ASSESSMENT OF THE POTENTIAL OF SEED TRAIT-BASED MODELS FOR PREDICTION OF DESICCATION SENSITIVITY OF FOREST TREE SEEDS IN ETHIOPIA

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ABSTRACT: The first challenge for the conservation of seeds of forest tree species is to determine their response to desiccation or seed storage behavior. This is particularly important in the tropical countries where the great portion of the forest tree species has recalcitrant seeds. The conventional experimental procedure of seed storage identification method is time consuming, requiring a germinative response and uses large amount of seeds. Estimation of seed desiccation sensitivity using seed trait-based models, thousand seed weight-moisture content (TSW-MC) criteria, and the models based on seed-coat ratio (SCR) and seed dry mass (SM) might be an alternative for the conventional experimental procedure. In this study, we assessed the potential of three seed trait-based models (i.e. TSW-MC criteria, and two other probabilistic models developed by Daws and Pelissari for prediction of desiccation sensitivity of 40 woody species with known storage behaviour from Ethiopia. The result of this study showed that the TSW-MC protocol, Daws' model and Pelissari's model to predict successfully the seed response to desiccation for 31 (77.5%), 36 (90%) and 38 (95%) of the 40 studied tree species, respectively. Once we observed a 95% efficiency rate, we have concluded that for forest tree species with unknown seed storage behavior in Ethiopia, Pelissari's model may provide more important information in a decision-making framework for the application of ex- situ seed conservation strategies.

Key words: Desiccation sensitivity, predictive model, seed trait, seed storage

INTRODUCTION

Ethiopia is one of the world's biodiversity rich countries and has a very diverse set of ecosystems ranging from humid forest and extensive wetlands to the desert of the Afar depression (Gebretsdik, 2016). The flora of Ethiopia is particularly very diverse with an estimated number more than 6,000 species of higher plants, of which about 10 per cent are endemic (Hedberg et al., 2009). This biodiversity resource in general, and vegetation resources, in particular, provide many ecosystem services to the local human communities (Brandon, 2014).

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The vegetation resource of the country, however, is rapidly diminishing due to mainly deforestation and loss of habitat. Deforestation rate in the Ethiopia is estimated at about 92,000 ha per year (FAO, 2015). High emphasis is thus needs to be given to the conservation of these valuable resources to preserve their ecological benefits for the future. Conservation through genebank and/or seed banks, along with massive tree planting as restoration and plantation are some of the conservation activities that can be used to conserve the threatened species and ecosystems (Maunder et al., 2004).

The first challenge for the conservation of seeds of plant species is to determine their response to desiccation or seed storage behavior. Determination of seed storage behavior is important as, it helps to identify the type of storage conditions that are required to maintain seed viability, and to choose appropriate conservation strategy of plant genetic resources. Prior knowledge of seed storage behaviour of tree species is particularly important in the tropics where about 47% of the forest tree species have recalcitrant seeds (Tweddle et al. 2003). Long term seed storage of tropical tree species without determining the seed storage behaviour is particularly risky because there is a high probability that the seeds might be desiccation sensitive and, thus, would die when dried for storage.

So far, some protocols have been developed to classify seeds regarding their desiccation sensitivity. The familiar protocol was that developed by Hong and Ellis (1996), in which seeds are grouped as orthodox, recalcitrant, or intermediate. Although this protocol is reliable, this approach is time consuming, requiring a germinative response and uses a large amount of seeds. As a result, it is highly unlikely that all tree species will ever be identified through this procedure (Pelissari et al., 2017). An alternative approach to this common procedure is therefore needed for investigation of desiccation tolerance of targeted species. The results of previous studies have shown the potential correlates of seed desiccation sensitivity with seed traits, this includes seed mass (Pritchard et al., 2004b), seed shape (Hong and Ellis, 1997), seed moisture content at shedding (Hong and Ellis, 1998), seed allocation to physical defence and both gross and local scale habitat variables (Daws et al., 2006). Besides, different probabilistic models have also been proposed based on seed traits to predict storage classification of forest tree seeds (For example, Pelissari et al., 2017; Wyse and Dickie 2017). Due to numerous advantages of these models compared with the conventional procedures, some germplasm banks, like Xishuangbanna Germplasm Bank of China, have been using this approach during the past two decades as a decision-making tool in the handling of species with unknown seed desiccation sensitivity Lan et al. (2014). Seed traits (e.g. seed mass and desiccation sensitivity) are, however, usually habitat-associated (Li and Pritchard, 2009; Walters et al., 2013). Evaluation of the efficiency of the seed trait-based models on typical vegetation is required before a broad usage of the models can be adopted to guide seed banking.

In Ethiopia, there exist some published studies which identifies seeds storage behaviour of forest tree species (Mewuded et al., 2017; Dagnachew et al., 2023) and there is an ongoing effort of studying seed storage behaviour of those tree species with unknown storage information by Ethiopian Biodiversity Institute. Due to the large number of tree species which requires urgent conservation action, it is highly unlikely that these efforts can generate the required information on time. This study was, therefore, initiated to assess the potential of seed trait-based models in predicting desiccation sensitivity of forest tree seeds in Ethiopia with the aim of identifying an alternative and high-throughput methods among the proposed seed trait-based models to the conventional procedure.

MATERIALS AND METHODS

Plant material

Matured fruit/seeds of 40 tree species from the Amhara, Benishangul-Gumuz, Gambela, Oromia and Southern Nations, Nationalities and Peoples (SNNP) regions of Ethiopia collected in years 2019-2021 were used in the study (Table 1). The altitudinal range of the specific areas from which the collection was made ranges between 448 to 2417 m.a.s.l. A change in color and fruit dehiscence was considered as an indicator of maturity during the collection.

Table 1. The list of studied species and the geographical information their collection sites

Species	Seed collection		Latitude	Longitude	Altitude (m.a.s.l.)
	Region	Zone			
Acacia abyssinica Hochst. ex Benth.	Addis Ababa	Yeka	9°02'06"	38°46'50"	2417
Acacia albida Del	SNNP	Hawassa	7°03'19"	38°28'06"	1691
Adansonia digitata L.	Benishangul	Sherkole	1036'08"	34°46'11"	770
Albizia gummifera J. F. Gmel.	SNNP	Hadya	7°07'38"	37°57'04"	1958
Aningeria adolfi-friendericii Engl. Robyns & Gilbert	Oromia	Bedele	7°45'16"	36°14'41"	2095
Balanites aegyptiaca (L.) Delile	Gambela	Agywa	8°16'17"	34°33'18"	451
Bersama abyssinica Fres.	Amhara	East Gojam	10°21'13'	37°41'34"	2351
Brucea antidysenterica J.F. Mill	Amhara	East Gojam	10°21'04"	37°41'41"	2408
Capparis tomentosa Lam.	Oromia	Jimma	7°42'37"	37°00'14"	1767
Cordia africana Lam.	Oromia	Jimma	7°42'37"	37°00'14"	1767
Cordia simensis C. gharaf, C. rothii	Oromia	Borena	4°54'52"	38°11'56"	1568
Croton macrostachyus Hochst. ex Delile	SNNP	Hadya	7°07'38"	37°57'04"	1958
Ekebergia capensis Sparrm.	Oromia	Bedele	8°20'43"	36°04'51"	1877
Erythrina abyssinica Lam. ex. DC	Oromia	Jimma	7°39'00"	36°27'41"	1740
Kigelia africana (Lam.) Benth.	Gambela	Agywa	8°16'17"	34°33'18"	451
Millettia ferruginea (Hochst.) Bak,	Amhara	Bahir Dar	11°41'39"	37°19'04"	1780
Mimusops kummel A.DC.	Oromia	West Arsi	7°214'00'	38°40'10"	2097
Moringa olifera L.	SNNP	Goffa	6°17'59"	36°52'35"	1350
Oncoba spinosa Forssk.	Oromia	Bale	6°24'47"	39°46'08"	1380
Pappea capensis Eckl. & Zeyh.	Benishangul	Metekel	10°33'42"	36°04'31"	1792
Pavetta abyssinica Fres.	Benishangul	Metekel	10°32'15"	36°05'07"	1698
Piliostigma thonningii (Schumach.) Milne-Redhead.	SNNP	Wolita	9°55'24"	34°39'46"	1461
Podocarpus falcatus (Thunb.) Mirb.	SNNP	Sidama	7°06'00"	38°37'41"	1816
Prunus africana (Hook. f.) Kalkman.	Addis Ababa	Yeka	9°02'06"	38°46'50"	2417
Prunus persica (L.) Batsch	Amhara	Central	12°36'15"	37°27'59"	2186
Pterocarpus lucens Lepr. ex Guill. & Perr.	Benishangul	Assosa	9°55'24"	34°39'46"	1461
Ricinus communis Linn.	Gambela	Agywa	8°13'48"	34°16'19"	448
Securidaca longipedunculata Fres.	Benishangul	Metekel	6°25'05"	39°48'36"	1351
Sterculia africana (Lour.) Fiori	Gambela	Agywa	8°06'19"	34°44'45"	457
Stereospermum kunthianum Cham.	Benishangul	Assosa	9°55'24"	34°39'46"	1461
Strychinos inocua Del.	Benishangul	Assosa	10°36'08"	34°46'11"	770
Syzygium guineense (Wild) DC	Amhara	Centra	12°37'41"	37°28'54"	2378
Tamarindus indica L.	Benishangul	Assosa	9°55'20"	34°39'24"	1432
Terminalia brownie Fres.	SNNP	Goffa	6°17'59"	36°52'35"	1350
Terminalia laxiflora Engl. & Diels	Gambela	Agywa	8°08'50"	34°09'45"	450
Trichilia dregeana Sond.	Oromia	Bedele	8°20'43"	36°04'51"	1877
Vangueria madagascariensis J. F. Gmel.	Benishangul	Metekel	10°38'22"	36'°07'30"	1450
Warburgia ugandensis Sprague	Oromia	Bale	6°25'05"	39°48'36"	1351

After collection, fruits/seeds were packed in cotton bags and taken to the forest seed lab of the Ethiopian Biodiversity Institute, Addis Ababa. For each species seed cleaning was done manually. Seeds were visually checked and all infested (by fungi or insects) seeds were discarded. Fleshy fruits were air-dried at room temperatures (20°-24°C) for 1 day, and cleaned within 2 days of collection by removing the fleshy pulp.

TSW–MC characterization

For each species, seed moisture content and 1000 seed weight (TSW) was determined by drying about 25 cleaned seeds (103 ± 2 ◦C for 17 ± 1 h) following the method recommended by Rao et al., (2006) and ISTA (2019), respectively, as follows:

Moisture content (MC) (%) $=\left(\frac{W2-W3}{W1-W2}\right) \times 100$

Where, W1 = weight of container; W2 = weight of container and seed sample before drying; and W3 = weight of container with seed sample after drying.

Weight of 1000 seeds (TSW) $= \frac{\text{Sample weight}}{Number\ of\ seeds\ counting} \times 1000$

Determination of water content of seed structures and ratio between tegument and dry mass of seed

For each species, five replicates of eight seeds were dissected in order to separate the seeds into their component parts: endocarp, testa, and embryo + endosperm following Grubb and Burslem, (1998). These component parts were subsequently dried at 103˚C for 17 h (ISTA, 1999) followed by mass determinations. Seed coat ratio (SCR), which is the ratio of the mass of covering structures (endocarp and testa) to the mass of the total dispersal unit was then determined for each species by using the method as described by Grubb and Burslem (1998).

Statistical analyses

The TSW–MC criteria for identification

According to the TSW–MC criteria, those species having seeds with a TSW of > 500 g and MC of >30% are desiccation-sensitive (Hong and Ellis 1996). In this study, seed desiccation responses categories were then assigned for each species as follows: we considered the seed lot as “Desiccation sensitive” (DS) when seeds had an initial moisture content (mc) >30% and a TSW >500 g. In contrast, when the initial mc<30% and TSW<500 g, we considered them as 'Desiccation tolerant' (DT). When seeds had only one of the two traits (when mc>30%, but TSW<500 g, and TSW>500 g, but mc<30%), we considered the seed as DS according to Lan et al. (2014).

The SCR-SM models for identification

Daws et al. (2006) model

The likelihood of desiccation sensitivity (P(D-S)) for seeds of each of the studied 40 tree species was estimated using the equation developed by Daws et al., (2006) as follows:

$$p\ (D\text{-}S) = \frac{e^{3.269-9.974a+2.15b}}{1+e^{3.269-9.974a+2.15b}}$$

Where: (P(D-S)) is the likelihood of desiccation sensitivity, a is SCR and b is log10 (seed mass) in gram.

To use this model, seed mass should range between 0.01 mg and 24 g, and SCR between 0 and 1. By using this model, seeds were categorized as desiccation-sensitive when P(D-S)>0.5. Otherwise, seeds were considered as desiccation-tolerant (i.e. when P(D-S) < 0.5).

The Pelissari et al. (2017) model

The third model tested was the probabilistic model which was proposed by Pelissari, et al. (2017) as follows:

$$P = \frac{1}{1+EXP(-0.1627245*A+1.372784*B-0.4599876*C+4.348336)}$$

Where A is the water content of embryo + endosperm; B is the SCR and C is the dry weight of the seed.

According to this model, seed is classified as desiccation-sensitive if the value of p is higher than 0.5 or desiccation-tolerant if p is lower than 0.5.

Seed classification based on these three models was then compared with the information found in literature, and the potential of the three models was then compared by observing the number of times that the model predicts the seed storage behaviour accurately.

RESULTS

Thousand seed weight, fresh seed MC, the probability of seeds of being desiccation-sensitive as determined using the Daws' et al (2006) and Pelissari's et al. (2017) models based on SCR and seed dry mass are shown in Table 2.

The TSW–MC criteria

The TSW–MC criteria allowed identifying 30 of the studied species as desiccation tolerant (DT: MC<30% and a TSW<500 g), and 10 species as desiccation sensitive (i.e. MC > 30 and TSW >500 g; mc>30%, but TSW<500 g; and TSW>500 g, but MC<30%) (Table 1). Generally, this criterion was found to predict accurately desiccation sensitivity of 31 (77.5%) of the studied species correctly.

Models' predictions

Daw's et al. (2006) model was found to predict 30 of the studied species as desiccation tolerant (P(D-S) <0.5), and 10 as desiccation sensitive (P(D-S)>0.5). This model and the TSW-MC criteria generated consistent results for 31 species (Table 2). The Daw's et al (2006) model predicted four species to be desiccation-sensitive with a P(D-S) value of >0.5 while three of these four species were predicted to be desiccation tolerant using the MC-TSW model as seed of these three tree species were small (TSW<500g) and had low MC (<30%). From the total of 40 studied species, Daw's model generally was found to predict their response to desiccation correctly for 36 species (success rate of 90%). On the other hand, Pelissari's et al., 2017 model was found to predict 28 of the studied species as desiccation tolerant (P(TD) <0.5), and 10 as desiccation sensitive (P(TD)>0.5). This model and the Daw's et al (2006) model consistently generated similar results for 37 of the 40 studied species, while Pelissari's et al. (2017) model generated similar results with the TSW-MC criteria for 31 species. From the 40 species studied, the Pelissari's et al., (2017) model correctly predicted desiccation sensitivity for 38 species (95%) (Table 2 and 3).

Table 2. Seed traits of the 40 tree species from Ethiopia with known seed storage behaviour that are used for evaluation of seed trait-based models.

Species	Family	MC (%)	TSW (gm)	MC-TSW model	Daws et al (2006) Model		Pelissari et al., 2017 model		DT/DS?
					Probability to be recalcitrant	Possible storage behaviour	Probability to be recalcitrant	Possible storage behaviour	
Acacia abyssinica Hochst. ex Benth.	Fabaceae	13.3	102	DT	0.013	DT	0.222	DT	DT[1]
Acacia albida Del	Fabaceae	14.02	122	DT	0.262	DT	0.414	DT	DT[1]
Adansonia digitata L.	malvaceae	16.5	114	DT	0.019	DT	0.001	DT	DT[1]
Albizia gummifera J.F. Gmel.	Fabaceae	11.9	133	DT	0.154	DT	0.001	DT	DT[1]
Aningeria adolfi-friendericii Engl. Robyns & Gilbert	Sapotaceae	34.2	1326	DS	0.803	DS	0.798	DS	DS [2]
Balanites aegyptiaca (L.) Delile	Balanitaceae	28.6	1404	**DS**	0.015	DT	0.002	DT	DT[3]
Bersama abyssinica Fres.	Francoaceae	26.8	495	**DT**	0.656	DS	0.542	DS	DS [2]
Brucea antidysenterica J. F. Mill	**Simaroubaceae**	22.11	155	DT	0.480	DT	0.566	**DS**	DT[2]
Capparis tomentosa Lam.	Capparidaceae	27.02	201	**DT**	0.014	**DT**	0.511	DS	DS[7]
Cordia africana Lam.	**Boraginaceae**	13.3	298	DT	0.038	DT	0.006	DT	DT[2]
Cordia simensis C. gharaf, C. rothii	**Boraginaceae**	12.45	401	DT	0.281	DT	0.152	DT	DT[8]
Croton macrostachyus Hochst. ex Delile	Euphorbiaceae	11.89	65	DT	0.017	DT	0.004	DT	DT[8]
Ekebergia capensis Sparrm.	Meliaceae	35.6	152	DS	0.833	DS	0.802	DS	DS[8]
Erythrina abyssinica Lam. ex. DC	Fabaceae	11.8	225	DT	0.029	DT	0.121	DT	DT[1]
Kigelia africana (Lam.) Benth.	**Bignoniaceae**	15.06	112	DT	0.001	DT	0.002	DT	DT[2]
Millettia ferruginea (Hochst.) Bak.	Fabaceae	16.08	322	**DT**	0.602	DS	0.753	DS	DS[7]
Mimusops kummel A.DC.	Sapotaceae	22.01	225	DT	0.018	DT	0.002	DT	DT[5]
Moringa olifera L.	Moringaceae	14.78	490	DT	0.738	**DS**	0.498	DT	DT[8]
Oncoba spinosa Forssk.	**Flacourtiaceae**	13.2	58	DT	0.225	DT	0.016	DT	DT[8]
Pappea capensis Eckl. & Zeyh.	Sapindaceae	16.3	154	DT	0.451	DT	0.202	DT	DT[8]
Pavetta abyssinica Fres.	Rubiacaea	12.08	420	DT	0.003	DT	0.001	DT	DT[8]

Table 2. (continued)

Species	Family	MC (%)	TSW (gm)	MC-TSW model	Daws et al (2006) Model		Pelissari et al., 2017 model		DT/DS?
					Probability to be recalcitrant	Possible storage behaviour	Probability to be recalcitrant	Possible storage behaviour	
Piliostigma thonningii (Schumach.) Milne-Redhead.	Fabaceae	14.5	126	DT	0.025	DT	0.008	DT	DT[8]
Podocarpus falcatus (Thunb.) Mirb.	Podocarpaceae	28.1	395	DT	0.578	**DS**	0.859	**DS**	DT[1]
Prunus africana (Hook. f.) Kalkman.	Rosaceae	37.1	326	**DT**	0.487	DT	0.491	DT	DS[1,10]
Prunus persica (L.) Batsch	Rosaceae	28.07	664	**DS**	0.395	DT	0.452	DT	DT[8]
Pterocarpus lucens Lepr. ex Guill. & Perr.	Fabaceae	18.7	152	DT	0.004	DT	0.001	DT	DT[8]
Ricinus communis Linn.	Euphorbiacaea	27.9	321	DT	0.368	DT	0.056	DT	DT[8]
Securidaca longipedunculata Fresen.	Polygalaceae	10.3	305	DT	0.015	DT	0.235	DT	DT[8]
Sterculia africana (Lour.) Fiori	Flacourtiaceaea	12	74	**DT**	0.016	**DT**	0.521	DS	DS[2]
Stereospermum kunthianum Cham.	Bignoniaceae	19.22	25	DT	0.365	DT	0.458	DT	DT[1]
Strychinos inocua Del.	Loganiaceae	32	458	DS	0.816	DS	0.635	DS	DS
Syzygium guineense (Willd.) DC.	Myrtaceae	34.2	1552	DS	0.991	DS	0.561	DS	DS[9]
Tamarindus indica L.	Fabaceae	14.5	490	DT	0.335	DT	0.197	DT	DT[8]
Terminalia brownie Fres.	Combretaceae	25.04	552	**DS**	0.002	DT	0.085	DT	DT[8]
Terminalia laxiflora Engl. & Diels	Combretaceae	22.11	415	DT	0.335	DT	0.482	DT	DT[6]
Trichilia dregeana Sond.	Meliaceae	38.09	1250	DS	0.950	DS	0.886	DS	DS[4]
Vangueria madagascariensis J. F. Gmel.	Rubiaceae	14.44	1203	**DS**	0.476	DT	0.381	DT	DT[8]
Warburgia ugandensis Sprague	**Canellaceae**	25.12	495	DT	0.407	DT	0.290	DT	DT[1]
Ximenia Americana L.	Olacaceae	36.66	1056	DS	0.995	DS	0.696	DS	DS[1]
Zizyphus mucronata Willd	**Rhamnaceae**	26.5	365	DT	0.212	DT	0.444	DT	DT[1]

[1]Girma (1999), [2]World agroforestry (2022), [3]Kamal (2014), [4]Anushka (2018), [5]Mewuded et al (2022), [6]Mewded et al. (2017), [7]Tessems (1993), [8] SER (2023), [9]Negash (2021), and [10]Sacandé (2004).

Cases where those models failed to predict desiccation sensitivity of the species are shown in bold font type

Table 3. Summary of the efficiency rate of seed trait-based models for prediction of seed desiccation sensitivity of the 40 studied species.

Model	No of spp. used	Wrong prediction	Correct prediction	Percentage
TSW-MC criteria	40	9	31	77.5%
Daws et al (2006)	40	5	35	87.5%
Pelissari et al. (2017)	40	2	38	95%

DISCUSSION

In conservation of plant genetic resources efforts, long-term seed storage is generally considered the safest, most inexpensive and most convenient method of conservation. Most plant genetic resources are conserved by this means. However, not all seeds of woody plant species tolerate desiccation to a lower level of moisture content at which they retain their viability and can be stored in a cold room for a long period. For this reason, classification of seed storage behaviour has become a prior step in devising a suitable method of conservation for particularly those plant species with unknown seed storage behaviour.

This study tested the potential of seed trait-based models for determining seed desiccation sensitivity for 40 woody plant species from Ethiopia. For the 40 woody species with known seed storage behaviour, the TSW-MC criteria predicted successfully the seed response to desiccation for 31 (77.5%) species. The success rate of TSW-MC criteria obtained in the present study is somewhat high as compared with the accuracy level of 55% reported by Athugala et al. (2021) for selected tropical montane species in Sri Lanka, but somehow comparable with the success rate of 83% reported by Lan et al. (2014) using this criteria for tropical woody species from Southern China. As discussed by Lan et al., (2014), the TSW–MC criteria are problematic in predicting smaller or drier desiccation-sensitive seeds, and this could explain the present result since three (60%) of the five cases that this model fails to predict desiccation sensitivity in the present study had a small and dried seeds.

As a rule of thumb, desiccation sensitive seeds are larger and have higher moisture content at dispersal. Accordingly, seed mass and initial moisture content (TSW-MC criteria) was described by Hong and Ellis (1996) as a predictive indicator for the response to desiccation tolerance. Although having some limitations, this protocol was used successfully to predict seed storage behaviour of woody species from various tropical regions; Woody species from tropical montane species in Sri Lanka (Athugala et al., 2021), for Caribbean native tree species (Mattanna et al., 2020) and for woody species from Southern China (Lan et al. 2014).

The SCR–SM models provided by Daws et al. (2006) and Pelissari et al. (2017) successfully predicted the seed response to desiccation for 36 (90%) and 38 (95%) of the woody species, respectively. This result is in accordance with the success rate (88%) achieved using Daws et al. 2006 model for 101 woody species from Southern China (Lan et al., 2014), and that of 92% reported by using Pelissari et al. (2017) model for 66 Brazilian tree species (Pelissari et al., 2017). The similarity of the success rates observed from the result of present study for those 40 tree species sampled from a large range of altitudinal differences, with that of previously reports suggested that the SCR–SM models are a reliable predictive method for Ethiopian woody species.

As described by Hill et al. (2012), the ratio between the dry weight of the tegument and endocarp (SCR) can be a better predictor than the seed itself. Desiccation sensitive seeds, when compared with desiccation tolerant seeds, usually have a thick seed coat (Pritchard et al. 2004b). These results corroborate those of Pritchard et al. (2004b), Daws et al. (2006) and Hamilton et al. (2013), once the mass allocation on the external seed layer becomes a desiccation tolerance indicator (Pritchard et al. 2004a). According to Daws et al. (2006), the SCR reduces the chances for large orthodox seeds, with high mass to be classified as recalcitrant, showing that SCR for orthodox seeds is high and identified as a good predictor of desiccation-tolerance.

The result of this paper showed that the protocols based on SCR is a reliable predictor for Ethiopians woody species seed classification regarding desiccation tolerance and storage as reported by Pelissari et al., (2017), Lan et al., (2014) and Daws et al. (2006). In particular, once we observed a 95% efficiency rate for the studied species which were collected from a divers set of environments, we have concluded that for forest tree species with unknown seed behavior in Ethiopia, the model provided by Pelissari et al., (2017) may provide more important information in a decision-making framework for the application of *ex- situ* seed conservation strategies. However, although the SCR–SM model is robust and more reliable than the TSW–MC criteria, a seed mass of 0.01 mg to 24 g is required (Pelissari et al., 2017, Daws et al. 2006), and in many species, data for SCR are not available. In which case, we recommend TSW–MC criteria as a practical tool to predict seed storage behaviour of woody species. Besides, TSW–MC criteria, with the observed 77.5% efficiency rate, may still be very important tool for decision making in cases where large collection of forest tree seeds with unknown seed storage behavior are made, and quick decision regarding the choice of appropriate conservation strategies for each of the collected species has to be made.

CONCLUSIONS AND RECOMMENDATION

In this study, the potential of three seed trait-based models in predicting seed storage behaviour of Ethiopian forest tree species was made by comparing the result obtained from each model to the report from published material that used the usual long experimental procedure. Although some additional studies with other tree species might be needed for the general acceptance of these models, the result of this study has witnessed that these models are robust and reliable for predicting seed storage behaviour of tree species with unknown seed storage behaviour in Ethiopia. These findings might particularly be important to demonstrate the potential of these models, if used in the future, as an alternative to the usual long experimental procedures in decision making regarding the choice of appropriate ex-situ conservation strategy for tree species with unknown seed information.

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