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Review Article

Impact of the orientation of seed placement and depth of its sowing on germination: A review

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Abstract
Seed orientation and its impacts on germination and seedling establishment mainly depend on the type of germination (hypogeal (or) epigeal), seed size and shape. Higher germination per cent is noticed when seeds are sown in the horizontal position. Planting seeds in a downward position can lead to a variety of physiological, chemical and morphological changes in seedlings. Consequences are usually manifested as noticeable modifications in their development. Vigorous seeds have strong, resilient seedlings due to their well-balanced metabolism and coordinated subcellular activity, making them well-suited for tough environments. Proper plumule and radicle growth require additional hormones and energy to ensure seedling survival. Four necessary factors must be considered while deciding the sowing depth *viz.,* soil moisture, optimum soil temperature, soil aeration and atmospheric humidity required for seed germination, emergence and seedling growth. Variations are observed in germination behaviour and seedling growth for different sowing depths. The necessary factors are very much important for efficient nursery seedlings production. This review looks at the effects of seed depth and orientation on the germination and growth of important agricultural, horticultural and silvicultural crops.

Keywords: Depth of sowing, Field emergence, Germination, Seedling growth, Seed orientation

INTRODUCTION

The seed germination of many plant species is affected by several climatic and edaphic factors, *viz.,* temperature, light, soil depth *etc.* (Ahirwar, 2015). One of the most critical aspects influencing seed germination in many plant species is sowing depth. Deep seeding is significant since it helps good plant stand, stability, and yields better. If the upper level of the soil doesn't hold enough moisture, sowing seeds at a shallow depth may result in poor germination (Desbiolles, 2002). Planting the seeds too deeply can have an adverse effect on crop growth, which in turn can cause a decrease in yield (Aikins *et al*., 2006).
Adeogun *et al*. (2012) stated that seed sowing at deeper depths during afforestation increases the soil pres-

sure during vegetative growth depending on the type and size of seeds used during nursery and plantation establishment. Agboola, (1996) and McWilliam *et al*. (1998) both mentioned that the planting depth for each plant species depends on its seed type and surrounding environmental conditions. It is a necessity for initial emergence. Seeds planting deeply can be a key factor in achieving good plant stand and better yields (Ali and Idris, 2015). As per Aou-ouad *et al*. (2014), *Rhamnus alaternus* and *R. ludovici-salvators* seeds suffers a delay in germination when planted in deeper soil.

The ultimate destination of a seed depends to a great extent on how deeply it has been planted in the soil (Guo *et al*., 2001; Benvenuti *et al*., 2001; Soltani *et al*., 2006; Koffi *et al*., 2022; Shahin *et al*., 2022; Srivastava *et al*., 2006; Singh *et al*., 2017). Because of the high water content in the seed region, depth is a crucial component during sowing because it eventually increases plant emergence and germination (Mahdi *et al*., 1998; Masilamani *et al*., 1999; Pommel, 1990; Power and Fonteyn, 1995; Rama, 2011 and Schillinger *et al*., 1998). According to Michael and Paul (2000) and Kos and Poschlad (2007), optimal temperature and humidity are essential for successful seed germination, emergence and selection of seedlings Yagmur and Digdem, (2009) found that optimising sowing depth and seed orientation lead to superior initial growth in seedlings, development and yield of certain crops. Poor germination from shallow sowing could be attributed to a lack of moisture in the top soil layer (Fredrick *et al*., 2018), making it susceptible to predation.

Different mechanisms which allow seeds to stay ungerminated in the deeper soil layers evolved. First, dormancy processes cause delayed germination. Second, light needs for germination because light can only permeate the top layer of soil, allowing seeds to remain deeper until disturbed. Third, the alternating temperature requirements for germination may also be used to determine burial depth and gap. (El-Keblawy *et al*., 2018). Because high soil moisture exists near the deeper layer as compared to the shallow layer, seed sowing at a deeper depth may produce rotting (Guo *et al*., 2010). Prolonged stagnation of soil water in terrestrial plants can be dangerous, as it impedes gas diffusion rates, as noted by Armstrong (2002). This can have several consequences on plant growth and development. This decreases respiration and photosynthesis rates and limits oxygen delivery to roots (Voesenek *et al*., 2006). Seeds of *Butea frondose* germinate better in a 2 cm depth of sowing. While seed sowing depth increases, the germination of seeds decreases (Ahirwar *et al*., 2015). Zheng *et al*. (2019) said that weedy rice seeds sown in deeper soil affect seedling emergence. Planting *Nitraria phaerocarpa* seeds at a depth of 2 cm resulted in better seedling emergence, mass and height than when they were sown at other depths. This proved to be an effective way to encourage the growth of these seedlings. When the depth of planting was increased, seedling emergence decreased (Li *et al*., 2006). *Castanea crenata* Sieb seeds are placed at a deeper depth lowering the seedling emergence. The biomass distribution to the plant stem has increased, whereas the distribution to the root zone decreased (Seiwa *et al*., 2002). In this situation, compared to seeds buried at shallower depths, germinating seeds must expend more energy shooting for their elongation before shoot apices may reach and emerge above the soil surface (Guo *et al.,* 2009).

Regarding seed germination and seedling emergence, sowing depth and seed orientation are both crucial factors (Aou-ouad *et al*., 2014; Huang *et al*., 2007; Thomas, 1978; Kevin *et al*., 2015; Reshma, 2021; Yao *et al*., 2021).In the plant life cycle, germination is an important step in producing a new population (Bewley, 1997). Seeds placed at the optimal depth result in increased germination, emergence, performance, and favourable soil conditions, resulting in increased nutrient and soil availability in the soil (Bowers and Hayden, 1972). Plant development evidently starts with germination. The first part is the root (radicle), which grows from the micropyle region. The micropyle area absorbs water and promotes germination. Gravitropism is the physiological ability of seeds to correctly position themselves in relation to gravity during germination (Takakura *et al*., 1992; Blancaflor and Masson, 2003; Jha *et al*., 2012). In the seed germination process, the root possesses positive geotropism and germinating shoot possesses negative geotropism. Micropyle serves a crucial function in seedling development during orientation that is associated with gravity throughout the seed germination process. During germination, the root develops downwards due to gravity, which is impacted by numerous environmental and biochemical components. These components are thought to be vital for plant development and survival (He and South, 2006; Rodriguez and Cassab, 2021). Coutts (1989) observed that the root tips develop downwards when seeds are sown in the vertical position in line with the micropyle. Similarly, if a seed is planted with a micropyle in an upward orientation, the seed will grow downward direction. The effect of seed orientation on physiological processes during germination is also connected to the germination condition. Positioning the micropyle in an upright direction lowers seed germination in some plant species because it uses the most energy to turn the hypocotyls. Physiological mechanisms regulated by plant growth hormones are significant in addition to the explanations given above. In this case, the flow of auxin generated at the root tip is insufficient to reach the region of the root required to affect development (Bhat, 2011) favourably. Poor morphological development and germination conditions are two effects of this abnormal chemical process. As a result, inadequate physiological stability increases energy requirements, and hormone distribution reduces the effectiveness of germination (Mahgoub, 1995; Masilamani *et al*., 1999).

Seeds placed vertically had 60% and 45% germination rates in *Crataegus stoloniferus* and *Calamus thwaitesii*. Seeds sown in horizontal and inverted positions had minimum germination of 20% in *Crataegus stoloniferus* and *Calamus thwaitesii* (Pandey and Khatoon, 1999). *Sterculia urens* seeds planted vertically at 2cm and horizontally at 4cm depth showed 80% germination. In teak, drupes placed in vertical positions had 100% germination, in other tree crops like *Gmelina arborea, Ceiba pentandra* and *Leuceana leucocephala* seeds sown in horizontal and vertical positions, 100% germination was recorded (Agboola *et al.,* 1993). Masilamani *et al.* (1999) reported that *Hardwickia binata* seeds sown in horizontal positions at 1.5 cm depth had germination of 81%. Whereas inverted positions had 65% germination. Coconut seeds sown in horizontal orientation position had faster germination and better seedling growth (Thomas, 1978). *Balanites aegyptiaca* seeds sown in horizontal or vertical positions showed good germination (Elfeel, 2012). Studies conducted on the *Lagenaria siceraria* showed that the main factors, such as sowing depth and seed orientation during sowing, can influence germination, emergence and seedling development (Koffi *et al*., 2015). Seed orientation also remarkably affected germination parameters (Rizwan and Aftab, 2018) on *Jatropha curcas*.

This review highlights a detailed insight into some of the aspects of seed orientation at the time of sowing; and the seedbed and sowing depth on germination and seedling growth for some of the important agricultural, horticultural and silvicultural crops.

I. Agricultural crops

Maize (*Zea maize* L.)

According to El-abady (2015), large and bold maize seeds (flat or round) developed the best result across all planting depths and temperatures. When round seeds are planted at deeper depths and at lower temperatures, they attain poorer seed emergence and seedling vigour than flat seeds in small and medium seed sizes. The difference in impacts on maize seed quality between flat and spherical forms correlates to unfavourable environmental circumstances (Table 1).

Molatudi and Mariga (2009) showed that maize seed size has no influence on seedling vigour when planted at 5 cm and 10 cm depths but has a negative impact on seedling emergence and vigour when planted at the same depths (Table 2).

Shiming *et al*. (2023) reported that summer maize seeds sown in four seed orientation positions *viz*., tip pointed up (T-U), tip pointed down (T-D), embryo lying up (E-U) and embryo lying down (E-D) to observe root mass density, root length density, specific root length, soil water content, shoot biomass, and yield of summer maize. The results showed that embryos lying up positions had 5% higher deep root mass density, 48% higher deep root length density, 10% higher average root length density, wider leaf growth azimuth (35% higher), larger leaf area index (7% higher), and higher shoot biomass (3% higher) and finally grain yield was also higher (8%).

Peanut (*Arachis hypogaea*)

Ahn *et al*. (2017) stated that peanuts planted in oak tree sawdust at a depth of 3.0 cm showed that regardless of orientation (vertically with the hypocotyl end down, vertically with the hypocotyl end up, horizontally

Table 1. Seed emergence percentage and seedling growth as affected by temperature, size/shape and planting depth of Maize (Source: El-abady, 2015)

Treatments	Emergence (%)	MET (day)	Shoot length (cm)	Root length (cm)	Seedlings dry weight (g)
Temperature effects (^{0}C)					
30	95.6	3.27	25.13	13.55	1.689
25	93.9	4.14	22.88	11.29	1.342
20	90.3	7.84	16.77	9.44	1.150
Size/shape effects					
Small/round	90.1	5.41	17.70	8.77	1.304
Small/flat	90.8	5.27	18.33	9.44	1.312
Medium/round	92.9	5.28	21.03	11.44	1.384
Medium/flat	93.5	5.21	21.18	11.74	1.386
Large/round	96.0	4.70	25.48	13.44	1.491
Large/flat	96.2	4.65	25.85	13.74	1.486
Planting depth effects (cm)					
2	96.6	4.33	24.57	13.70	1.442
4	94.4	5.08	21.79	11.33	1.393
6	88.8	5.85	18.42	9.25	1.347

Table 2. Percentage of Maize seeds that emerged eight, twelve, fourteen, and eighteen days after planting impacted by seed size and planting depth (Source: Molatudi and Mariga, 2009)

Treatments	8DAP	12DAP	14DAP	18DAP
Seed size				
Large	15.8	62.5	68.8	72.1
Small	7.5	52.5	61.3	71.7
Planting depth (cm)				
5	29.2	90.0	95.0	96.7
10	11.7	65.0	75.0	81.7
15	3.3	42.5	52.5	62.5
20	2.5	32.5	37.5	46.7

DAP - Days after planting

with the hypocotyl end down, or horizontally with the hypocotyl end up), it can all result in successful peanut plants. Out of all the tested orientations, vertical orientation with hypocotyl-end-down yielded the highest germination rates at 91.7%. It also resulted in higher biomass output and overall seedling quality, making it an ideal choice for planting seeds. Therefore, it is best to plant the seeds vertically with their hypocotyl end pointing downwards (Fig. 1 and 2).

Wheat

Hines *et al*. (1991) studied the effect of sowing depth on the emergence of six different wheat cultivars. The results revealed that all the wheat cultivars showed 96% or greater emergence from a sowing depth of 30 mm (Table 3).

II. Horticultural crops

Fluted pumpkin (*Telfairia occidentalis* hook. F.)

Willie and Waya (2018) reported that the fluted pumpkin seedling emergence and early seedling performance were not affected differently by seed sowing orientation (Four different ways to sow seeds: flat, sideways, up, and down with the micropyle pointing.) from one another (Table 4).

Bottle gourd (*Lagenaria sciceraria*)

Kevin *et al*. (2015) studied the planting depth and orientation of bottle gourd seeds and concluded that these factors positively impact germination, seedling vigour, and yield. The study involved testing three different planting depths (2 cm, 6 cm, and 10 cm) and four diverse orientations (vertical with the seed extremity upward; vertical with the seed extremity downward; horizontal with the seed on the side; horizontal with the seed on the flattening face).

Seedling vigour was highest when the seedlings were in the vertical position, yet germination was best when they were laid horizontally. Vertical upward sowing depth was the most effective, with the highest germination rate being observed at 2 cm, according to statistics. The best results were achieved when sowing seeds at 10 cm depth with a flattening face. Moreover, plants were more resilient and yielded higher grain production than other depths. Thus, this technique proves to be an effective way of ensuring positive yield outcomes (Fig. 3).

Faba bean (*Vicia faba* L.)

Ali and Idris (2015) conducted their research with three variations of seed sizes (small, medium and large) which were planted to two different depths (5cm and 10cm). The finding shows that there was virtually little difference between large and medium seeds. As the depth of seeding decreased, seed germination and other characteristics improved. A germination rate of

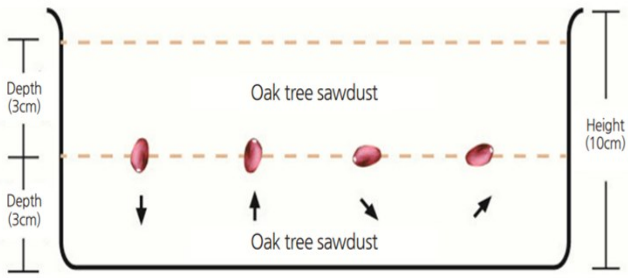

Fig 1. *Showing four orientations displayed for the peanut plant* (Source: Ahn *et al*., 2017)

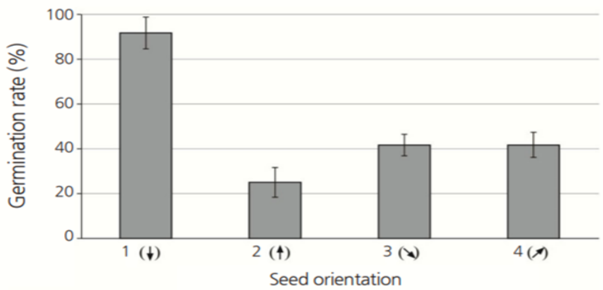

Fig. 2. *Impact of planting direction on peanut germination rate* (Source: Ahnet *al*., 2017)

Table 3. Effect of sowing depth (30 and 90 mm) on emergence percentage of six New Zealand wheat cultivars (Source: Hines *et al*., 1991)

Cultivars	Emergence (%) (From two sowing depths)	
	30mm	90mm
Sapphire	100	77
Batten	97	76
Otane	96	58
Bounty	100	33
Brock	98	31
Pernel	99	22

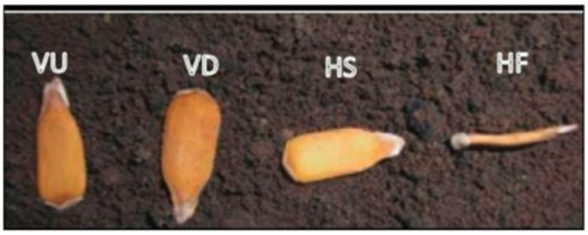

Fig 3. *Bottle gourd seed orientation positions* (Source: Kevin *et al*., 2015)

86.7% and seedling vigour index of 20.7 was noted in medium-sized seeds which were planted at a depth of 5 cm. It was observed that a large seed size and planting depth of 5 cm resulted in superior germination, as well as higher root and seedling length and fresh and dry root weight. Faba bean should not be sown at greater depths for optimal seedling development (Fig 4).

Mango (*Mangifera indica*)

According to the research conducted by Reshma and Simi (2019), it was observed that mango stones showed higher germination when sown with the stalk facing up. This orientation resulted in the earliest start to germination, maximum germination rate, and increased vigour of seedlings (Table 5).

Coconut (*Cocos nucifera* L.)

Raja and Sivasubramaniam (2015) have reported the suitable seednut size, sowing orientation and nursery area for producing vigorous seedlings in coconut var. East Coast Tall. The results revealed that coconut seed nuts sown vertically with calyx end pointed upward orientation have registered higher germination and seedling vigour (Table 6).

Onion (*Allium cepa* L)

Swaminathan *et al*. (2020) evaluate the germination of onion bulbs under three different orientations (root tip downwards, root tip upwards and horizontally). The experiment results revealed that when onion bulbs were sown with the root section facing downward, 93% germination rate was observed. Planting bulbs horizontally and sowing them root tips up gave respective germination rates of 87.17% and 78.78% (Table 7 and Fig 5).

Litchi (*Litchi chinensis*)

A study by Zhang *et al*. (2015) determined that when sowing seeds in four specific directions (flat, edge, vertical up and vertical down) in the soil of varying depths (2 cm, 4 cm and 6 cm), the growth rate was impacted. Burial depth and seed orientation both had a substantial impact on seedling growth. With increasing burial depth, there was a decrease in seedling emergence. Most seedlings, around 90%, were observed to have germinated when planted 2 cm deep. Litchi seeds that were laid flat and had their roots pointing downward showed the highest rates of emergence as well as the quickest speed of germination (Fig. 6).

III. Silvicultural crops

Wild mango (*Spondias pinnata*)

Tomar and Srivastava (2017) studied how seed germination impacts wild mango seeds, when the seeds were planted in vertical (micropyle end pointed up) and horizontal (micropyle facing side-ways) orientations at a depth of 2cm. Germination rates were significantly higher in a vertical orientation compared to a horizontal orientation, with 92% observed in the former and 80% in the latter. This highlights that vertical orientation is more efficient than horizontal (Table 8).

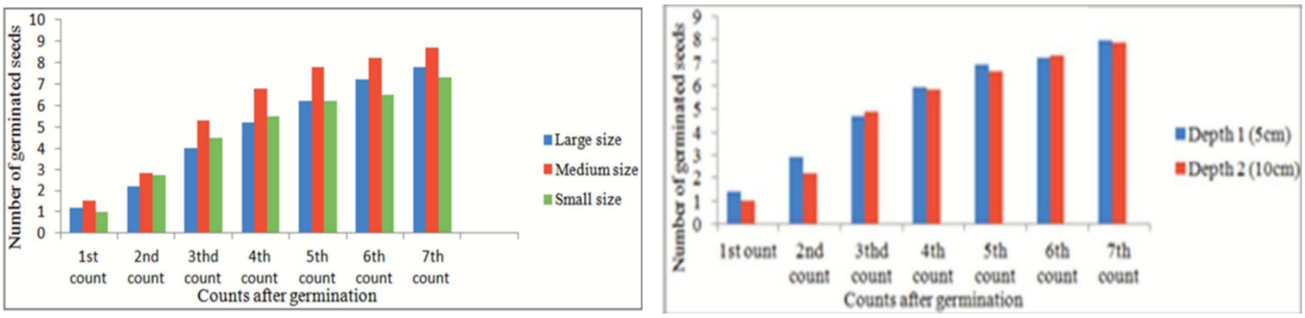

Fig 4. *Effect of seed size and sowing depths on the number of germinated seeds in Faba bean* (Source: Ali and idris, 2015)

Gulmohar (*Delonix regia*)

Zewdie and Welka (2015) reported that *Delonix regia* seeds were used for four different seed sowing orientations (micropyle upright, micropyle downward, micropyle horizontal and micropyle-not considered). The sowing position with the seed micropyle pointed downward produced the greatest results in terms of germination speed, mean germination time, mean daily germination, peak value, germination value, and germination percentage of *Delonix regia* (Table 9 and Fig. 7).

***Tejpat* (*Cinnamomum tamala*)**

Singh *et al*. (2017) discovered that the direction of sowing has an impact on *Cinnamomum tamala* Nees seed germination and seedling emergence. Upright seeding orientation was proven beneficial for germination, as opposed to its horizontal or inverted positions. Different orientations proved to be quite influential in shoot and root length, biomass distribution among shoot and root, and the number of leaves produced (Fig. 8).

Pereira *(Aframomum citratum)*

Grace and Mbogue (2020) reported that when *Aframomum citratum* seeds were sown in three different depths 0, 3 and 6 cm. Sowing depths significantly affected germination. They found that the greatest number of seedlings germinated when the depth of planting was 0 cm. It was followed by 3 cm and then 6 cm, respectively, having a lesser amount of germination.

Table 5. Effect of different sowing positions on growth parameters in mango stones (Source: Reshma and Simi, 2019)

Sowing positions	Days taken for initial emergence	Days taken for 50% germination	Germination (%)	Rate of germination	Vigour index -I	Vigour index- II
Flat	29.15	40.91	40.95	0.26	746.93	304.15
Stalk end up	22.95	31.75	60.85	0.47	1324.23	521.67
SE (m)	0.046	0.166	0.690	0.001	0.226	0.143
CD	0.130	0.466	1.940	0.004	0.637	0.402

Table 6. Effect of seed nut sowing orientation on germination and seedling vigour in coconut (Var. East Coast Tall) (Source: Raja and Sivasubramaniam, 2015)

Sowing orientation	Growth rate	Germination (%)	Plant height (cm)	Collar girth (cm)	No. of split leaves
Vertical orientation	2.12	90	78.6	8.1	3.8
Slanting orientation	2.10	90	77.9	8.0	3.6
Horizontal orientation	2.0	89	73.1	8.0	3.6
Inverted orientation	1.43	70	52.5	6.3	2.0
SEd	0.10	3.1	5.2	0.5	0.5
CD (P=0.05)	0.20	6.5	11.1	1.0	1.1

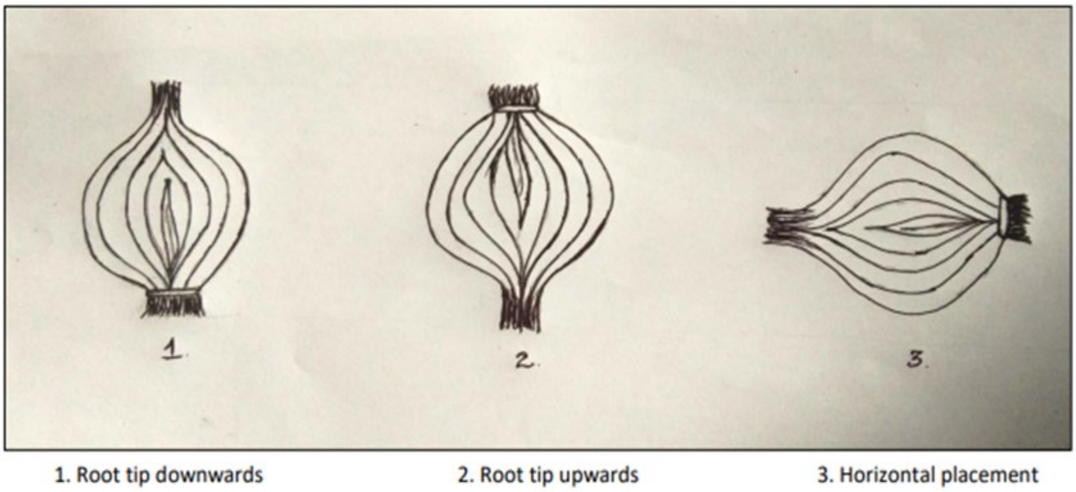

Fig 5. *Different orientations and placement of onion bulbs* (Source: Swaminathan *et al*., 2020)

Table 7. Effect of bulb orientation on germination in onion (Source: Swaminathan *et al*., 2020)

Deposition and sowing orientation of bulbs	Germination (%)
bulb with root tip downwards	93.0
bulb with root tip upwards	78.7
horizontal placement of bulbs	87.1

Table 8. Effect of seed orientation on *Spondias pinnata* (Source: Tomar and Srivastava, 2017)

Orientation	Total germination (%)	Period of germination
Vertical	92	7-19 days
Horizontal	80	8-21 days

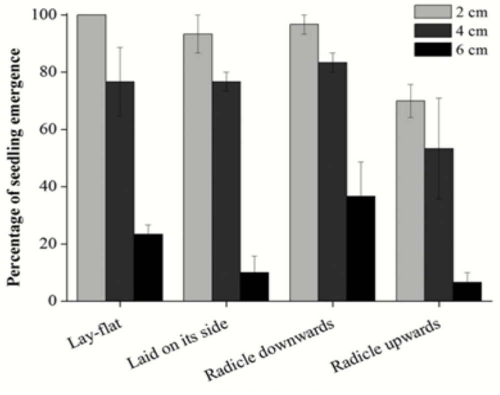

Fig 6. *Different orientations and depths in Litchi* (Source: Zhang *et al*., 2015)

Table 9. *Delonix regia* seed germination influenced by seed orientation (Source: Zewdie and welka, 2015)

Parameter	Micropyle upright	Micropyle downward	Micropyle horizontal	Seed sown randomly (control)	P value
Speed of germination	2.91	11.95	6.57	6.04	0.01
Mean germination time	49.94	192.24	119.01	108.13	0.01
Mean daily germination	0.31	0.78	0.67	0.65	0.02
Peak value	0.33	0.83	0.69	0.68	0.02
Germination value	0.11	0.67	0.47	0.47	0.06
Germination percent at 27th date	23.81	60.0	51.43	50.48	0.02

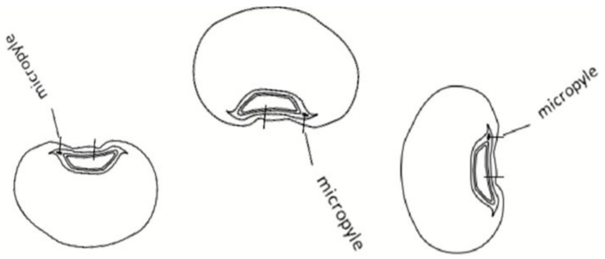

Fig 7. *Seed orientation positions of Delonix regia* (Source: Zewdie and Welka, 2015)

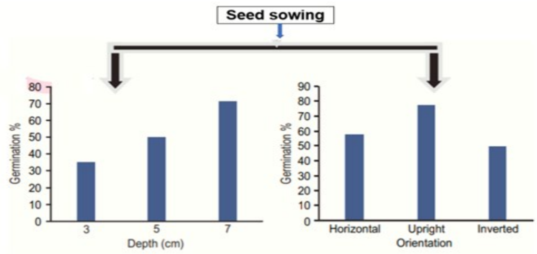

Fig 8. *Effect of sowing depth and orientation on Cinnamomum tamala* (Source: Singh *et al*., 2017)

Anjan (*Hardwickia binata*)

Masilamaniet *et al*. (1999) conducted a study to examine the sowing of anjan seeds in sand-filled earthen pots at different depths and with three different orientations of the embryo (i.e. facing up, horizontal or inverted). Specifically, the depths tested were 1.5 cm, 3 cm and 5 cm. Planting the seeds at a depth of 1.5 cm to 3.0 cm can help to increase the germination rate, the best position being with the embryo laid horizontally or inverting it for ideal conditions during early growth (Table 10).

Velvet tamarind (*Dialium guineense*)

Fredrick *et al*. (2018) reported that seeds of velvet tamarind sown at 3 and 6 cm had 80% germination, and the lowest germination at 13 % was recorded at 0 cm depth (Fig. 9).

Palas (*Butea frondose*)

According to Ahirwar (2015), when *Butea frondose* seeds were seeded in perforated polythene bags at different depths of the soil, namely 1 cm, 2 cm, 3 cm, 4 cm, 5 cm, and 10 cm. The results showed that seeds sown with 2 cm depth gave the highest seed germination, followed by 2cm soil depth. With increasing depth of seeding, the percentage of seed germination decreased gradually. To get maximum seedlings, the seeds should be placed at a depth of 2 cm (Fig. 10).

Teak (*Tectona grandis*)

Masilamani and Dharmalingam (1998) claim that teak drupes were sown in 1.5, 3, and 5 cm depths and drupe oriented vertically, horizontally, and inverted. The findings demonstrated that sooner and more significant germination occurred when the drupes were buried with horizontally at a depth of 1.5 cm to 3 cm (Table 11).

Table 10. Seed orientation and sowing depth on germination of *Anjan* (Source: Masilamani *et al*., 1999)

Parameters	Germination (%)		
Seed orientation	1.5 cm	3.0 cm	5.0 cm
Upward	38	31	19
Horizontal	81	61	47
Inverted	65	35	21

Table 11. Percentage of seed germination, seedling emergence time and the number of seedlings/100 drupes influenced by orientation and depth of drupe sowing in teak (Source: Masilamani and Dharmalingam, 1998)

Orientation of placement	Germination (%)				Number of seedlings/100 drupes			
	1.5 cm depth	3 cm depth	5 cm depth	Mean	1.5 cm depth	3 cm depth	5 cm depth	Mean
Downward	20[b]	23[a]	17[a]	20	30[a]	32[a]	22[a]	28
Upward	37[a]	32[a]	17[a]	29	41[a]	42[a]	22[a]	35
Horizontal	27[ab]	29[a]	19[a]	24	33[a]	38[a]	21[a]	31
Mean	28	28	17		35	37	21	

Table 12. Effect of seed orientation and sowing depth on germination of *Jatropha curcas* (Source: Masilamani *et al*., 2012)

Parameters	Germination (%)		
Seed orientation	1.5 cm	3.0 cm	5.0 cm
Upward	61	51	43
Horizontal	47	40	28
Inverted	20	19	17

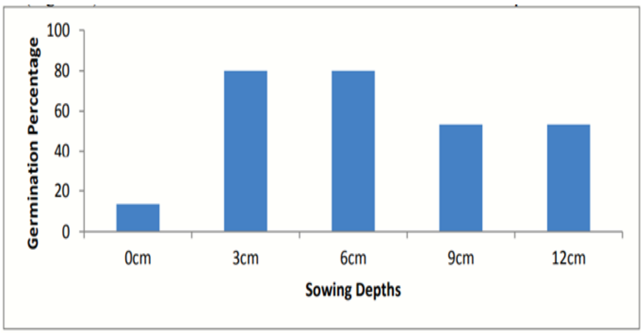

Fig. 9. *Effects of sowing depth on germination percentage of Dialium guineense* (Source: Fredrick *et al*., 2018)

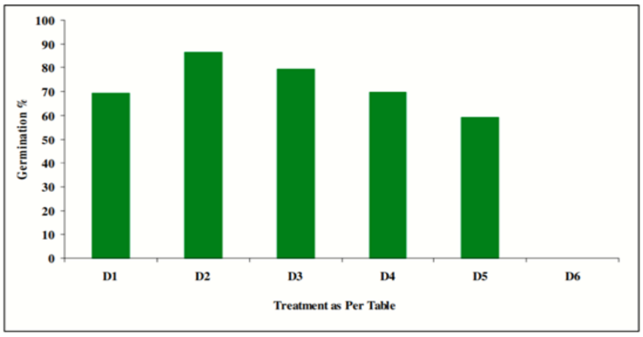

Fig. 10. *Effect of soil depth on seed germination of Butea frondose* (Source: Ahirwar, 2015)

Jatropha (*Jatropha curcas*)

Masilamani *et al*. (2012) stated that *Jatropha* seeds were sown in sand-filled earthen pots at 1.5, 3.0 and 5.0 cm depth, and inverted, upright and horizontal orientation positions were used. The placement of the seeds with the embryo upright or horizontally at a depth of 1.5 cm to 3 cm led to earlier and more vigorous germination, according to their findings (Table 12).

Shea Tree (*Vitellaria paradoxa*)

According to Yao *et al*. (2021), Shea tree seeds were planted at three different depths (5 cm, 10 cm, and 15 cm) and in five different seed orientations (vertical seed orientation with the apical end upwards, vertical seed orientation with the apical end downwards, horizontal seed orientation with the hilum upwards, horizontal seed orientation with the hilum downwards, and horizontal seed orientation with the hilum sidewards). Shea seeds successfully germinate and grow vigorously in the nursery when the seeds are sown at a depth of 5 cm with the hilum facing sideways (Fig. 11).

Mahua (*Madhuca longifolia*)

Masilamani *et al*. (2022) reported that placing *mahua*

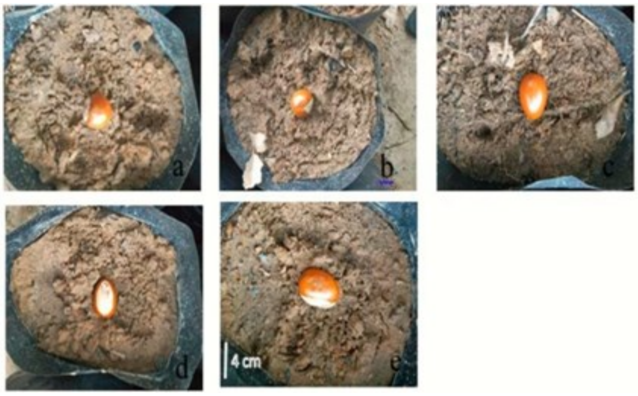

Fig 11. *Seed orientations tested during shea seed sowing* (Source: Yao *et al*., 2021)

seeds with the embryo in an upright position at a depth of 1.5 cm and 3.0 cm resulted in early and higher germination, higher seedling growth, greater dry matter production and vigour index I and vigour index II.

Conclusion

This review concludes that the seed orientation sowing in the soil media and depth of sowing affect the germination efficiency and seedling growth of agricultural, horticultural and silvicultural crops. Sowing depth is an important factor which has to be considered while sowing. Sowing in shallow depth can reduce germination and gives more energy reserves to shoot for their elongation. When growing robust, healthy, well-shaped seedlings, it is crucial to consider optimal seed orientation and sowing depth. In addition, seed orientation and depth vary depending on plant species, variety, and environmental conditions. In the general orientation of seed, placement has more influence on bigger/larger seeds, whereas sowing depth has more influence on tinny/small seeds. Therefore, to achieve a discernible difference in improving germination, promoting speedy emergence, and stimulating the growth and vigour of seedlings, both seed orientation and depth of planting need to be considered.

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