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Germination Optimization Study of Five Indigenous Fabaceae Tree Species from Burundi Miombo Woodlands

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Abstract
Burundi miombo woodlands is typically forest established on harsh environment by the means of its mycorrhizal status and therefore interesting for its socio-economical and ecological role by protecting soil and producing edible mushrooms. Due to the population pressure on these ecosystems, the present study aims to understand the domestication process of some key species. We investigate the effect of imbibition time (0, 6, 12 and 24 hours) and of germination temperature (20, 28 and 35 ° C) on the germination parameters of five indigenous Fabaceae tree species, IFTS. Results show that all seed species present no-dormancy. The final germination percentage, FGP is about 100% except *B. bussei* whose optimal FGP reaches nearly 80%. This suggests viability conservation of seeds after six months of collection and storage. The mean germination time and the time to 50% of seed germination (T_{50}) range from 5.30±0.50 to 2.06±0.16 days and from 4.72±0.25 to 1.57±0.06 days respectively. Germination temperature and imbibition time influenced differently analyzed germination parameters. We propose to consider the optimum imbibition time of six hours except for *P. angolensis* and *B. microphylla*. The first doesn't require imbibition and the last requires 12 hours of imbibition. Such study reveals relative less restrictive germination conditions and provides key useful informations for forestry and nursery management. The germination of IFTS seeds is not tedious and can be carried out at regional or local level (accessible to village population) and at lower cost. Due to their mycorrhizal status, it would be interesting to couple future investigations on plant production with their artificial inoculation.

Keywords: Germination, Fabaceae, indigenous species, reforestation, domestication, miombo woodlands

1. Introduction
Burundi (central-east Africa) is ranked second most densely populated in Africa with 321 hab/km^2 [1]. This situation causes a great pressure on natural ecosystems whose relics are found mostly in protected areas. At global level, FAO [2] reported that 25 percent of planted forest area is made up with exotic species whilst Burundi has been classified among countries where planted forests are almost exclusively exotic. Based on our field observations, no indigenous species is used in reforestation program in Burundi. Moreover, Bigirimana et al. [3] have shown that in african cities instead of Bujumbura, urbanization affect indigenous species to be replaced by exotic ones. Inexorably, due to the anthropization and urbanization phenomena, exotic species are replacing indigenous ones and raises the conservation issue of biodiversity as a heritage. Are really countries aware or convinced of issues of biodiversity conservation? Are there established priorities for the purpose of promoting species and ecosystem conservation? Notwithstanding, scientists could anticipate policy-makers by proposing

priorities and conservation techniques to understand the domestication process of indigenous species particularly those with high socio-economic value [4].

Miombo woodlands corresponds to Zambezian region, a wide african region of 2 592 500 km^2 with only 0.1% for Burundi [5]. Thus this ecosystem constitutes a "pearl of Burundi" from its ecological and socio-economical point of view. In fact, on one hand, this ecosystem is the most productive of edible mushrooms in the region by means of mycorrhizal symbiosis, contributing consistently in socio-economic tissue of rural population and strengthening their livelihood [6]. In the other hand this mycorrhizal association allow miombo woodlands to established on harsh environmental conditions [7], therefore interesting in current context of climate change and soil degradation. Their conservation and restoration is crucial.

However, due to the demographic pressure of Burundi population, miombo woodlands as other natural ecosystems are continuously facing illegal exceeding limits for agriculture, levy wood for construction and energy. When the recovery of forest area is carried out, restoration is made up by exotic tree species. This leads to create exclusively an "exotic tree species landscape" to detriment of the natural landscape. It is then, high time to investigate and master agronomic tools of domestication of indigenous tree species like miombo woodlands.

The knowledge of the germination requirements of species constitutes the key-major factor of artificial regeneration and restoration and is prior to cultivation process, selection and improvement of indigenous species [8-10]. This study aims to provide a technical tool to agronomists and forestry managers for their activities of afforestation and reforestation. We set up to optimize seed germination of five indigenous Fabaceae tree species, IFTS occurring mainly in Burundi miombo woodlands. No previous study has investigated any aspect of their domestication except *Julbernardia globiflora* and *Brachystegia microphylla* for which some indications were reported.

2. **Materials and methods**

2.1. Plant material

Seeds of five indigenous Fabaceae tree species, IFTS (Table 1) were collected from two Burundi miombo woodlands under protection status: three species from Gisagara Protected Landscape, GPL (Eastern) and two other species from Rumonge Natural Forest Reserve, RNFR (Southern-West) (Figure 1) during July and August 2015. This period corresponds to the major dry season which coincides with their fruit maturation. GPL forest is located between 1500 and 1900 m altitude while the highest altitude in RNFR is 1000 m [7 ; 11]. In both sites, the soil is leached, skeletal or stony with hard ecological conditions; the climate is typically tropical [7; 11]. The species chosen (Table 1) were reported to be mycorhized and dominant or co-dominant of miombo woodlands from Tanzania to Zimbabwe through Zambia and Malawi and Burundi [7; 12-15].

Table 1: Presentation of five indigenous Fabaceae tree species from Burundi miombo

Species	**Subfamily**	**Vernacular**	**Collection site**	**Distribution in Burundi**
Pericopsis angolensis (Baker) Meeuwen	Faboideae	Umubanga	GPL	Miombo woodlands and Savannah
Julbernardia globiflora (Benth.) Troupin	Caesalpinioideae	Umutuntu	GPL	Miombo woodlands
Brachystegia utilis Burtt Davy & Hutch.	Caesalpinioideae	Ingongo kigabo	RNFR	Miombo woodlands
Brachystegia bussei Harms	Caesalpinioideae	Ingongo kigore	RNFR	Miombo woodlands
Brachystegia microphylla Harms	Caesalpinioideae	Umugongori	GPL	Miombo woodlands

GPL: Gisagara Protected Landscape; RNFR: Rumonge Natural Forest Reserve

The seeds were collected on the ground; mature and dry pods burst and project their seeds under the tree mother. We received assistance and expertise from forest guards and guides of these respective protected areas who contributed during the seed collection. However, seeds of *Pericopsis angolensis* were harvested from the tree mother. Indeed, among IFTS studied here, it is the only species whose mature and dry pods don't erupt. We judged and chose one potential good tree mother.
Collected seeds were stored at room temperature in airtight jars.

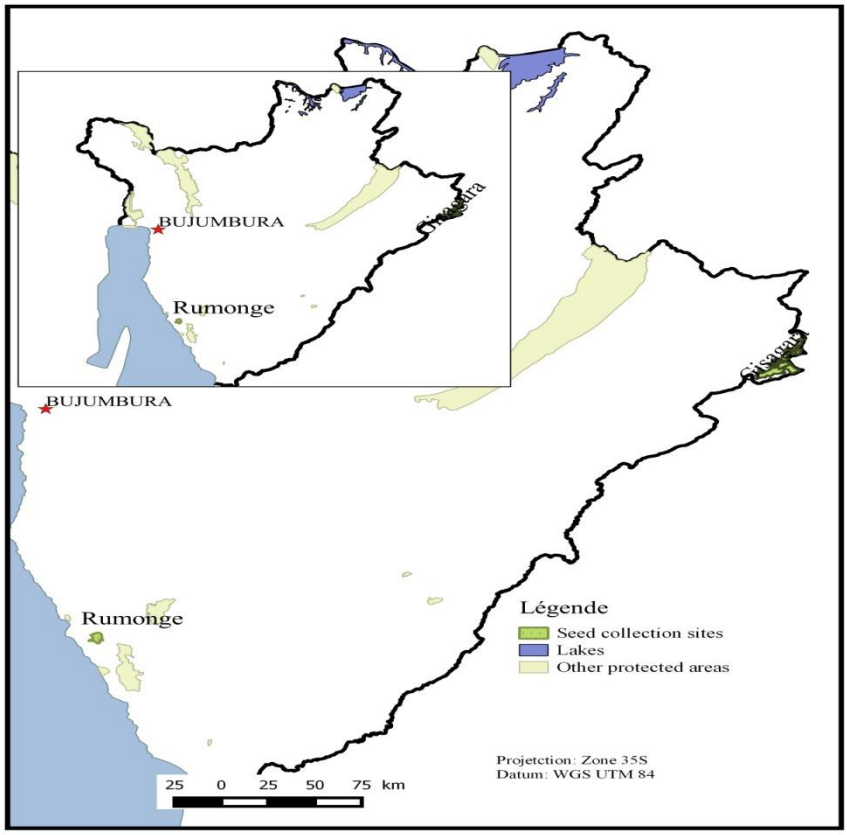


Figure 1: Geographic location of seed collection of five indigenous Fabaceae tree species from Burundi miombo woodlands.

2.2. Experimental procedure
Seeds were visually checked; rotten, damaged or infected seeds were discarded. Before experimentation, pilot germination tests were carried out for all seed species to assess their eventual dormancy: all seed species were subject to boiling water, removal of seed coat portion and sulfuric acid pretreatments. Seed species germinated well in the control than in treated ones which rotted rapidly [16]. Then, we decided to use intact seeds instead of any chemical or physical scarification treatment.
To optimize seed germination, we adopted an experimental design which is accessible to the population at village level, mixing seed imbibition and germination temperature. Seeds were disinfected with bleach water (20%). Four different imbibition times (0, 6, 12 and 24 hours) were adopted and germination were conducted under three different temperatures (20±0.8; 28±1.4 and 35±0.6 °C) in different germination chambers equipped with thermometers. Germination was performed on virgin peat containing water at 67.39±0.03% and supplemented with 150 ml per liter of peat in plastic bags. Monitoring of seed germination was conducted daily for 12 days (maximum days of observed seed germination before they decayed). Seeds were considered to be germinated when the radical emerged about 2 mm length. The germinated seeds were counted and discarded; inventory began a day after the experiment started up.

2.3. Studied parameters

2.3.1. Morphological characterization of seeds species:

The morphological and weight assessment of seed species were carried out by direct measurements of 25 randomly selected seeds in each seed species; each seed was measured individually. The length was measured from the hilum and perpendicularly to the main width axis. Maximum width and thickness were considered.

2.3.2. Germination parameters

- *Final germination percentage (FGP):* is the ratio of the number of germinated seeds on the total number of seeds [17]. It was calculated according to modified Larsen & Andreasen [18] formula as the cumulative number of germinated seeds as follows:

$$FGP = \sum_i^k (n/N)x100$$

Where, n is the number of germinated seeds at each i (daily) till k (last day) counting and N, the total seeds in each treatment.

- *Germination kinetic*: is expressed by the cumulative number of seeds germinated daily throughout the experiment.

This parameter provides a better view and understanding of the ecological significance of germination behavior [16].

- *Time to 50% germination (T_{50})*: can be defined as the time required for each replicate to reach 50% of germination [19]. It is a efficient method used to measure the central tendency of germination [20] and is expressed according to Sandhya et al. [20] as follows :

$$T_{50} = t_i + \frac{(\frac{N}{2} - n_i)(t_j - t_i)}{n_j - n_i}$$

Where N is the final number of germinated seeds; n_i and n_j are the cumulative number of seed germination by adjacent counts at times t_i and tj when $n_i<N/2<n_j$.

- *Mean germination time (MGT):* corresponds to the weighted mean of the germination time as proposed by Labouriau 1983 *in* Ranal & Santana [20]:

$$MGT = \sum_{i=1}^k n_i t_i / \sum_{i=1}^k n_i$$

where t_i is the number of days from the start of the experiment to the i^{th} counting day ; n_i is number of germinated seeds on i^{th} day, and *k* is the last day of germination count. MGT can also be simply expressed as follows: $(G_1T_1 + G_2T_2 + ... + G_nT_n) / (G_1 + G_2 + ... + G_n)$ where: *G* is the daily germination count and T_n, n^{th} counting day corresponding to the last germination day.

2.4. Statistical analysis

For each species, a total of 288 seeds in three replications of sets of 8 seeds were used for four imbibition time and three germination temperatures. Morphological characterization consisted of 25 seeds. Values of different parameters were expressed as the mean±standard deviation (x ± S.D). Statistical analysis was performed by one and two ways analysis of variance (ANOVA) using IBM SPSS statistics version 21 by the means of multiple comparison based on Tukey's test; p=0.05.

3. Results and discussion

3.1. Morphological characterization of seeds of five indengenous Fabaceae tree species from Burundi miombo woodlands

The morphological and weight assesment of studied seed species are presented in Table 2. As shown in Figure 2, all the seeds species can be recognized by their flat shape. The seed thickness measurements of each species showed no significant difference (Table 2), reflecting their flattened in shape similarities. This may suggest an adaptation to dispersion away from their tree mother. Ernst [16] reported that nearly 50% of *Brachystegia*

spiciformis seeds were dispersed beyond the edge of the mother tree crown. Indeed, after maturation process, dry pods crack, burst and spread their seeds. Given a similar weight, more a seed is flattened more it should acquire a best propulsion capability away from the mother tree, ensuring its dispersion.

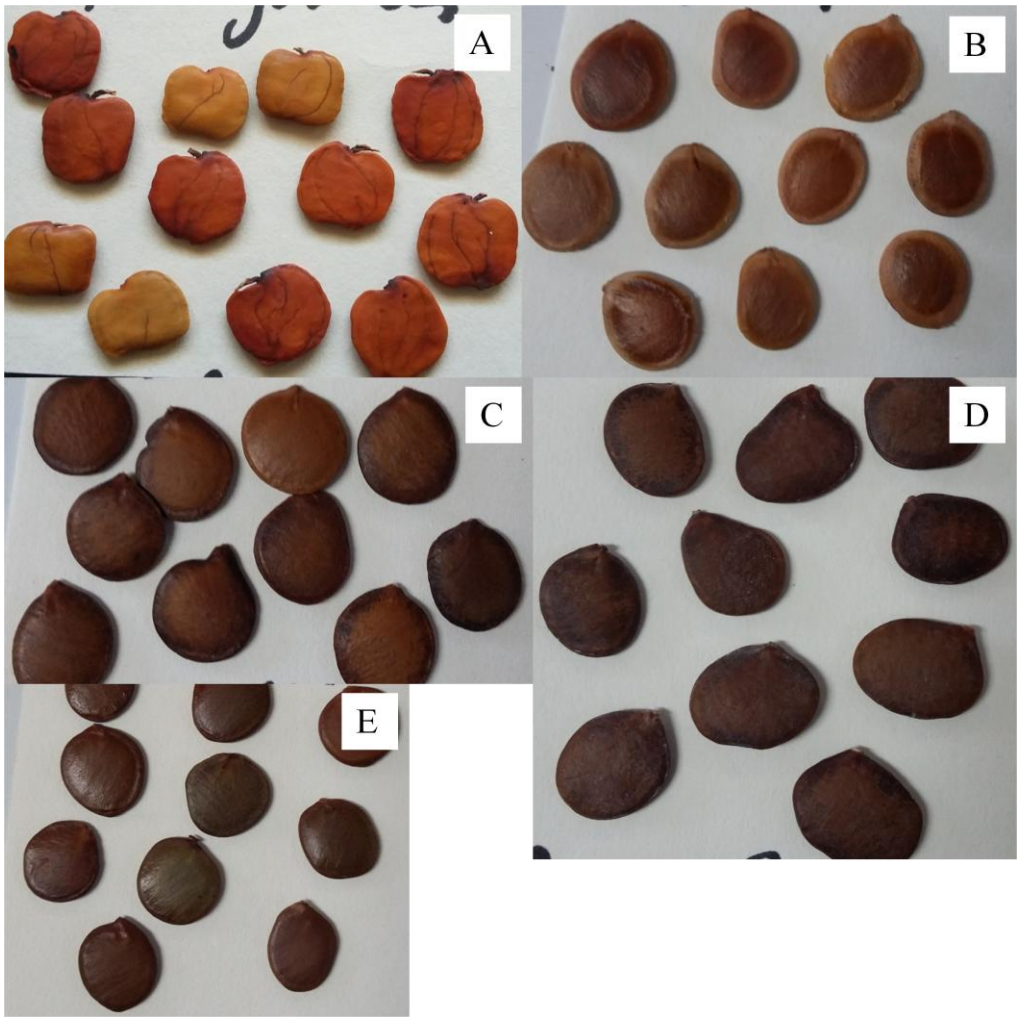


Figure 2: Seeds of five indigenous Fabaceae tree species from Burundi miombo woodlands: *P. angolensis* (A); *J. globiflora* (B); *B. utilis* (C); *B. bussei* (D) and *B. microphylla (E)*.

Table 2: Morphological characterization of seeds of five indigenous Fabaceae tree species from Burundi miombo woodlands

	P. angolensis	*J. globiflora*	*B. utulis*	*B. bussei*	*B. microphylla*
Length (mm)	12.88±0.97^{a}	16.10±1.10^{c}	15.90±1.30^{bc}	17.18±1.762^{d}	15.02±1.10^{b}
Width (mm)	12.43±0.93^{a}	12.65±0.80^{a}	13.88±0.81^{b}	17.16±1.19^{c}	12.97±2.41^{ab}
Thickness (mm)	2.63±0.18^{a}	2.91±0.25^{a}	3.00±0.23^{a}	3.23±0.41^{a}	3.08±1.95^{a}
Weight (g)	0.30±0.02^{a}	0.40±0.05^{c}	0.42±0.04^{c}	0.59±0.08^{d}	0.35±0.03^{b}

Significant differences in the same row are shown by different letters (a–d); $p < 0.05$.

The length and width of studied seed species relatively differ one another. *B. bussei* seeds are the most important in size and weight. Their length (17.16±1.19 mm), width (17.18±1.762 mm) and weight (0.59±0.08 g) are significantly higher than the rest of the studied seeds whilst *P. angolensis* seeds are the smallest (12.43±0.93mm; 12.88±0.97 mm and 0.30±0.02 g respectively length, width and weight). Pluess et al. [22] suggested that evolution may retain lager seeds at the expense of seed number in stressful environments.

P. angolensis seeds have a recognizable form square in shape and an apricot colour tending to amber-ochre colour. All *Brachystegia* seed studied here are brown to dark brown in color, more pronounced in *B bussei* and less intense in *B. utilis*. The seeds of *J. globiflora* are hazel in color with edges colored in ocher-amber. *B bussei* could be distinguished from the two other species of the same genus by its butterfly-like shape, relatively rough with distinctly larger area. However, *B. utilis* and *B. microphylla* seeds are not easily distinguishable even though, those of *B. utilis* are more clearly colored and shaped relatively like *B. bussei* seeds.

Previous studies [23] reported lightweight seeds of *J. globiflora* ranging from 0.26±0.08 g to 0.27±0.06 g unlike in our study (0.40±0.05 g). Likely, Chidumayo [23] found significant weight differences between seeds from two sites. Seed weight has been recognized to be a crucial plant life history trait that determines establishment success, dispersal ability. Its variation within species could be adaptive in heterogeneous landscapes [22 ; 24]. In agroforestry and reforestation, seed weight constitutes an important parameter in nursery management. Indeed, prior knowledge on seed weight give an overview on required seed quantity based on number of plants to be produced.

3.2. Final germination percentage of seeds of five indigenous Fabaceae tree species from Burundi miombo woodlands

In general, seeds of five indigenous Fabaceae tree species from Burundi miombo woodlands, IFTS studied here show no dormancy although Fabaceae family is ranked among 15 families which present a physical dormancy [25-27]. In particular, the dormancy have been reported in Fabaceae species from savannah, arid and semi-arid ecosystems [8 ; 28; 29]. Ernst [16] and Chidumayo [23] suggested to consider a seed species with no dormancy when it germinates just after a complete imbibition and no-germinated seeds should decay rapidly. Our preliminary germination tests revealed that any seed pretreatment (sulfuric acid, scraping, boiling water) decreased germination percentage, proving the absence of dormancy.

In the present study, the final germination percentage, FGP of IFTS is presented in Figure 3. The optimum FGP of up to 100% for all studied seed species is obtained except *B. bussei* whose maximal FGP doesn't reach 80%. Could the low FGP of *B. bussei* seeds be related to their storage conditions? If this is the case, it should implicate a relative shelf life weakness because all IFTS seeds were collected and kept in same storage conditions. Previous studies showed some cases where viability tends to be lost during storage. Ngulube and Kananji (1989) *in* Prins & Maghembe [10] reported the loss of viability of *Uapaca kirkiana* seeds within a month of collection. *B. spiciformis* seeds showed no germinability loss after one year storage whilst seed viability of *J. globiflora* and *J. paniculata* decreased after one year of storage respectively from 73.3 % to 35 % and 67% to 17 % [23 ; 30]. Although the latter author reported *J. globiflora* germinability loss after one year, we didn't notice any sign of viability loss in our study (germination experiments were performed six months after seed collection and storage). We hypothesized that *B. bussei* may require specific storage condition to keep their viability. It would be interesting to investigate the seed viability and its evolution along seed storage time; a key parameter in seed bank management.

The present study focused on the importance of germination temperature and imbibition on the seed germination optimization of IFTS. In general, temperature germination and imbibition influenced FGP. However, these parameters affected differently the five IFTS seeds studied. Germination temperature influenced significantly the

FGP of only two seed species: *B. bussei* and *B. microphylla*. In *B. bussei*, the mean FGP at 20 °C and 28 °C was significantly higher than at 35 °C; suggesting the ideal temperature of germination to range from 20 to 28 °C. *B. microphylla* showed a better FGP at 35 ° C. It is noteworthy that the three other seeds of IFTS showed no effect of germination temperature on the FGP unlike the imbitition; revealing the easiness and flexibility during plant production regarding to the temperature. These results confirmed the conclusions of Teketay [8] suggesting a wide temperature range for germination of Fabaceae seeds: the major Fabaceae species may germinate with an optimum of 20 to 30 °C.

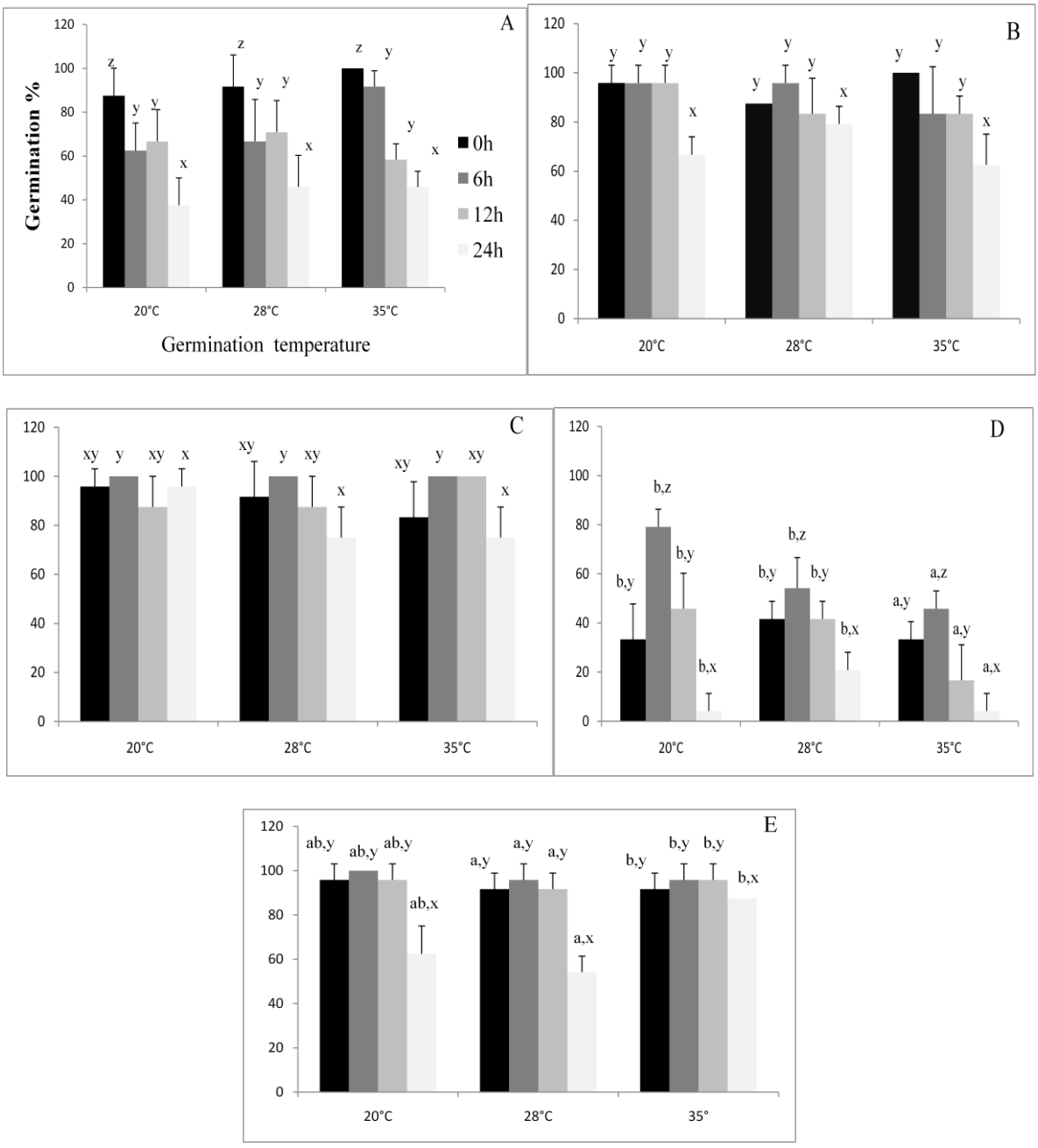


Figure 3: Final germination percentage of seeds of five indigenous Fabaceae tree species from Burundi miombo woodlands. *P. angolensis*, A ; *J. globiflora*, B ; *B. utilis*, C; *B. busei*, D; *B. microphylla*, E. Significant differences are shown by different letters for germination temperature (a,b) and imbibition (x,y,z); $p<0.05$.

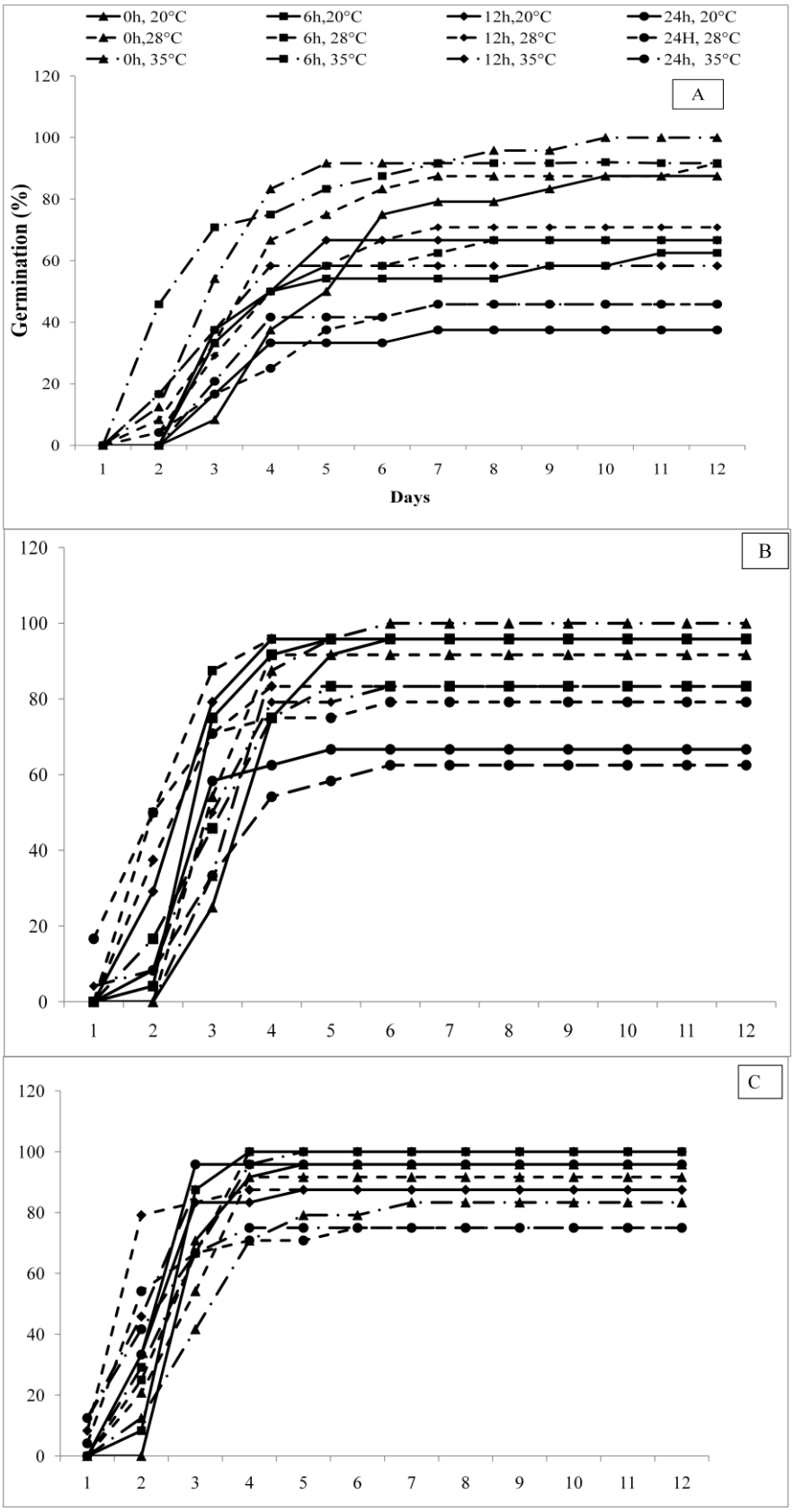
The four imbibition times (0, 6, 12 and 24 hours) significantly and differently influenced the FGP, from positive to harmful effect (Figure 3). *P. angolensis* showed a negative effect of imbibition on the FGP; any imbibition level revealed a negative effect whilst *J. globiflora* seeds showed no improvement on the FGP up to 24 hours of imbibition to become negative. Therefore, this species seem to be adapted to a wide range of soil water content. By contrast, 6 hours of imbibition boosted significantly FGP of *B. utilis* and *B. bussei* seeds. Nonetheless, *B. bussei* showed a very high sensibility to imbibition, falling from 59.72% (6 hours) to 9. 72% (24 hours). In contrast, *B. microphylla* revealed an improvement of imbibition to FGP up to 12 hours imbibition. Previously, studies in pea reported that damaged coat (mechanically) of seeds allowed almost complete imbibition up to 6 hours while after 24 hours intact ones were not yet at complete imbibition suggesting low imbibition rate for intact than damaged seeds [31 ; 32]. In addition, Ernst [16] repported that seed falling on stones during the dispersal process may be helpful in imbibition process by shortening its duration. In the present study, seeds were collected on the ground (except *P. anglonsis*), suggesting an eventual seed damage leading to boost imbibition. Unlikely, excessive imbibition was associated with reduced germination and production of more abnormal seedlings [33]. Thus, for each seed species, it is crucial to determine the optimum imbibition time (and temperature) to expect better FGP and seedling quality (see key technical informations in table 5).

The seed germination kinetic of IFTS is presented in Figure 4. For all studied species, a global view shows a start of germination (emergence of radicle) the second day. The curves of cumulative germination number are characterized by an important slope from the second day till fourth; suggesting a period of three days where most seed germination is focused. During the two following days (5 and 6), the slope falters to become almost constant from the seventh day. These results provide a global view of seed germination of IFTS studied here to occur in six first days of germination. This could be another proof of no-dormancy of studied seed species. In fact, Chidumayo [23] and Ernst [16] suggested that in the case of no-dormancy, seeds which did not germinate should rot more rapidly. The authors precised that viable *B. spiciformis* seeds germinated (seedling emergence) after 7-11 days. We believe that germination kinetic of this species is similar to the five species under the present study because seedling emergence requires more time to constitute the shoot before germination is noticed.

Our results show that imbibition and germination temperature seem to allow germination precocity to the seeds of IFTS. It is noticed an early germination with increasing of temperature (28 to 35 °C) and imbibition. If the germination kinetic reflects the percentage and speed of seed germination, it eventually also gives a view of the mean germination time, GMT and the time to 50% of seed germination (T_{50}).

3.4. Mean germination time and Time to 50% of seed germination of five indigenous Fabaceae tree species from Burundi miombo woodlands

As for the FGP, the T_{50} and the MGT are important parameters in nursery management. Such parameters allow a best resource management (human and logistical) and sustain work planning during the plant production. The T_{50} and MGT are presented respectively in Table 3 and Table 4. The MGT ranks from 5.30±0.50 (*P. angolensis*) to 2.06±0.16 days (*B. utilis*) while the T_{50} is located between 4.72±0.25 (*B. bussei*) and 1.57±0.06 days (*B. utilis*). These values should be considered in precise case of germination taking in count just emergence of the radicle. Previous study [23] reported about 85% of *J. globiflora* seedlings emerged in 14 days instead of a maximum MGT of 3.46±0.77 days for radicle emergence in the present study. This should imply that seed germination as defined by seedling emergence require more time to form not only radicle but also shoots of a certain height to emerge on soil surface.


0h, 20°C
6h,20°C
12h,20°C
24h, 20°C
0h,28°C
6h, 28°C
12h, 28°C
24H, 28°C
0h, 35°C
6h, 35°C
12h, 35°C
24h, 35°C
A
B
C
Germination (%)
Days
0
20
40
60
80
100
120
1
2
3
4
5
6
7
8
9
10
11
12

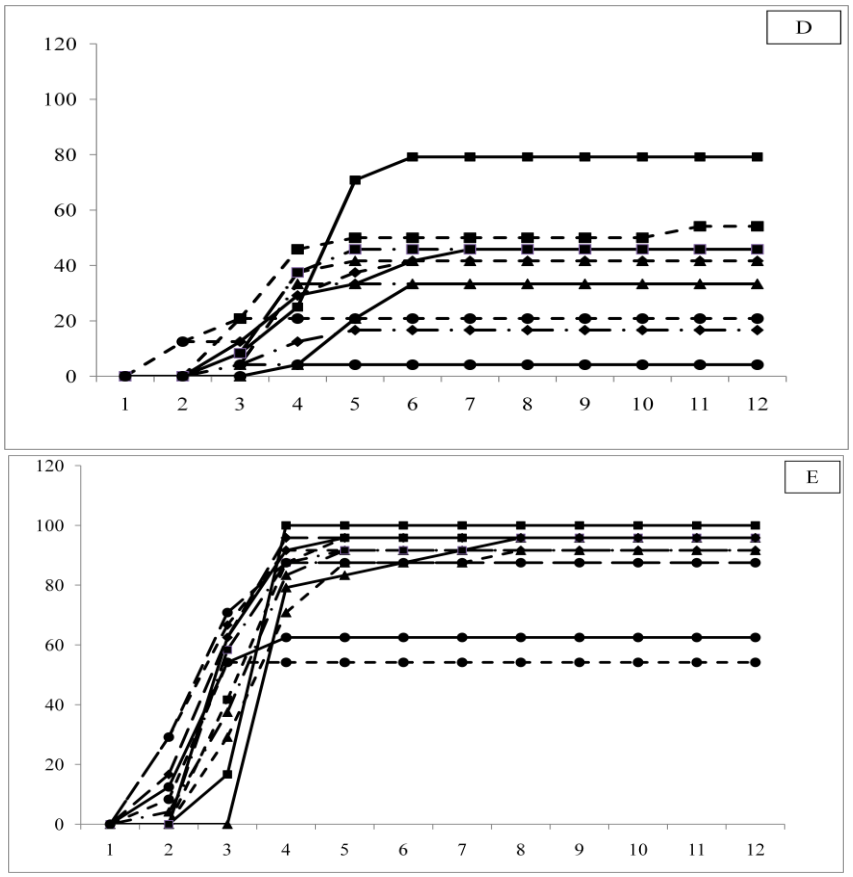


Figure 4: Germination kinetic of five indigenous Fabaceae tree species from Burundi miombo woodlands: *P. angolensis*, A ; *J. globiflora*, B ; *B. utilis*, C; *B. busei*, D; *B. microphylla*, E.

The fact of *P. angolensis* to show the highest MGT and unlike the T_{50} is explained by some late germinating seeds delaying the final germination time with no impact on T_{50}. Although we collected all seeds from one tree-mother, they behave differently in germination time. This has been reported by [34] who suggested that delay in germination time within seeds of same tree should be adaptive from savannah species. Although *P. angolensis* seeds have been collected from miombo woodlands, this savannah trait seem to remain. We referred to this seed species to fix twelve days the number of days reported on germination kinetic presented in Figure 4. Only *P. angolensis* seeds germinated beyond 8 days (up to 12 days). Previous studies reported *J. globiflora* and *B. microphylla* seeds to complete germination (seedlings emergence) in 12 and 13 days respectively after sowing [35]. It has been suggested that the quick germination observed in seeds of miombo Fabaceae species helps seedlings to take advantage of short period of rain. This may lead species to establish in those harsh environment before rain saison end [35].

In the present study, the germination temperature and imbibition promoted fast germination by shortening the MGT and T_{50} (Table 3 and 4). Ernst [16] reported from *B. spiciformis* that all viable seeds germinated between 7 and 11 days at a temperature regimes of 25/20 °C and 20/15 °C (day/night) respectively. Nevertheless, the MGT and T_{50} were not improved by an "excessive" imbibition from a certain duration threshold beyond which germinated seeds showed signs of rotting. This fact may suggest also that the reduction of FGP especially for 24 hours imbibition occurred for all seed species (Figure 3) may be explained by seed decaying caused by an excessive imbibition. In the miombo woodlands, seeds of *B. spiciformis* started to germinate after some days of

rains [16]. This could mean water requirement relatively important to induce seed germination; thus it is interest to be able to determine its optimum threshold. This suggests the importance of seed imbibition to be wisely adopted while optimizing the germination time parameters, FGP and plant quality to be produced. The Table 5 makes a summary view of required conditions based on data of the present study.

Table 3: Time to 50% of seed germination of five indigenous Fabaceae tree species from Burundi miombo woodlands

T °C	Imbibition	*P. angolensis*	*J. globiflora*	*B utilis*	*B. bussei*	*B. microphylla*
20 °C	0h	$4.21\pm0.67^{b,y}$	$3.46\pm0.77^{b,y}$	$2.81\pm0.48^{b,y}$	$4.72\pm0.25^{b,y}$	$3.24\pm0.65^{a,y}$
	6h	$3.19\pm0.39^{b,x}$	$2.62\pm0.06^{b,x}$	$2.54\pm0.23^{b,y}$	$4.13\pm0.46^{b,y}$	$3.39\pm0.05^{a,y}$
	12h	$3.12\pm0.43^{b,xy}$	$2.38\pm0.21^{b,x}$	$2.13\pm0.34^{b,x}$	$3.86\pm1.37^{b,y}$	$2.83\pm0.36^{a,x}$
	24h	$3.19\pm0.17^{b,y}$	$2.51\pm0.14^{b,x}$	$2.14\pm0.35^{b,x}$	$3.5\pm0.00^{b,x}$	$2.45\pm0.07^{a,x}$
28 °C	0h	$3.30\pm0.52^{b,y}$	$2.89\pm0.35^{a,y}$	$2.60\pm0.18^{a,y}$	$3.41\pm0.14^{a,y}$	$3.46\pm0.26^{a,y}$
	6h	$3\pm0.50^{b,x}$	$1.97\pm0.24^{a,x}$	$2.59\pm0.31^{a,y}$	$3.19\pm0.33^{a,y}$	$3.16\pm0.29^{a,y}$
	12h	$3.36\pm047^{b,xy}$	$2.11\pm0.31^{a,x}$	$1.57\pm0.06^{a,x}$	$3.25\pm1.39^{a,y}$	$2.35\pm0.13^{a,x}$
	24h	$3.75\pm0.43^{b,y}$	$1.74\pm0.74^{a,x}$	$1.66\pm0.07^{a,x}$	$1.83\pm0.28^{a,x}$	$2.40\pm0.08^{a,x}$
35 °C	0h	$3.05\pm0.50^{a,y}$	$3.28\pm0.30^{b,y}$	$2.72\pm0.25^{ab,y}$	$3.42\pm0.14^{a,y}$	$3.14\pm0.15^{a,y}$
	6h	$2.08\pm0.51^{a,x}$	$2.93\pm0.70^{b,x}$	$2.53\pm0.05^{ab,y}$	$3.50\pm0.50^{a,y}$	$2.89\pm0.23^{a,y}$
	12h	$2.61\pm0.62^{a,xy}$	$2.83\pm0.41^{b,x}$	$2.08\pm0.29^{ab,x}$	$3.50\pm0.00^{a,y}$	$2.69\pm0.17^{a,x}$
	24h	$3.19\pm0.17^{a,y}$	$2.86\pm0.42^{b,x}$	$1.86\pm0.27^{ab,x}$	$2.5\pm0.00^{a,x}$	$2.40\pm0.30^{a,x}$

Significant differences in same column are shown by different letters for germination temperature (a,b) and imbibition (x,y,z); $p<0.05$.

Table 4: Mean germination time of seeds of five indigenous Fabaceae tree species from Burundi miombo woodlands

T °C	Imbibition	*P. angolensis*	*J. globiflora*	*B. utilis*	*B. bussei*	*B. microphylla*
20 °C	0h	$5.30\pm0.50^{b,x}$	$3.97\pm0.73^{ab,x}$	$3.33\pm0.46^{a,y}$	$5.25\pm0.25^{b,y}$	$4.36\pm0.18^{b,z}$
	6h	$4.46\pm1.00^{b,x}$	$3.22\pm0.08^{ab,x}$	$3.04\pm0.31^{a,y}$	$4.69\pm0.42^{b,y}$	$3.83\pm0.07^{b,y}$
	12h	$3.66\pm0.16^{b,x}$	$2.87\pm0.21^{ab,x}$	$2.69\pm0.31^{a,x}$	$4.38\pm1.22^{b,y}$	$3.38\pm0.32^{b,x}$
	24h	$3.80\pm0.39^{b,x}$	$3.04\pm0.27^{ab,x}$	$2.65\pm0.32^{a,x}$	$4.00\pm0.20^{b,x}$	$2.93\pm0.11^{b,x}$
28 °C	0h	$3.88\pm0.75^{b,x}$	$3.41\pm0.26^{a,x}$	$3.18\pm0.06^{a,y}$	$3.89\pm0.19^{a,y}$	$4.06\pm0.28^{a,z}$
	6h	$4.54\pm0.90^{b,x}$	$2.56\pm0.18^{a,x}$	$3.08\pm0.31^{a,y}$	$3.69\pm0.30^{a,y}$	$3.67\pm0.29^{a,y}$
	12h	$4.14\pm0.62^{b,x}$	$2.69\pm0.17^{a,x}$	$2.06\pm0.16^{a,x}$	$3.80\pm1.16^{a,y}$	$2.96\pm0.20^{a,x}$
	24h	$4.29\pm0.07^{b,x}$	$2.40\pm0.96^{a,x}$	$2.45\pm0.34^{a,x}$	$2.33\pm0.29^{a,x}$	$2.85\pm0.13^{a,x}$
35 °C	0h	$3.83\pm0.95^{a,x}$	$3.83\pm0.38^{b,x}$	$3.59\pm0.08^{a,y}$	$3.89\pm0.19^{a,y}$	$3.64\pm0.19^{a,z}$
	6h	$3.02\pm0.46^{a,x}$	$3.44\pm0.72^{b,x}$	$3.08\pm0.14^{a,y}$	$4.00\pm0.50^{a,y}$	$3.59\pm0.36^{a,y}$
	12h	$3.11\pm0.55^{a,x}$	$3.34\pm0.21^{b,x}$	$2.54\pm0.14^{a,x}$	$3.54\pm0.66^{a,y}$	$3.18\pm0.15^{a,x}$
	24h	$3.80\pm0.39^{a,x}$	$3.55\pm0.18^{b,x}$	$2.39\pm0.04^{a,x}$	$3.10\pm0.09^{a,x}$	$2.86\pm0.25^{a,x}$

Significant differences in same column are shown by different letters for germination temperature (a,b) and imbibition (x,y,z); $p<0.05$.

3.5. Relative key informations on germination optimization and plant production of five indigenous Fabaceae tree species

The Fabaceae species presented here are common and dominant of miombo woodlands from Tanzania to Zimbabwe via Burundi, Zambia and Malawi [13 ; 23 ; 34; 37]. Studies on their domestication have been partially carried out but their interest seems to backward during the two last decades (in view of available published

papers). Based on present results, temperature and imbibition time influence different germination parameters. These treatments improve differently seed germination. Particularly, high imbibition time (especially 24 hours) seems to be "excessive" and showed negative effect on FGP. Some germinated seeds manifested signs of rotting and may produce seedlings of low quality [31]. Nonetheless, seed germination requires a complete imbibition [16]. Moreover, this latter author [16] reported *B. spiciformis* to start germination after some days of rains, proving the necessity of seed imbibition. In order to expect better germination parameters, it is therefore interesting to propose an optimum imbibition time as well as germination temperature. We propose to fix this optimum to the minimum imbibition time which manifests the better FGP. We believe that MGT and T_{50} can be secondarily considered. In fact, a maximum shortening of 1 to 3 days was noticed as imbibition improvement effect on MGT and T_{50}. Therefore, in practice, this shortening seems tolerable in the nursery management.
Accordingly, we provide an overall view of studied seeds in Table 5 and gather key informations useful for forestry and nursery managers for reforestation and restoration purposes regarding (i) number of seeds per kilogram, (ii) optimum imbibition and germination temperature, (iii) predicted FGP and (iv) germination time (MGP and T_{50}).

Table 5. Summary information on germination conditions of seeds of five indigenous Fabaceae tree species from Burundi miombo woodlands

	P. angolensis	***J. globiflora***	***B. utilis***	***B. busei***	***B. microphylla***
Seeds/kg	3293	2475	2380	1696	2848
T (°C)	35 (20-35)	28 (20-35)	28 (20-28)	28-30 (20-35)	35
Imbibition (hours)	0	6 (0-6)	6	6	12 (0-12)
Predicted FGP (%)	100	95.83	100	79.17	95.83
Predicted T_{50}	3.05-4.21	1.97-3.46	2.54-2.59	3.19-4.13	2.69-3.14
Predicted MGT	3.83-5.30	2.56-3.97	3.04-3.08	3.69-4.69	3.18-3.64

Values in parentheses represent an alternative which doesn't affect the final percentage of germination; FGP: Final germination percentage; MGT: mean germination time; T_{50}: Time to 50% of seed germination.

Conclusion

The present study investigated the germination of five IFTS from Burundi miombo woodlands focusing on the effect of germination temperature and imbibition time. According to previous studies, we found all these seed species to have no-dormancy as a seedling establishment adaptation to short period of rain. The FGP was about 100% except *B. bussei* whose in optimum condition approached 80%, suggesting no-loss of viability after six months of collection and storage of seeds for the most of seed species studied. Germination temperature and imbibition time influenced differently germination parameters tested here. Six hours imbibition was considered as the most optimum time even *P. angolensis* and *B. microphylla* showed respectively 0 (no-required imbibition) and 12 hours imbibition as optimum. Regarding germination temperature, results showed relative less restrictive conditions. Thus, this study will have provided key useful informations for forestry and nursery management.
Our findings showed that the germination of IFTS seeds is not tedious and can be carried out at regional or local level (accessible to village population) and at lower cost. However, due to their mycorrhizal status, future investigation on plant production should be coupled with their artificial inoculation.

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