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Evaluation of Seed Germination Parameters of Kalmegh Genotypes in Nursery

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ABSTRACT

An experiment was conducted during June-July of 2018 and 2019 at Birsa Agricultural University, Ranchi, Jharkhand, India to screen out the most promising genotypes suited for the climatic and edaphic conditions of Jharkhand. Mean number of days taken for completion of seed germination varied from 3.33 days (OAP_6) to 13.67 days ($JHAP_3$). Germination period of different Kalmegh genotypes varied from 6.33 days (OAP_6) to 15.67 days ($JHAP_2$, $JHAP_3$ and $CHAP_1$). Out of the days taken to complete germination period, nearly 43% of the time was required for seed germination initiation and 62% time to achieve 50% of final germination count. Once the seed started germination, it took 8.82 days to complete seed germination i.e. 57% time was required from initiation to completion of germination. Germination trend of seeds shows that most of the seeds germinated between third to sixth days. Mean germination percentage varied from 21.00% (OAP_1) to 97.67% ($MPAP_3$). Altogether eight genotypes namely $JHAP_1$, OAP_6, $MPAP_2$, $MPAP_3$, $MPAP_4$, IC111286, IC471890 and GAP_1 showed excellent germination percentage having value more than 90.00%. Three Kalmegh genotypes ($MPAP_3$, OAP_6, $JHAP_1$) gave highest germination percentage (94.00, 93.00 and 90.67%) respectively. The five genotypes namely; $JHAP_1$, OAP_6, $MPAP_2$, $MPAP_3$, and GAP_1 were found as most promising genotypes of Kalmegh suited for the climatic and edaphic conditions of Jharkhand.

KEYWORDS: *Andrographis paniculata*, germination period, germination energy, germination percentage

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1. INTRODUCTION

Germination of a seed involves the reactivation of the metabolic pathways that lead to growth and the emergence of the radicle and plumule (Anonymous, 2006). Since germination is a complex biological process and several factors must enact simultaneously on it; the resultant effect is reflected in the form of emergence of seedling, after a certain period of time (Black and Halmer, 2006). Only those seeds which germinate rapidly and vigorously under favourable and controlled conditions are likely to be capable of producing vigorous seedlings in field conditions. Thus, it would be desirable to have information regarding germination parameters for producing good quality seedlings. A systematic study on seed germination parameters is essential for any seed propagated crop to ensure crop stand and yield. Since Kalmegh is seed propagated, it is essential to assess the seed quality for ensuring the crop stand and herb yield which depend on quality seed (Kumar et al., 2011). Seed germination is a big problem in Kalmegh due to its wild nature. Internal factors affecting seed germination are seed viability, genotype, seed maturation and seed dormancy. Low seed germination is one of the main problems in Kalmegh because of dormancy (Saraswathy et al., 2004; Kumar et al., 2011b; Talei et al., 2012). Seed dormancy in Kalmegh is mainly caused by two different mechanisms consists of: a hard seed-coating layer and existence of unknown inhibitor proteins in the seed and seed coat. The hard seed-coating layer in Kalmegh seeds provides a combination of physical and physiological dormancy that prevents water uptake by the embryo resulting in lower germination percentage. The information available on seed quality and germination of Kalmegh is very meager. Therefore, enhancing seed germination to produce healthy and vigorous seedlings is crucial to meet current requirements (Kohli and Kumari, 1986; Kumari et al., 2012). Swamy et al. (2012) mentioned that optimum numbers of seedlings for transplantation were produced with 3 g seed m^{-1} row spaced at 15 cm distance. A shed net with 75% light reduction helped in early production of maximum number of seedlings ready for transplanting which would be helpful in preparedness for early monsoon. Verma et al. (2015) found highest herb and andrographolide yield in Kalmegh (218% and 61.3%, respectively) in treatment (NPK+Bacillus sp.) compared with control followed by okra at 50% plant population (4253 kg ha^{-1}) and Kalmegh+pigeon pea at 75% plant population (4011 kg ha^{-1}) over the Kalmegh sole (3080 kg ha^{-1}).

Species selected for the investigations was *Andrographis paniculata* Wall. ex-Ness, commonly known as Kalmegh used as a wonderful drug in all prevailing systems of medicine viz. Ayurvedic, Siddha, Unani, Homeopathic, traditional and modern system as well as in tribal medicine of India and South East Asian countries (Chadha, 1985). Kalmegh is a member of the Acanthaceae family, is an important indigenous medicinal plant found throughout tropical and sub-tropical Asia. It is an annual, erect, stem acutely quadrangular, with many four-angled branches, grows to a height of around 30–110 cm in moist, shady places. Fruit is a linear-oblong capsule, 1–2 cm long and 2–5 mm wide, compressed loculicidal, nearly glabrous, longitudinally furrowed on the broad faces. Capsule contains 6–12 small, subquadrate, yellow to dark brown, slightly translucent seeds (Norman and Bunyapraphatsara, 1992). It thrives well in tropical climatic conditions i.e. hot and humid. However, it can be cultivated in subtropical regions during the monsoon season (Lattoo et al., 2008). Keeping in views, the present study was conducted to find out the most promising genotypes suited for the climatic and edaphic conditions of Jharkhand.

2. MATERIALS AND METHODS

The experiment was conducted during 2018 and 2019 in the month of June- July each year. The experimental site was Birsa Agricultural University, Kanke, Ranchi, located at 23°26'30" N latitude and 85°18'20" E longitude in Chhota Nagpur plateau, situated in north eastern part of India and at an altitude of between 646 m above the mean sea level in Jharkhand. The soil of the site is lateritic, developed from granite-gneiss, sandy loam in texture, sedentary in nature and well drained with low water holding capacity and poor consistency. The general climate of the region is classified as 'sub humid megathermal' with mean daily temperature of about 24.2°C. The mean relative humidity is about 70.88% with it ranges from 57.0 to 92.0%. The monsoon breaks out in the middle of June and last till mid-October. The average annual rainfall of this area is approximately 1400 mm which is mostly erratic, punctuated with occasional dry spells.

The experimental materials comprised of twenty-five genotypes of Kalmegh, for which seeds were collected from its natural habitat across six states of India and NBPGR, New Delhi including wild and cultivated varieties. Out of 25 Kalmegh genotypes, 4 each were collected from Jharkhand, Chhattisgarh, Madhya Pradesh, Karnataka each, 6 from Orissa, 2 from NBPGR and one from Gujarat. Care was taken to maintain a geographical distance of about 8–10 km between each collection site in order to reduce genetic similarity in genotypes and to minimize sampling error while interpreting the data. Genotypes collection of Kalmegh was organized as an assemblage of seeds collected through explorations and established in nursery in May–June 2018 at Research Farm of Birsa Agricultural University, Ranchi. While collecting plants from their natural habitats stratified random sampling method (Moss and Guarino, 1995) was followed. Collected seed samples were germinated, raised in polytubes and maintained under identical growing conditions in experimental area. Forty-five days old seedlings were transplanted in field at a spacing of 30×30 cm^2 (Table 1).

Table 1: Details of Kalmegh genotypes used as experimental materials

Sl. No.	State / Institution	Genotypes and location
1.	Jharkhand	T_1: JHAP$_1$ (Ranchi East Forest Division), T_2: JHAP$_2$ (Hazaribag Forest Division), T_3: JHAP$_3$ (Ramgarh Forest Division), T_4: JHAP$_4$ (Khunti)
2.	Orissa	T_5: OAP$_1$ (Angul), T_6: OAP$_2$ (Nayagarh), T_7: OAP$_3$ (Puri), T_8: OAP$_4$ (Cuttuck), T_9: OAP$_5$ (Dhenkanal), T_{10}: OAP$_6$ (Keonjhar)
3.	Chhattisgarh	T_{11}: CHAP$_1$ (Dhamtari), T_{12}: CHAP$_2$ (Sonpur Road, Dhamtari), T_{13}: CHAP$_3$ (Bastar), T_{14}: CHAP$_4$ (Rajnandgaon)
4.	Madhya Pradesh	T_{15}: MPAP$_1$ (Amarkantak), T_{16}: MPAP$_2$ (Vindhyan Range, Mandwa), T_{17}: MPAP$_3$ (Rewa), T_{18}: MPAP$_4$ (Kanha)
5.	Karnataka	T_{19}: KAP$_1$ (Bijapur), T_{20}: KAP$_2$ (Mysore Madikeri Road), T_{21}: KAP$_3$ (Mysore Ooty Road), T_{22}: KAP$_4$ (IIHR, Bangalore)
6.	NBPGR, New Delhi	T_{23}: IC 111286 (New Delhi), T_{24}: IC 471890 (New Delhi)
7.	Gujarat	T_{25}: GAP$_1$ (Junagarh)

Germination study of all the 25 genotypes of Kalmegh was undertaken in polythene tubes (13×7 cm^2) by establishing nursery. Experiment was conducted in Completely Randomized Design with 25 treatments replicated thrice by following the procedure outlined by Panse and Sukhatme (1985). Number of polytubes kept in a treatment was 50 and in each polytube two seeds of Kalmegh were sown. Finely powdered, sieved farm yard manure, sand and soil in the ratio of 1:2:1 was taken and filled into poly tubes. The mixture was treated with carbendazim (0.2%) before seed sowing. Data on germination trend was recorded from initiation to completion of germination (Kumar et al., 2010) and based upon this different germination parameters was calculated.

The details of observations recorded on different seed germination parameters were days to initiate germination, days taken for 50% germination, days taken for completion of germination, rate of germination (reciprocal of the number of days to complete germination; Bewley and Black, 1982), germination period, germination energy (percentage by number of seeds in a sample that have germinated up to the time when the number of seeds germinating per day reaches its peak; Khanna, 1993), germination percentage (Czabator, 1962), shoot and root length of seedlings at time of transplantation, root-shoot ratio of seedlings and seedling vigour index (Abdul-Baki and Anderson (1973). Collected data on seed germination parameters was subjected to analysis of variance (ANOVA) and significant difference at 5% and 1% level was used to compare the means of different test parameters for all the genotypes as described by Panse and Sukhatme (1985). Standard error of mean, coefficient of variation and critical difference was computed by the procedure given by Singh and Chaudhary (1985). Germination percentages (original values) were transformed into arc sine root transformation used for statistical analysis.

3. RESULTS AND DISCUSSION

3.1. *Germination parameters of kalmegh seeds in nursery*

Seed germination parameters like mean number of days taken for initiation of germination, 50% of final germination and completion of seed germination by different Kalmegh genotypes is presented in Table 2.

Table 2: Mean number of days for initiation of germination, 50% of final germination and completion of seeds germination taken by different Kalmegh genotypes in nursery

Treatments	Days taken for initiation of seed germination		Days taken for 50% of final seed germination		Days taken for completion of seed germination	
	1st year	2nd year	1st year	2nd year	1st year	2nd year
T_1 (JHAP$_1$)	7.00	6.67	10.67	9.67	10.33	11.00
T_2 (JHAP$_2$)	7.00	7.67	10.33	9.67	10.33	9.33
T_3 (JHAP$_3$)	7.00	6.67	9.00	9.33	7.33	8.33
T_4 (JHAP$_4$)	7.00	8.00	9.00	10.67	4.67	6.67
T_5 (OAP$_1$)	8.00	10.00	12.33	13.67	10.33	7.00
T_6 (OAP$_2$)	6.00	6.00	10.67	8.67	12.33	11.00
T_7 (OAP$_3$)	8.00	7.67	11.00	9.67	10.00	12.00
T_8 (OAP$_4$)	8.00	6.67	10.00	8.67	9.33	10.33
T_9 (OAP$_5$)	7.00	8.00	11.00	10.33	9.33	8.00
T_{10} (OAP$_6$)	9.00	7.67	10.33	9.67	7.67	7.33
T_{11} (CHAP$_1$)	7.00	6.33	12.00	11.00	9.33	9.67
T_{12} (CHAP$_2$)	7.00	7.00	10.00	9.00	5.33	6.67
T_{13} (CHAP$_3$)	7.00	7.67	10.67	9.33	10.33	8.33

Table 2: Continue...

Treatments	Days taken for initiation of seed germination		Days taken for 50% of final seed germination		Days taken for completion of seed germination	
	1st year	2nd year	1st year	2nd year	1st year	2nd year
T_{14} ($CHAP_4$)	7.33	8.00	10.00	9.00	6.33	6.00
T_{15} ($MPAP_1$)	7.33	7.00	9.00	9.33	6.67	10.00
T_{16} ($MPAP_2$)	6.33	7.00	10.33	9.00	11.67	9.00
T_{17} ($MPAP_3$)	6.33	5.67	10.00	8.00	8.33	7.67
T_{18} ($MPAP_4$)	6.00	6.00	10.67	9.00	10.67	10.00
T_{19} (KAP_1)	7.00	6.00	8.67	8.33	5.00	6.67
T_{20} (KAP_2)	6.33	5.67	10.00	8.00	9.33	8.33
T_{21} (KAP_3)	7.00	6.67	9.00	8.00	8.33	7.33
T_{22} (KAP_4)	6.33	5.33	10.00	8.33	10.33	11.00
T_{23} (IC 111286)	7.33	5.67	10.00	9.00	9.33	9.67
T_{24} (IC 471890)	7.00	6.67	10.00	9.00	8.67	9.33
T_{25} (GAP_1)	6.33	6.00	10.33	9.00	10.00	10.00
Grand mean	6.55	6.87	10.20	9.33	8.85	8.79
SEm±	0.19	0.20	0.35	0.53	0.53	0.33
CD (p=0.05)	0.54	0.56	1.01	1.50	1.52	0.94
CD (p=0.01)	0.70	0.73	1.31	1.94	1.97	1.22
CV (%)	4.65	4.99	5.99	9.74	10.43	6.45

3.2. Number of days for initiation of seed germination

During 2018–19, the number of days taken by Kalmegh seeds to initiate germination varied from 6.00 days (OAP_2 and $MPAP_4$) to 9.00 days (OAP_6) and highly significant difference was observed among them. 11 Kalmegh genotypes took 7 days to initiate seed germination. The maximum variability was noticed in Orissa genotypes, while no or little variation was recorded in Jharkhand and Chhattisgarh genotypes. The grand mean of all the 25 Kalmegh genotypes was calculated as 6.55 days, which was little bit less (6.87 days) than of 2019–20. In 2019–20, the minimum value of days to initiate seed germination was observed in KAP_4 (5.33 days) and the maximum in OAP_1 (10.00 days). In 2019–20, many genotypes took lesser days, while some genotypes took more time for it. The grand mean of all the 25 Kalmegh genotypes to initiate seed germination was calculated as 6.71 days. Perusal of seed germination parameters in nursery showed that the seeds of most the Kalmegh genotypes initiated their germination between 6–7 days. All genotypes except OAP_1 and OAP_6 took 6–7 days for initiation by seed germination, while these two genotypes took nearly 9 days to initiate seed germination. All the Karnataka genotypes took least number of days among the selected genotypes to initiate seed germination.

Hartmann and Kester (1983) highlighted the role of temperature and humidity in softening the seed coats, removal of inhibitors and reducing the time required for germination and increased germination percentage. Kumar et al. (2011) also recorded number of days for initiation of Kalmegh seed germination as 5–6 days in nursery. They found days to initiation of seed germination of Kalmegh as 3rd days from seed sowing at 30°C and they noticed maximum seed germination on 7th day at 25°C. They revealed variation in seed germination of Kalmegh at different level of temperature. Mean seed germination percentage over the temperature varied from 17.55 (15°C)–71.14 (25°C). Highest mean germination percentage (71.14) was observed at 25°C followed by 30°C, 20°C, 35°C and 15°C. Talei et al. (2012) recorded initiation of seed germination of Kalmegh seeds as three days with germination percentage between 34.33–94.33% under different scarification treatment. They found seed coat protein extracts significantly decreased the germination percentage and rate of germination.

3.3. Number of days for 50% of final seed germination

The number of days to achieve 50% of final seed germination by different Kalmegh genotypes during 2018–19 varied from 8.67 days (KAP_1)–12.33 days (OAP_1) and different genotypes showed highly significant difference among them. Nearly 3–4 days were taken by the genotypes to achieve 50% germination of final germination count. Grand mean of all the Kalmegh genotypes was calculated as 10.20 days during 2018–19, while in 2019–20, lesser value (9.33 days) was recorded. In 2019–20, the minimum value to achieve 50% germination of final germination count was recorded as 8.00 days for $MPAP_3$, KAP_2 and KAP_3 while its maximum value was recorded in case of OAP_5 (13.67 days). The pooled mean of both the year to achieve 50% of final germination count by different Kalmegh genotypes was calculated as 9.77 days. Just after the initiation of germination, on the average basis, three more days was required to achieve 50% of final seed germination by most of the genotypes. However, two genotypes OAP_1 and $CHAP_1$ took 4–5 days to achieve it, but in case of OAP_6, it was observed as less than one day.

3.4. Number of days for completion of seed germination

During 2018–19, the minimum number of days to complete seed germination was recorded for $JHAP_4$ (4.67 days) and the maximum for OAP_2 (12.33 days) and different Kalmegh genotypes showed highly significant difference among them. Grand mean for all 25 Kalmegh genotypes for the year 2018–19 was calculated as 8.85 days, which was nearly same for the year 2019–20 i.e. 8.79 days. In 2019–20, range of days for completion of seed germination varied from 6.00 days ($CHAP_4$) to OAP_3 (12.00 days) and in this year also, highly significant difference was observed between different Kalmegh genotypes. The grand pooled mean of number of days for completion of seed germination by different Kalmegh genotypes was calculated as 10.00 days with its range 5.67 days ($JHAP_4$)–11.67 days (OAP_2) and different genotypes showed highly significant difference among them. After the initiation of seed germination, the germination process was found completed between 7–9 days for most of the genotypes, however some genotypes like $JHAP_4$, $CHAP_2$, $CHAP_4$, KAP_1 took less than one week to complete it. Raven et al. (2005) highlighted the presence of certain plant hormones like abscisic acid, which inhibits germination and causing physiological dormancy in seeds. Kumar et al. (2011) also recorded number of days for completion of germination from 7–9 days of Kalmegh.

Seed germination parameters like mean number of days for germination period, rate of germination and germination energy by different Kalmegh genotypes in nursery is presented in Table 3.

3.5. Number of days for germination period

The germination period of different Kalmegh genotypes during 2018–19 varied from 11.67 days ($JHAP_4$) to 18.33 days (OAP_1 and OAP_2) and they showed highly significant relation among them. 18 Kalmegh genotypes took more than 15 days to complete their germination period. Grand mean of all 25 Kalmegh genotypes recorded as 15.84 days during 2018–19, however in 2019–20, little less value of germination period was observed (15.67 days). In 2019–20, the germination period of different Kalmegh genotypes ranged from 12.67 days (KAP_1) to 19.67 days (OAP_3) and different genotypes showed highly significant relation among them. The grand mean of all 25 Kalmegh genotypes to complete the germination period was calculated as 10.76 days. The time required from seed sowing to completion of seed germination was observed more than two weeks for most of the genotypes. Nearly 12 genotypes showed their germination period between 16–18 days, while four genotypes $JHAP_4$, $CHAP_2$, $CHAP_4$ and KAP_1 recorded lesser germination period (12–13 days).

Saraswathy et al. (2004) also reported number of days required for germination period of Kalmegh seeds as 18 days. Sanjutha et al. (2008) also reported number of days for completion of Kalmegh seed germination from seed sowing as 18 days. Kumar et al. (2011) recorded a germination period of Kalmegh seeds from 7 to 9 days at different temperature range of 20°C–35°C and revealed that days 5–6 and days 7–9 after seed sowing is the ideal for first and final count respectively for seed germination of Kalmegh. Kumari et al. (2012) revealed number of days required for germination period of Kalmegh seeds as 16 days. Among all the genotypes, Karnataka genotypes took least number of days for germination period; however, the genotypes of Orissa took highest number of days to complete it. Perusal

Table 3: Mean number of days for germination period, rate of germination and germination energy taken by different Kalmegh genotypes in nursery

Treatments	Germination period of seeds (days)		Rate of germination of seeds		Germination energy of seeds (%)	
	1st year	2nd year	1st year	2nd year	1st year	2nd year
T_1 ($JHAP_1$)	17.33	17.67	0.097	0.090	57.00	14.00
T_2 ($JHAP_2$)	17.33	17.00	0.097	0.107	29.67	17.00
T_3 ($JHAP_3$)	14.33	14.67	0.145	0.120	18.67	8.67
T_4 ($JHAP_4$)	11.67	14.33	0.217	0.150	10.00	9.67
T_5 (OAP_1)	18.33	17.00	0.099	0.142	13.67	5.00
T_6 (OAP_2)	18.33	17.00	0.081	0.090	30.33	18.33
T_7 (OAP_3)	18.00	19.67	0.101	0.080	14.00	8.67
T_8 (OAP_4)	17.33	17.00	0.107	0.097	33.33	22.00
T_9 (OAP_5)	16.33	16.00	0.107	0.125	15.67	9.33
T_{10} (OAP_6)	16.67	15.00	0.131	0.136	39.67	30.33
T_{11} ($CHAP_1$)	16.33	15.67	0.108	0.103	8.33	6.00
T_{12} ($CHAP_2$)	12.33	13.67	0.189	0.150	30.67	27.33
T_{13} ($CHAP_3$)	17.33	16.00	0.097	0.120	26.67	15.33
T_{14} ($CHAP_4$)	12.67	14.00	0.161	0.166	26.33	18.67
T_{15} ($MPAP_1$)	14.00	17.00	0.150	0.100	13.67	9.00
T_{16} ($MPAP_2$)	18.00	16.00	0.085	0.110	44.67	32.00
T_{17} ($MPAP_3$)	14.67	13.33	0.151	0.131	65.33	31.33
T_{18} ($MPAP_4$)	16.67	16.00	0.093	0.100	40.33	25.67
T_{19} (KAP_1)	12.00	12.67	0.200	0.150	12.33	16.00
T_{20} (KAP_2)	15.67	14.00	0.111	0.120	38.67	21.67
T_{21} (KAP_3)	15.33	14.00	0.153	0.136	31.67	23.33
T_{22} (KAP_4)	16.67	16.00	0.097	0.090	20.00	17.33
T_{23} (IC 111286)	16.67	15.33	0.108	0.103	47.33	27.00
T_{24} (IC 471890)	15.67	16.67	0.117	0.108	40.67	22.33
T_{25} (GAP_1)	16.33	16.00	0.102	0.100	43.67	19.33
Grand mean	15.84	15.67	0.12	0.12	30.11	18.21
SEm±	0.68	0.87	0.01	0.01	1.88	1.10
CD (p=0.05)	1.95	2.49	0.02	0.01	5.36	3.15
CD (p=0.01)	2.53	3.23	0.03	0.02	6.96	4.08
CV (%)	7.47	9.67	11.26	7.21	10.82	10.49

of seed germination parameters of Kalmegh seeds in nursery revealed that out of the days taken to complete germination period (15.70 days), nearly 43% of the time was required for seed germination initiation (6.71 days) and 62% time (9.77 days) to achieve 50% of final germination count. Once the seed started germination, it took 8.82 days to complete seed germination i.e. 57% time was required from initiation to completion of germination.

3.6. Rate of germination of seeds

During 2018–19, the rate of germination of seeds of different Kalmegh genotypes varied highly significantly and its minimum value was recorded in OAP_2 (0.081) and the maximum in $JHAP_4$ (0.217). The grand mean of all 25 Kalmegh genotypes had higher recorded value in 2018–19 (0.124) than of 2019–20 (0.117). In 2019–20, again different Kalmegh genotypes showed highly significant difference among them and the maximum value was recorded for $JHAP_4$, $CHAP_2$ and KAP_1 (0.150) and the minimum for OAP_3 (0.086). The grand mean of all the 25 Kalmegh genotypes was calculated as 0.121. In nursery, nearly 12% of the seeds found germinated per day, but less than 10% germination rate was recorded for $JHAP_1$, OAP_2, OAP_3, $MPAP_2$, $MPAP_4$ and KAP_4. Four genotypes namely $JHAP_4$, $CHAP_2$, $CHAP_4$ and KAP_1 showed higher rate of germination (more than 0.16), while for rest of the genotypes, it lied between 0.08–0.12.

Rate of germination is the length of time taking by seeds to germinate, useful for calculating the seed requirements for a given area or desired number of plants. In the early stages the rate of germination is slowed down by deficiencies of water and oxygen in the embryo and the overall rate depends not only on the rate of the chemical process, but also on the rates of diffusion of water and oxygen through the seed coat. Roberts (1988) mentioned that temperature can affect the percentage and rate of germination through its effects on loss of dormancy and the germination process itself. Optimum germination temperature was reported to be 30°C for Kalmegh seeds by Chaudhary (1975) and Baskin and Baskin (2001). Kumar et al. (2011) inferred 25°C is the best temperature for higher germination percentage and energy in Kalmegh seeds. They found significant reduction in germination percentage and energy at above or below at 25°C temperature is an indication of threshold high and low cut-off between studied ranges of temperature. Highest germination rate was observed around 25°C with its range varied from 10°C to 30°C.

3.7. Germination energy of seeds

During 2018–19, the germination energy of Kalmegh genotypes varied from 8.88% ($CHAP_1$) to 65.33% ($MPAP_3$) and different genotypes showed highly significant difference among them. Genotypes like $JHAP_1$ (57.00%), $MPAP_2$ (44.67%), $MPAP_3$ (65.33%), $MPAP_4$ (40.33%), IC111286 (47.33%), IC471890 (40.67%) and GAP_1 (43.67%) gave good germination energy. During 2019–20, sharp decrease in germination energy was observed for all the genotypes. During 2018–19, the mean of germination energy of all the 25 genotypes was calculated as 30.11% and it was only 18.21% in 2019–20. In 2019–20, the maximum germination energy was recorded for $MPAP_2$ (32.00%) and the minimum in OAP_1 (5.00%). $CHAP_1$ gave minimum value (7.17%) while $MPAP_3$ gave maximum value (48.33%) and different Kalmegh genotypes showed highly significant difference among them with grand mean of 24.16%. Germination energy is a measure of the speed of germination and hence, it is assumed, to be responsible for the vigor of the seed and of the seedling which it produces. Only those seeds which germinate rapidly and vigorously under the favorable situation are likely to be capable of producing vigorous seedlings in field conditions (Czabator, 1962).

Kumar et al. (2011) recorded mean germination energy of Kalmegh seeds as 23.65%. At the peak rate of seed germination, nearly 25% of seeds found germinated on average basis of all the 25 genotypes, but some genotypes, like $CHAP_1$, OAP_1 and $JHAP_4$ gave very low rate of germination energy. High difference in seed germination percentage was recorded even in genotypes of same state like 25.50% for $JHAP_4$ and 83.17% for $JHAP_1$, 21.84% for OAP_1 and 83.33% for OAP_6, 27.67% for $MPAP_1$ and 91.00% for $MPAP_4$.

Seed germination parameters like mean germination percentage, shoot and root length of different Kalmegh genotypes at the time of transplantation is presented in Table 4.

3.8. Germination percentage of seeds

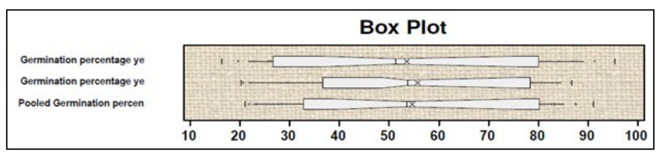
During 2018–19, highly significantly difference was observed in germination percentage of different Kalmegh genotypes and the maximum value was observed with $MPAP_3$ (95.33%) and the minimum with $JHAP_4$ (16.33%). Six genotypes namely $JHAP_1$ (87.67%), OAP_6 (82.33%), $MPAP_2$ (87.00%), $MPAP_3$ (95.33%), IC111286 (84.00%) and GAP_1 (91.33%) gave excellent germination percentage. The mean of all the 25 Kalmegh genotypes in first year was calculated as 53.56%, while in second year, slightly higher value of germination percentage (55.71%) was observed. During 2019–20, the range of germination percentage varied from 20.33% (OAP_5) to 86.67% ($MPAP_3$) with highly significant value among them. The grand mean of germination percentage for both the year was calculated as 54.64% and its range lied between 21.00% ($CHAP_1$) to 91.00% ($MPAP_3$).

Baskin and Baskin (2001) mentioned that for germination

Table 4: Mean germination percentage, shoot and root length of different Kalmegh genotypes in nursery

Treatments	Germination percentage of seeds (%)		Shoot length (cm) of seedlings at transplantation stage		Root length (cm) of seedlings at transplantation stage	
	1st year	2nd year	1st year	2nd year	1st year	2nd year
T_1 ($JHAP_1$)	87.67	78.67	5.69	7.55	9.70	9.17
T_2 ($JHAP_2$)	52.33	55.33	3.57	9.87	8.36	12.27
T_3 ($JHAP_3$)	36.00	48.33	3.26	6.67	7.42	15.07
T_4 ($JHAP_4$)	16.33	34.67	3.84	3.93	6.94	8.90
T_5 (OAP_1)	23.00	20.67	2.80	4.17	7.86	7.00
T_6 (OAP_2)	55.00	53.33	2.46	5.33	8.38	10.56
T_7 (OAP_3)	27.00	29.67	2.17	9.60	5.55	13.07
T_8 (OAP_4)	61.33	64.00	2.70	7.53	7.88	11.63
T_9 (OAP_5)	26.33	20.33	2.86	5.10	6.67	8.90
T_{10} (OAP_6)	82.33	84.33	3.46	8.67	12.08	13.17
T_{11} ($CHAP_1$)	19.67	22.33	4.38	4.87	10.57	8.50
T_{12} ($CHAP_2$)	45.67	53.67	3.13	7.57	9.22	12.27
T_{13} ($CHAP_3$)	51.33	53.33	5.34	4.82	11.60	9.26
T_{14} ($CHAP_4$)	38.00	38.67	4.34	6.81	7.74	7.79
T_{15} ($MPAP_1$)	26.00	29.33	3.32	8.33	8.87	12.50
T_{16} ($MPAP_2$)	87.00	78.33	4.88	13.13	10.50	13.77
T_{17} ($MPAP_3$)	95.33	86.67	7.02	8.80	11.28	16.99
T_{18} ($MPAP_4$)	77.67	78.33	5.47	9.37	11.80	11.73
T_{19} (KAP_1)	25.67	48.67	4.13	8.25	9.97	9.63
T_{20} (KAP_2)	50.67	61.33	6.36	5.55	13.14	6.88
T_{21} (KAP_3)	54.33	50.33	6.87	6.57	11.41	9.23
T_{22} (KAP_4)	47.33	59.67	7.50	7.20	10.94	11.09
T_{23} (IC 111286)	84.00	78.33	5.96	7.85	12.51	12.00
T_{24} (IC 471890)	77.67	80.67	5.89	5.75	11.33	7.97
T_{25} (GAP_1)	91.33	83.67	7.68	8.92	13.15	12.52
Grand mean	53.56	55.71	4.60	7.29	9.79	10.87
SEm±	1.77	1.48	0.29	0.41	0.47	0.56
CD (p=0.05)	5.06	4.21	0.83	1.16	1.33	1.61
CD (p=0.01)	6.56	5.47	1.07	1.51	1.73	2.08
CV (%)	6.44	5.26	10.90	9.68	8.27	8.97

percentage, the difference between high and low temperature must be 10°C or more. Saraswathy et al. (2004) also reported the maximum germination percentage of Kalmegh seeds as 84.00%. Sabu (2006) reported high germination percentage (93.60%) in Kalmegh seeds of Tamil Nadu but low germination percentage in Kerala and Maharashtra genotypes (42.00% and 33.50% respectively). Kumar et al. (2011) recorded mean germination percentage of Kalmegh seeds as 94.62%. Talei et al. (2012) found that due to hard seed-coating layer in Kalmegh seeds provides a combination of physical and physiological dormancy that prevents water uptake by the embryo resulting in lower germination percentage. Kumari et al. (2012) observed highest germination (99.2% and 88.3%) in Kalmegh variety CIM-Megha and wild collection, respectively after treatment with GA_3 (200 ppm). Studies on seed germination revealed that freshly harvested seeds seldom germinated and a certain period (3 months) of storage is needed with concomitant reduction in moisture content from 17.4 to 13.7% to obtain maximum germination. Even prolonged storage up to 9 months with the subsequent decrease in moisture level to less than 10.0% did not cause significant reduction in percentage germination. Results suggest that the seeds of Kalmegh belong to orthodox type where considerable reduction in internal moisture content without loss of viability is noticed. Apart from the observed differences in germination percentage due to moisture levels, possible genotypic effects is also evident as reported by Singh and Ahmad (1997).



Graph 1: Box plot analysis of germination percentage of Kalmegh seeds in nursery

Graph 1 represents box plot analysis of germination percentage of Kalmegh seeds in nursery. Positive skewness was observed in both the year of experimentation. Moreover, for both the year, value of germination percentage of most of Kalmegh genotypes lied between 50th–75th percentile.

3.9. Shoot length of seedlings at transplantation stage

The shoot length of Kalmegh seedlings at transplantation stage varied from 2.17 cm (OAP_3) to 7.68 cm (GAP_1) with highly significant difference among the genotypes in 2018–19, while in year 2019–20, the maximum value was recorded in case of $MPAP_2$ (13.13 cm) and the minimum in $JHAP_4$ (3.93 cm). Grand mean of all 25 Kalmegh genotypes during 2018–19 was calculated as 4.60 cm, while in 2019–20, it was 7.29 cm. So almost double shoot length was recorded in second year of experimentation than first year. Mean data of both the year of shoot length recorded its range from 3.49 cm (OAP_1) to 9.01 cm ($MPAP_2$) and highly significant difference was observed among the genotypes. Five genotypes like $MPAP_2$, $MPAP_3$, $MPAP_4$, KAP_4 and

GAP_1 gave maximum length of shoot (more than 7 cm), however four genotypes such as $JHAP_4$, OAP_1, OAP_2 and OAP_5 gave lowest shoot length (less than 4 cm).

3.10. Root length of seedlings at transplantation stage

During 2018–19, the maximum value of root length at transplantation stage was recorded in GAP_1 (13.15 cm) and minimum in OAP_3 (5.55 cm) with the grand mean of all 25 Kalmegh genotypes as 9.79 cm, while in 2019–20, the maximum value was recorded as 16.99 cm ($MPAP_3$) and the minimum as 7.00 cm (OAP_1) with its grand mean 10.87 cm. So, at seedling stage, the root length of Kalmegh seedlings was found almost double than its respective shoot length. In both the year, highly significant difference was observed among different Kalmegh genotypes. Pooled mean for both the year of root length of Kalmegh genotypes was recorded as 10.33 cm and again highly significant difference was observed between them. Five genotypes like OAP_6, $MPAP_2$, $MPAP_3$, IC 111286 and GAP_1 gave maximum root length (more than 12 cm), while lowest root length (less than 8 cm) was recorded in case of $JHAP_4$, OAP_1, OAP_5 and $CHAP_1$. At initial stage of vegetative growth, the root length was almost double to its shoot length, which helps in the better establishment of seedlings after transplanting.

Seed germination parameters like mean root-shoot ratio, seedling vigour index of different Kalmegh genotypes at transplantation stage is presented in Table 5.

3.11. Root-shoot ratio of seedlings at transplantation stage

During 2018–19, the root-shoot ratio of Kalmegh genotypes varied from 1.48 (KAP_4) to 3.55 (OAP_6), while in 2019–20, the maximum value was recorded in $JHAP_3$ and $JHAP_4$ (2.28) and the minimum in $MPAP_2$ (1.05). In both the year, highly significant difference was observed between different Kalmegh genotypes. In 2019–20, all Kalmegh genotypes except $MPAP_3$ gave lesser value of root-shoot ratio. For balanced seedlings, root-shoot ratio near about one is preferred, so it may be inferred that in second year, healthier seedlings of Kalmegh were produced. Nearly 40% decrease was observed in the value of root-shoot ratio of second year than first year. Grand mean of all the 25 Kalmegh genotypes during 2018–19 was recorded as 2.31, while in 2019–20, it was 1.55. The pooled mean of root-shoot ratio of all the 25 Kalmegh genotypes was recorded as 1.93 with highly significant difference among them. High value of root-shoot ratio (1.93) was calculated for all the genotypes, but as per balanced seedling requirement, $JHAP_1$, $CHAP_4$, KAP_4, KAP_3 and GAP_1 was found best as they have their root-shoot ratio near to 1.50.

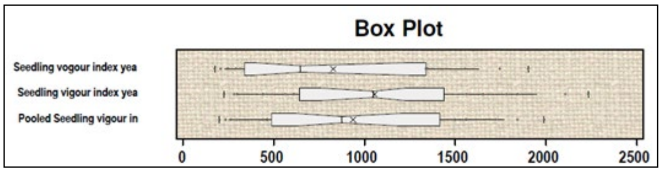
3.12. Seedling vigour index of Kalmegh genotypes at transplantation stage

During 2018–19, the maximum value of seedling vigour index was recorded for GAP_1 (1901.79) and the minimum for $JHAP_4$ (176.03), while in year 2019–20, its maximum value was recorded for $MPAP_3$ (2232.58) and the minimum for OAP_1 (227.83). In both the year, different Kalmegh genotypes showed highly significant difference among them. Grand mean value of all the 25 Kalmegh

Table 5: Mean root-shoot ratio, seedling vigour index of different Kalmegh genotypes in nursery

Treatments	Root-shoot ratio of seedlings at transplantation stage		Seedling vigour index of seedlings at transplantation stage	
	1st year	2nd year	1st year	2nd year
T_1 ($JHAP_1$)	1.70	1.22	1349.38	1313.73
T_2 ($JHAP_2$)	2.34	1.24	624.29	1229.18
T_3 ($JHAP_3$)	2.31	2.28	384.72	1049.87
T_4 ($JHAP_4$)	1.82	2.28	176.03	442.55
T_5 (OAP_1)	2.82	1.72	245.26	227.83
T_6 (OAP_2)	3.46	2.00	596.38	854.39
T_7 (OAP_3)	2.57	1.37	208.53	673.00
T_8 (OAP_4)	3.22	1.54	648.87	1233.87
T_9 (OAP_5)	2.33	1.75	250.92	282.99
T_{10} (OAP_6)	3.55	1.53	1279.95	1844.17
T_{11} ($CHAP_1$)	2.43	1.76	293.78	299.33
T_{12} ($CHAP_2$)	3.00	1.62	563.90	1060.73
T_{13} ($CHAP_3$)	2.17	1.94	869.70	746.26
T_{14} ($CHAP_4$)	1.82	1.14	459.04	565.07
T_{15} ($MPAP_1$)	2.75	1.50	316.70	611.80
T_{16} ($MPAP_2$)	2.19	1.05	1337.77	2105.57
T_{17} ($MPAP_3$)	1.60	1.94	1745.17	2232.58
T_{18} ($MPAP_4$)	2.18	1.26	1340.93	1653.00
T_{19} (KAP_1)	2.46	1.12	361.80	865.88
T_{20} (KAP_2)	2.07	1.27	987.86	762.40
T_{21} (KAP_3)	1.68	1.41	992.97	799.88
T_{22} (KAP_4)	1.48	1.54	872.60	1086.45
T_{23} (IC 111286)	2.10	1.53	1551.48	1560.55
T_{24} (IC 471890)	1.93	1.40	1337.56	1107.30
T_{25} (GAP_1)	1.73	1.46	1901.79	1782.72
Grand mean	2.31	1.55	819.32	1055.64
SEm±	0.14	0.10	51.70	62.94
CD (p=0.05)	0.39	0.27	147.30	179.51
CD (p=0.01)	0.51	0.36	191.32	232.89
CV (%)	10.25	10.65	10.82	10.33

genotypes recorded lesser value in first year (819.32) than of second year (1055.64). Pooled mean of seedling vigour index for both the year was calculated as 937.48. The genotypes which showed low germination percentage gave low value of shoot and root length at transplantation stage as well as low seedling vigour index. Germination and establishment of seedlings are critical phases in the life of a plant when they are the most vulnerable to injury, disease and water stress (Raven et al., 2005).



Graph 2: Box plot analysis of seedling vigour index of Kalmegh seedlings under field conditions

Graph 2 represents box plot analysis of seedling vigour index of Kalmegh genotypes in nursery. In first year, the mean value of seedling vigour index of all the 25 Kalmegh genotypes was much higher than its medium value i.e. highly positive skewness was observed. However, in second year slightly less positive skewness was observed. In first year, the value of seedling vigour index of most of the Kalmegh genotypes lied between 50th–75th percentile, but its distribution was found almost equal in second year i.e. almost same in 25th–50th percentile and 50th–75th percentile.

4. CONCLUSION

Eight genotypes of Kalmegh namely $JHAP_1$, OAP_6, $MPAP_2$, $MPAP_3$, $MPAP_4$, IC111286, IC471890 and GAP_1 showed excellent germination percentage. The germination percentage was not found correlated with its geographical distribution.

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