on a one-meter raised mesh-wired bed, can be attributed to their weakened sprouting and seedling emergence. This, in turn, directly contributes to inferior plant growth, ultimately resulting in reduced assimilation and translocation of photosynthetic materials into the rhizome sink. These findings are consistent with the research of Kumar *et al*. (2006), who found that the overall performance of ginger in the field was negatively impacted by a lower rate of sprouting and the presence of withered stored seed rhizomes. Similar results have also been reported in ginger research by Hailemichael & Seyoum (2016).

The increased weight of both mother and finger rhizomes, as well as the overall rhizome yield of turmeric obtained from seed rhizomes stored under tree shade, can be attributed to the higher number of rhizomes produced per individual plant. This productivity is primarily caused by improved sprouting and the early field emergence of individual seedlings, leading to enhanced plant growth and prolonged photosynthesis. Consequently, this progression results in better allocation of dry matter, leading to increased rhizome formation and production in individual turmeric plants. The present result agreed with the research of Masreshaw (2020), who also found that the mother seed rhizomes stored under a tree shade yielded the highest fresh rhizome yield of turmeric (36.7 t ha^{-1}). The finding of Hailemichael & Seyoum (2016) also support our results, who observed the maximum fresh rhizome yield of ginger when seed rhizomes were stored under tree shade and covered with mulch. Conversely, the lower rhizome weight and fresh rhizome yield of turmeric obtained from seed rhizomes stored on a one-meter raised mesh-wired bed can be due to poor sprouting and seedling emergence. This directly contributes to reduced plant growth and weakened photosynthetic assimilation, ultimately resulting in decreased rhizome formation and growth, leading to a lower final yield. Kumar **et al.** (2006) also found that improper storage methods and deteriorated stored seed rhizomes reduced the fresh rhizome yield of ginger. Similar findings have also been reported by Rahamanet **et al.** (2007) and Babu **et al.** (2013) in turmeric.

4. CONCLUSION

The overall results of this study revealed that the seed quality, growth, and yield attributes of turmeric were significantly ($p<0.05$) influenced by the main effects of both planting material and storage method. Nevertheless, their interaction did not significantly affect these attributes ($p>0.05$). Notably, improved seed quality attributes, including clean and sprouted seed rhizomes with minimal seed weight losses, were observed in mother seed rhizomes when stored under tree shade. Conversely, finger seed rhizomes stored in soil-covered pits exhibited the highest rates of non-sprouting and decay. Additionally, storing seed rhizomes on cemented floors led to undesirable outcomes in terms of seed weight losses. Regarding growth attributes, mother seed rhizomes consistently outperformed finger seed rhizomes across various parameters, including plant stand, plant height, stem girth, leaf growth, and tiller number. Storing seed rhizomes under tree shade with grass cover proved to be the most effective method for promoting growth attributes. In terms of yield, turmeric plants grown from mother seed rhizomes yielded the highest number of mother and finger rhizomes per plant, as well as the highest fresh rhizome yield. Similarly, an enhanced rhizome number per plant and an increased fresh rhizome yield of turmeric were obtained when seed rhizomes were stored under tree shade covered with grass. In general, the mother seed rhizomes and storing seed rhizomes under tree shade with grass cover independently proved to be the most appropriate planting material type and storage method for enhancing fresh rhizome yield, respectively. Therefore, based on the findings of this study, it is recommended that the aforementioned planting material type and storage method be adopted by farmers in the study area for enhanced seed quality, growth, and seed rhizome yield. Nevertheless, it is important to note that further research and economic assessments are necessary to evaluate the feasibility and sustainability of implementing these practices on a broader scale.

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Authors' Contributions

BM was involved in research idea, research designing, conducting the experiment, data analysis and writing the manuscript; AC was involved in the research designing, conducting the experiment.

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