Effect of seed maturity and morphotype traits on seed germination of *Lannea microcarpa* in the dry Sudanian region of Benin

Eude O. A. Goudégnon[1,2]
Kolawolé Valère Salako[3]
Oscar Teka[1]
Gérard N. Gouwakinnou[1,4]
Kisito Gandji[3]
Roméo Tohoun[3]
Madjidou Oumorou[1,2]
Brice Sinsin[1]

[1] Université d'Abomey-Calavi
Faculté des Sciences Agronomiques
Laboratoire d'Écologie Appliquée
01 BP 526, Cotonou
Bénin

[2] Université d'Abomey-Calavi
École Polytechnique d'Abomey-Calavi
Laboratoire de Recherche en Biologie
Appliquée (LaRBA)
01 BP 2009, Cotonou
Bénin

[3] Université d'Abomey-Calavi
Faculté des Sciences Agronomiques
Laboratoire de Biomathématiques
et d'Estimations Forestières
04 BP 1525, Cotonou
Bénin

[4] Université de Parakou
Faculté d'Agronomie
Laboratoire d'Écologie, de Botanique
et de Biologie Végétale
03 BP 125, Parakou
Bénin

Auteur correspondant / Corresponding author:
KISITO GANDJI - gkisito@gmail.com

Photo 1.
Fruits of *Lannea microcarpa* at different maturity stage considered.
(a): Green fruits, (b): Green-red fruit ; (c): Red-purple fruit.
Photo E. O. A. Goudégnon.

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E. O. A. Goudégnon, K. V. Salako, O. Teka, G. N. Gouwakinnou, K. Gandji, R. Tohoun, M. Oumorou, B. Sinsin

RÉSUMÉ

Effets de la maturité des graines et des caractéristiques du morphotype sur la germination des graines de *Lannea microcarpa* dans la région soudanienne sèche du Bénin

Comprendre l'effet de la taille et du niveau de maturité des graines sur leur capacité de germination est essentiel pour la propagation efficace d'une essence. La présente étude a évalué la variabilité de la germination de graines de l'essence fruitière indigène *Lannea microcarpa* en fonction des niveaux de maturité des graines et des caractéristiques du morphotype. Trois niveaux de maturité des fruits (fruits verts, vert-rouge et rouge-pourpre) et quatre morphotypes, déterminés selon les caractéristiques morphologiques des fruits et des graines (diamètre des fruits, masse des fruits, épaisseur des graines, largeur des graines et poids des graines) ont été considérés. Le protocole expérimental prévoyait un bloc complet randomisé avec trois répétitions. Le taux de germination et le temps jusqu'à la première germination ont été calculés et analysés à l'aide de modèles linéaires généralisés à effet mixte et quasi-Poisson, respectivement. Les résultats ont donné le meilleur taux de germination (82,78 ± 5,2 %, 45 jours après le semis) pour le morphotype 2 (graine de taille moyenne) et le plus faible (33,90 ± 1,49 %, 45 jours après le semis) pour le morphotype 3 (graine de plus grande taille). Le temps le plus court pour la première germination a été enregistré pour le morphotype 2 (6,89 ± 1,08 jours après le semis) et le plus long (9,96 ± 3,2 jours après le semis) pour le morphotype 1 (graines plus petites). Les graines des fruits verts avaient un meilleur taux de germination que les graines des fruits vert-rouge et rouge-pourpre. Des variations considérables ont également été observées d'un arbre à l'autre, ce qui suggère un rôle moteur potentiel du génotype dans la capacité de germination des graines. Nos résultats suggèrent que les graines de taille intermédiaire prélevées sur des fruits verts présentent les meilleures performances en matière de germination.

Mots-clés : *Lannea macrocarpa*, germination, niveaux de maturité, caractéristiques morphologiques, morphotypes, Bénin.

ABSTRACT

Effect of seed maturity and morphotype traits on seed germination of *Lannea microcarpa* in the dry Sudanian region of Benin

Understanding the effect of seed size and maturity level on their germination capacity is essential to propagate a species effectively. This study assessed variations in seed germination of the indigenous fruit tree species *Lannea microcarpa* in relation to seed maturity levels and morphotype traits. Three fruit maturity levels (green, green-red, and red-purple fruit) and four morphotypes determined according to fruit and seed morphological characteristics (fruit diameter, fruit mass, seed thickness, seed width and seed weight) were considered. The experimental design was a randomized complete block with three replicates. Germination rate and time to the first germination were computed and analyzed using linear mixed-effect and quasi-Poisson generalized linear models, respectively. The results gave the highest germination rate (82.78 ± 5.2%, 45 days after sowing) for morphotype 2 (medium sized seed) and the lowest (33.90 ± 1.49%, 45 days after sowing) for morphotype 3 (larger seeds). The shortest time to the first germination was recorded for morphotype 2 (6.89 ± 1.08 days after sowing) and the longest (9.96 ± 3.2 days after sowing) for morphotype 1 (smaller seeds). Seeds from green fruits had a better germination rate than seeds from green-red and red-purple fruits. Considerable variation was also observed between individual trees, which suggests a potential genotype driving-force in seed germination capacity. Our findings suggest that seeds of intermediate size collected from green fruits perform best as regards germination.

Keywords: *Lannea macrocarpa*, seed germination, maturity levels, morphological characteristics, morphotypes, Benin.

RESUMEN

Efecto de la madurez de la semilla y de los rasgos del morfotipo sobre la germinación de la semilla de *Lannea microcarpa* en la región sudanesa seca de Benín

Comprender el efecto del tamaño de las semillas y su nivel de madurez en la capacidad de germinación es esencial para propagar una especie de forma eficaz. Este estudio evaluó las variaciones en la germinación de semillas de la especie de árbol frutal autóctono *Lannea microcarpa* en relación con los niveles de madurez de las semillas y los rasgos del morfotipo. Se consideraron tres niveles de madurez del fruto (fruto verde, verde-rojo y rojo-morado) y cuatro morfotipos determinados según las características morfológicas del fruto y de la semilla (diámetro del fruto, masa del fruto, grosor de la semilla, anchura de la semilla y peso de la semilla). El diseño experimental fue un bloque completo aleatorio con tres repeticiones. La tasa de germinación y el tiempo hasta la primera germinación se calcularon y analizaron mediante modelos lineales de efectos mixtos y modelos lineales generalizados cuasi-Poisson, respectivamente. Los resultados dieron la tasa de germinación más alta (82,78 ± 5,2 %, 45 días después de la siembra) para el morfotipo 2 (semilla de tamaño medio) y la más baja (33,90 ± 1,49 %, 45 días después de la siembra) para el morfotipo 3 (semilla de mayor tamaño). El tiempo más corto hasta la primera germinación se registró para el morfotipo 2 (6,89 ± 1,08 días después de la siembra) y el más largo (9,96 ± 3,2 días después de la siembra) para el morfotipo 1 (semillas más pequeñas). Las semillas de los frutos verdes tuvieron un mejor índice de germinación que las semillas de los frutos verde-rojo y rojo-morado. También se observó una considerable variación entre árboles individuales, lo que sugiere un potencial efecto del genotipo en la capacidad de germinación de las semillas. Nuestros resultados sugieren que las semillas de tamaño intermedio recogidas de frutos verdes son las que proporcionan mejores resultados de germinación.

Palabras clave: *Lannea macrocarpa*, germinación de semillas, niveles de madurez, características morfológicas, morfotipos, Benín.

Introduction

Germinated seed is a key stage in plant life cycle which determines seedling establishment, abundance, and spatial distribution (Souza and Fagundes, 2014). Seeds morphological characteristics and physiology determine germination rate, seedling vigor and survival (Baskin and Baskin, 2014). Seed size and/or mass may determine germination rate (Nagarajan and Mertia, 2006; Assogbadjo *et al.,* 2011; Noor *et al.*, 2016) and seedling vigor (Idohou *et al.*, 2015). Large seeds tend to produce more vigorous seedling than small seeds because they potentially store more resources, which enhance seedling survival.

On the other hand, fruit maturity determines seed physiological state and seed germination capability (Keeley, 1991; Murdoch and Ellis, 2000). For instance, *Gmelina arborea* Roxb. fruits which maturity index colour are greenish yellow, yellow brown, dark brown, yellow, and green, give the best germination rate with yellow brown fruit seeds than those from dark brown fruits (Adebisi *et al.*, 2011). In addition, oil content of seeds of *G. arborea* has been also found as important factor in seed germination. Indeed, oil content amount and germination rate were positively linked and increase from young green fruit to yellow fruit and brown fruit in *Jatropha curcas* L. (Negasu, 2015).

In the last decades, there are gaining efforts to domesticate indigenous fruit tree (IFT) species and to promote their cultivation to improve their uses. Examples included *Strychnos cocculoides* Baker in Zambia (Mkonda *et al.*, 2003), *Phoenix dactylifera* L. (Chao and Krueger, 2007), *Sclerocarya birrea* (A. Rich.) Hochst. in South Africa and Benin (Moyo *et al.*, 2009 and Gouwakinnou *et al.*, 2011, respectively), *Chrysophyllum caimito* L. in Central Panama (Parker *et al.*, 2010), *Adansonia digitate* L. in Benin and Sudan (Assogbadjo *et al.*, 2011; Wiehle *et al.*, 2014), *Synsepalum dulcificum* (Schumach. & Thonn.) Daniell (Achigan-Dako *et al.*, 2015; Tchokponhoué *et al.*, 2020, 2021), among others. IFT species of dry areas, such as the African grape *Lannea macrocarpa* Engl. & K. Krause, play an important role for rural communities through the various uses it provides, such as food, medicine, and fodder (Adjanohoun *et al.*, 1980; Arbonnier, 2000; Marquet and Jansen, 2005). Its seeds are used for biofuel processing (Yunus *et al.*, 2013) and as alimentary oil for human and animal feeding (Bazongo *et al.*, 2014). The importance of *L. microcarpa* in rural communities' livelihoods has led to overexploitation and the concomitant population decline (Haarmeyer *et al.*, 2013). In addition, the species natural regeneration is rare and natural populations are ageing (Agbogan *et al.*, 2015) in Togo, as in Benin, where adult trees density was found to be less than 7 trees/km^2 with very few natural regeneration individuals (Goudégnon, 2018).

Therefore, to reduce human pressure and ensure a sustainable use of *L. microcarpa*, conservation actions, domestication, and promotion of its cultivation are essential. In particular, understanding how to effectively propagate the species is a key step in its domestication process. For instance, how seed size and maturity levels affect their germination capability are yet to be understood. In a previous study, four morphotypes on basis of fruits and seeds morphological characteristics has been identified (Goudégnon, 2018) and their germination capacity and seedling growth performance are yet to be studied.

Lannea microcarpa could be propagated through seeds (Neya, 2006). Seeds are drought tolerant (Daws *et al.*, 2004) and have low germination rate mainly because of their oil content amount (Neya, 2006) that causes them to quickly lose viability. As oil content in seeds depends on fruit maturity levels (Negasu, 2015), it is expected that germination potential of seeds varies with the fruit maturity level. However, studies on the relationship between seed oil content and maturity level have shown contrasted results. While some studies reported positive relationships (Mtambalika *et al.*, 2014; Idohou *et al.*, 2015), others reported no consistent relationships (Shoab *et al.*, 2012). The above suggests species-specific relationship and then species-specific investigation. Despite the growing number of studies on *L. microcarpa* (Daws *et al.*, 2004; Neya, 2006; Picerno *et al.*, 2006; Sereme *et al.*, 2008; Bationo *et al.*, 2012; Yunus *et al.*, 2013; Haarmeyer *et al.*, 2013; Sereme *et al.*, 2014; Bazongo *et al.*, 2014; Agbogan *et al.*, 2015; Goudégnon *et al.*, 2016), little have covered the how seed size and maturity levels affect their germination capability. Therefore, this study aims to evaluate the influence of morphological characteristics and maturity levels of *L. microcarpa* seeds on germination rate and germination time.

Table I.
Discriminating morphological traits (mean ± se) of *Lannea microcarpa* morphotypes.

Morphological traits	Morphotype 1	Morphotype 2	Morphotype 3	Morphotype 4
Fruit diameter (cm)	9.99 ± 0.64	10.67 ± 0.60	11.79 ± 0.78	11.03 ± 0.50
Fruit mass (g)	0.78 ± 0.09	0.85 ± 0.07	1.16 ± 0.13	1.13 ± 0.11
Seed thickness (cm)	5.02 ± 0.41	5.39 ± 0.39	6.17 ± 0.77	5.24 ± 0.32
Pulp + seed mass (g)	0.61 ± 0.09	0.67 ± 0.05	0.93 ± 0.11	0.92 ± 0.12
Seed width (cm)	6.50 ± 0.25	7.13 ± 0.31	7.75 ± 0.25	6.94 ± 0.39
Seed mass (g)	0.19 ± 0.02	0.23 ± 0.03	0.30 ± 0.04	0.21 ± 0.03

Materials and methods

Study area

The study was conducted in the Sudanian zone of the Republic of Benin. The Sudanian zone is subdivided into a dry and humid Sudanian zones corresponding to the phytodistricts Mékrou-Pendjari (annual rainfall of 900-1,000 mm) and Atacora Chain (annual rainfall of 1,000-1,200 mm), respectively (Adomou *et al*., 2006). Fruits used for morphotypes identification were collected within two natural populations of *L. microcarpa* located in dry and humid parts of the Sudanian zone, respectively. The nursery experimentation was carried out at the experimentation site of the former National School of Natural Resources Management and Protection of University of Parakou in the district of Kandi, northwest of Benin in northern Benin where the annual average rainfall amount is about 1030.34 mm with temperature ranging from 25.2 °C to 32.5 °C (respectively for the coolest and driest seasons).

Study species

Lannea microcarpa commonly called African grape is a dioecious indigenous fruit species belonging to the Anacardiaceae family. It is an edible IFT of West Africa (Arbonnier, 2000; Marquet and Jansen, 2005). *Lannea microcarpa* occurs in Sudanian zones of West Africa where it is found on deep and lateritic soil. According to Sacande (2007), the northern limit of its habitat is the Sahelo-sudanian zone (500-900 mm) and the southern limit is the Guinean zone (> 1,100 mm). In Benin, the species is mainly located along Sudanian zone in various land uses including protected areas and farmlands (Sinsin and Kampmann, 2010). The fruit of species is one-seeded ellipsoid drupe that turns from green to red/black-purple when ripening (Neya, 2006). The seed contains about 35% oil, which has been pointed out as factor that could weak seeds germinating capacity. *Lannea microcarpa* is used for various purposes such as food (fruits consumption), medicine, firewood, construction, ceremony, textile dyeing (Vodouhê *et al.*, 2009; Bationo *et al.*, 2012; Mabika *et al.*, 2013; Garba *et al.*, 2015; Goudégnon *et al.*, 2017). The species populations found are ageing with low natural regeneration (Agbogan *et al.*, 2015; Haarmeyer *et al.*, 2013).

Four statistical morphotypes of *L. microcarpa* were previously identified based on morphological traits of fruits and seeds collected on trees from the Sudanian zone (table I). All morphotypes exhibited significant differences between fruits and seeds. Seeds of morphotype 1 were the smallest, followed by morphotype 4, morphotype 2 and morphotype 3 seeds. Morphotype 1 seeds were the thinnest (5.02 ± 0.41 cm), with smaller width (6.50 ± 0.25 cm) and lower weight (0.19 ± 0.02 g) whereas morphotype 3 seeds have the greater values (thickness: 6.17 ± 0.77 cm; width: 7.75 ± 0.25 cm; weight: 0.30 ± 0.04 g). Seeds of morphotype 2 (thickness: 5.39 ± 0.39 cm; width: 7.13 ± 0.31 cm; weight: 0.23 ± 0.03 g) and morphotype 4 (thickness: 5.24 ± 0.32 cm; width: 6.94 ± 0.39 cm; weight: 0.21 ± 0.03 g) were of intermediate size.

Experimental design and data collection

For each morphotype, three trees were randomly selected and, on each tree, fruits at different levels of maturity (photo 1) were harvested. Fruits maturity levels were determined based on their physical colour. The maturity levels considered were green fruits (unripe), green red (ripe) fruits and red purple (ripe) fruits. Sixty (60) fruits from which seeds (60 seeds) were extracted were randomly collected from each tree for a total of 2,160 seeds for the four morphotypes. The experimental units (set of 20 polyethylene pots, containing each one seed) were arranged in randomised complete block design with three replicates (720 seeds per replicate). For each morphotype, seeds were sown at 1 cm depth in polyethylene pots filled of compost soil. Experimentation was conducted during rainy season (June-July 2016) and pots were exposed to sunshine and rain. The nursery experimentation was carried out at the experimentation site of the former National School of Natural Resources Management and Protection of University of Parakou in the district of Kandi, northwest of Benin in northern Benin where the annual average rainfall amount is about 1,030.34 mm with temperature ranging from 25.2 °C to 32.5 °C (respectively for the coolest and driest seasons). Pots were watered the days it did not rain. Germination in each pot was recorded every day for the 45 days after sowing. Seed has germinated as soon as the seedling emerge out.

Data analysis

Germination rate and germination time (number of days to the first germination) were computed as response parameters. For each experimental unit, germination rate was calculated as the number of germinated seeds divided by the total number of seed sowed (here 20 seeds). Germination rate was computed at day 3 (when the first seed germinated) and then every 3 days till the 45th day. Data were analysed using linear mixed effects model (Pinheiro and Bates, 2000) on longitudinal data. Factors "morphotype", "time" and "maturity stage" were included as fixed effects while "Block" and "tree" were included as random effects. Large variance due to factor "tree" (as compared to residual variance) suggested important tree-to-tree variation. The final germination rate (at day 45 after sowing) was also analyzed using linear mixed effect models. The same factor as in the longitudinal models were considered except the time. Effects of morphotype and maturity stage on the time (number of days) to the first germination was analysed using quasi-Poisson generalized linear model. All statistical analyses were performed using the package nlme (Pinheiro *et al.*, 2016) in R 3.3.2 software (R Development Core Team, 2016).

Results

Effect of seed maturity and morphological differences on time-related seed germination

There were significant variations ($P < 0.05$) in the germination rate according to time and among morphotypes but not among fruit maturity levels ($P > 0.05$) (table II). In addition, significant interaction ($P < 0.05$) was found between time and morphotypes, indicating that differences among morphotypes varied with time and vice-versa. Accordingly, there was relatively little difference among morphotypes between day 3 and day 9 while greater differences were noted from day 9 although these differences became stable after day 21 (figure 1). Morphotype 2 germination behaviour is relatively different from other morphotypes, which show very similar patterns, particularly during the first 15 days. In morphotype 2, germination curve reached 51.40 ± 15.72% in nine days whereas morphotype 4 seeds took 27 days for the germination rate curve to reach 50.37 ± 12.30%. The other morphotypes (1 and 3) seeds germination rate (49.44 ± 12.30% and 41.48 ± 15.55% respectively) did not reach 50% before the end of the experiment.

Therefore, medium size seeds (morphotype 2) germinated better than larger seeds (morphotype 3). There was also significant interaction ($P < 0.05$) between morphotype and maturity stage on germination rate. Thus, differences in germinate rate among maturity levels were not similar across morphotypes. Seeds from green fruits germinated better than those from green-red and red-purple fruits (82.78 ± 5.2%, 77.08 ± 6.98% and 69.17 ± 5.07% respectively; figure 2a-c). Seeds of morphotype 2 gave the highest germination rate (82.78 ± 5.2%) for green fruits at the day 24 and the lowest germination rate was recorded for green-red fruits (33.90 ± 1.49%) of morphotype 3 at day 21. Seeds of morphotype 4 germinated and reached 50.60 ± 12.30% (for green-red fruits at day 21; figure 2b) whereas those of morphotype 1 reached 56.10 ± 11.60% for green-red fruits at day 33 (figure 2b). There was also a large amount of variance due to the random effect of trees (0.06 compared to 0.04 for residuals; also see the greater differences between the marginal and the conditional R^2), suggesting important variation among trees. This indicates that for a given morphotype and a fruit maturity level, important variation could arise from one tree to another.

Table II.
Effect of *Lannea microcarpa* fruits maturity level and morphological differences on seed germination rate: results of the linear mixed effect models.

Terms in the model	Chi-square	Df	Pr (> Chi-square)
Fixed factors			
Time	762.06	1	< 0.001
Morphotype	31.90	3	< 0.001
Maturity level	4.77	2	0.092
Time: Morphotype	30.22	3	< 0.001
Time: Maturity level	0.38	2	0.828
Morphotype: Maturity level	65.43	6	< 0.001
Time: Morphotype: Maturity level	7.19	6	0.304
Random terms			
Variance due to random effect of trees	0.06		
Variance due to random effect of block	0.00		
Variance due to random effect of time	0.00		
Variance of residual	0.04		
R^2 marginal (%)	29.51		
R^2 conditional (%)	71.44		

Df: degrees of freedom; Pr (> Chi-square): probability (> Chi-square).

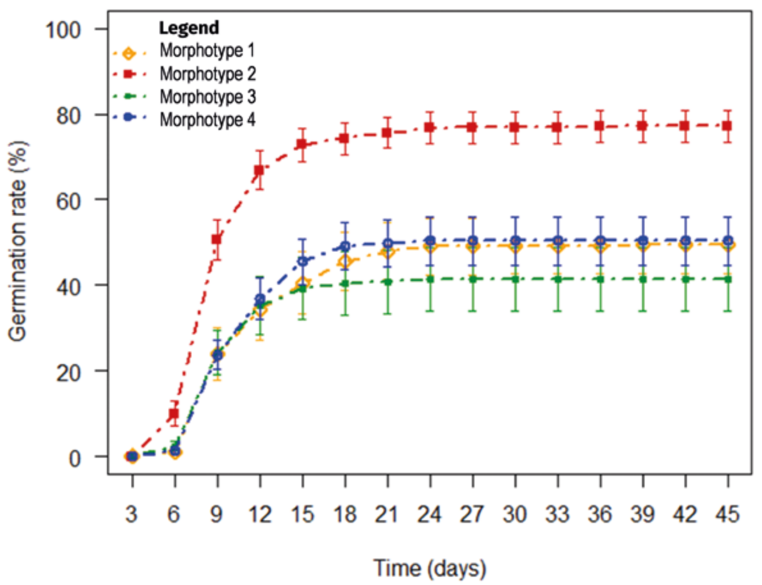

Figure 1.
Evolution of *Lannea microcarpa* seeds germination kinetics according to time and morphotype. The vertical bars are the standard errors.

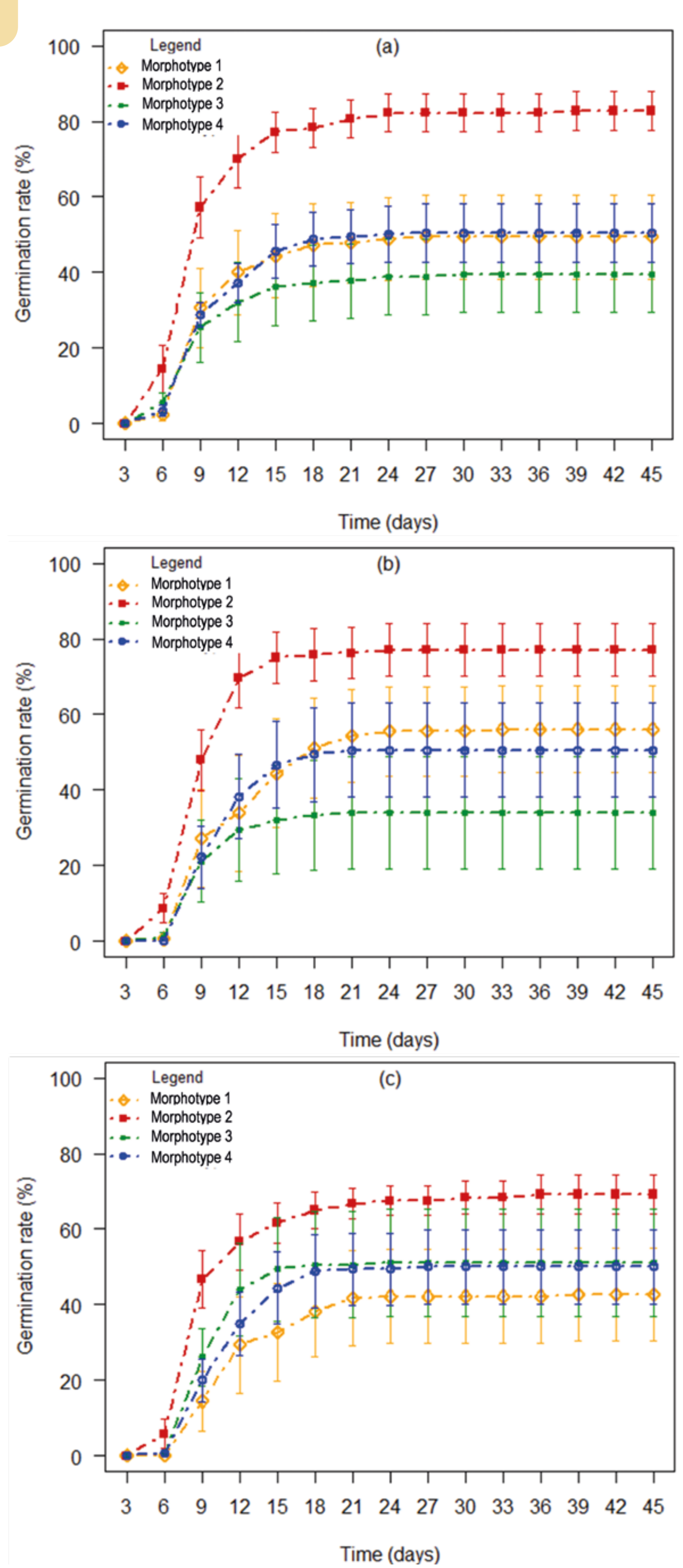

Figure 2.
Evolution of *Lannea microcarpa* seeds germination rate according to time for (a): Green fruit; (b): Green-red fruit and (c): Red-purple fruit.
The vertical bars are the standard errors.

Effect of seed maturity and morphological differences on the final seed germination rate

The final (asymptotic) seed germination rate differed only among morphotypes (P = 0.009; table III). Accordingly, morphotype 2 showed the highest final germination rate (77.22 ± 1.94%) while the lowest final germination rate was recorded for larger seeds i.e. morphotype 3 (41.48 ± 3.88%). Germination rate of morphotypes 1, 3, and 4 seeds did not show significant differences (figure 3A). As mentioned above, there was also important variation due to trees (large variance due to random effect of trees and large difference between marginal and conditional R^2) (table III).

Effect of seed maturity and morphological differences on the time to first germination

The time (number of days) to the first germination varied significantly ($P < 0.05$) according to morphotypes and fruits maturity levels (table IV). Accordingly, earlier germination was observed within morphotype 2 (6.89 ± 1.08 days) followed by seeds of morphotype 3 (7.71 ± 1.82 days), morphotype 4 (8.25 ± 2.36 days) and morphotype 1 (9.96 ± 3.20 days) (figure 4). Regarding fruits maturity levels, the first seed germination occurred before ten days. Seeds from green fruits germinated first (7.47 ± 2.03 days) followed by those from green-red fruits (8.45 ± 2.27 days) and red-purple fruits (8.81 ± 3.04 days). Therefore, medium size seeds (seeds form morphotype 2) and large seeds (morphotype 3) germinated earlier and seeds from green fruits germinated earlier than those from green-red fruits and red-purple fruits.

Discussion

This study revealed significant variation in *L. microcarpa* seed germination rate according to morphotypes, fruit maturity levels and time. Morphotypes have been pointed out as influencing seed germination rate in several studies (Nagarajan and Mertia, 2006; Assogbadjo *et al.*, 2011; Padonou *et al.*, 2015; Noor *et al.*, 2016; Baskin and Baskin, 2014). Our study showed that the germination rate of morphotype 1 (smaller seeds) was lower than that of morphotype 2 (medium seed) which germinated faster and showed higher germination rate than morphotype 3 (larger seeds). Fast germination and high germination rate in small seeds have been reported by Mogie *et al.* (1990), Souza and Fagundes (2014) and Idohou *et al.* (2015). On the other hand, Hopper *et al.* (1979) found within *Glycine max* that small seeds were slower to germinate than medium and large-sized seeds. The difference in seed germination rate in our study could be due to seed coat water permeability which decreases with seed coat thickness increase given that seed size and coat thickness are positively related and inversely linked to water absorption ability (Beninger *et al.*, 1998; Souza and Fagundes, 2014). Also, seed coat thickness was reported to impose constraint to *L. microcarpa* seed germination by inducing a secondary dormancy (Neya *et al.*, 2008). Therefore, medium size seeds have certainly thinner coat than larger ones and are more water permeable and consequently will germinate faster. Lower germination rate in morphotype 1 seed may suggest that within the species, small seeds are not enough vigorous to initiate good germination because they contain low stored resource than larger seed. Seed stored resource in relation to seed size, germination ability and seedling vigour have been reported and small seeds were found to have not enough resource to initiate fast and high germination than larger ones. Within morphotypes, we found that seed germination rate and germination speed were related to fruits maturity levels. Green fruit seed germinated better and faster than seed from green-red and red-purple fruit. These results contrast with findings of Murrinie *et al.* (2019) and Adebisi *et al.* (2011) who reported increasing seed germination rate with fruit maturity levels in *Feronia limonia* and *G. arborea,* respectively. Results revealed that green fruit maturity level favour seed germination than green-red and red-purple ones. The fact that seed extracted from green-red and red purple had relatively lower germination rate may be linked to the increasing amount of oil content in seeds with fruit increasing maturity level. Negasu (2015) have reported the increasing of seed oil content amount with fruit maturity level in *J. curcas* seeds. This report relies on Neya (2006) and Sacande (2007) findings who indicated that seed oil content amount (about 35%) are suspected to cause seed viability loss and therefore reduce seed germination rate. In addition, Haarmeyer *et al.* (2013) have stressed on seed oil content as a factor which could favour low natural regeneration. Therefore, mature green fruit seeds of morphotype 2 are recommended for *L. microcarpa* nursery for seedling production for reforestation or farmland enrichment activities.

Future studies should look at seedling growth performance according to seed size and fruit maturity level as seedling and seed vigour were also found determinant in the seedling establishment (Idohou *et al.*, 2015). The large variation in germination rate related to the random effect of trees suggests that important variation was due to variability within trees despite the small number of trees (3 per morphotype) due to the limitation of logistics. This suggests genetic variation at tree level as morphotype are composed of different trees and seed are genetically linked to mother tree (Foley and Fennimore, 1998; Mbora *et al.*, 2009). In our experiment, all seeds were sown and germinated in the same experimental conditions. In addition, variance partitioning for morphotypes used in this study indicated greater part of variation within population at tree level. Therefore, further investigation might focus on genotype influence on seed vigour. Sereme *et al.* (2014) also has reported wide variation in the offspring, making very difficult the selec-

Table III.
Effect of Lannea microcarpa seed maturity and morphological variation on the final seed germination.

Terms in the model	Chi-square	Df	Pr (> Chi-square)
Fixed terms			
Morphotype	11.65	3	0.009
Maturity level	0.45	2	0.799
Morphotype: maturity level	10.12	6	0.119
Random terms			
Variance due to random effect of trees	0.07		
Variance due to random effect of block	0.00		
Variance of residual	0.03		
R^2 marginal (%)	21.60		
R^2 conditional (%)	79.33		

Df: degrees of freedom; Pr (> Chi-square): probability (> Chi-square).

Table IV.
Effect of Lannea microcarpa fruits maturity and morphological differences on the time to first germination: results of the quasi-Poisson generalized linear model.

Terms in the model	LR Chi-square	Df	Probability
Morphotype	29.77	3	< 0.001
Maturity level	7.66	2	0.022
Morphotype: maturity level	6.65	6	0.354

LR Chi-square: likelihood-ratio chi-squared test; Df: degrees of freedom.

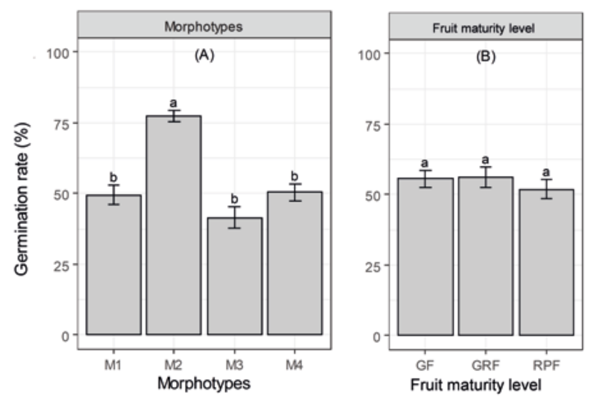

Figure 3.
Final germination rate of *Lannea microcarpa* seeds according to morphotypes (A) and fruit maturity level (B). M1: Morphotype 1; M2: Morphotype 2; M3: Morphotype 3; M4: Morphotype 4; GF: Green fruit; GRF: Green-red fruit and RPF: Red-purple fruit. The vertical bars are the standard errors. The bars with different letters have significantly different means.

tion, and multiplication of superior genotypes of interest when seeds are used for propagation and suggest asexual propagation using micro cutting explants of young shoots from seedlings.

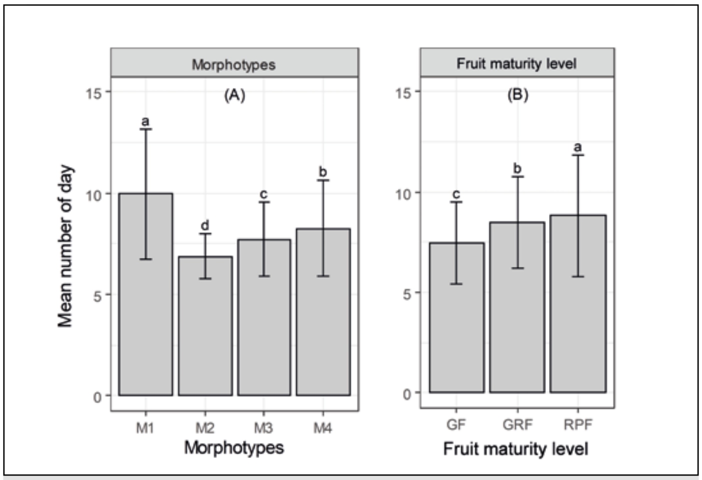

Figure 4.
Mean number of days to the first germination of *Lannea microcarpa* seeds in relationships to morphotypes (A) and fruit maturity level (B). M1: Morphotype 1; M2: Morphotype 2; M3: Morphotype 3; M4: Morphotype 4; GF: Green fruit; GRF: Green-red fruit and RPF: Red-purple fruit. The vertical bars are the standard errors. The bars with different letters have significantly different means.

Conclusion

This study focused on the germination of *Lannea microcarpa* seeds in relationship to morphological characteristics and fruit maturity levels. Both factors had significant effects on germination rate and time. The highest germination rate was observed in mature green fruit seed of medium size that germinate rapidly. Morphotype with larger seeds have shown the lowest germination performance. Therefore, mature green fruit seed of medium size could be used for the species propagation using seed and for domestication process. Our study further suggests great tree-to-tree variation in germination rate and time, which requires further investigation with higher number of individual trees (seed family) for confirmation.

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Data access
The data used in this study are available from the corresponding author upon a reasonable request.

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Goudégnon *et al.* – Authors' contributions

Contributor role	Contributor names
Conceptualization	E. O. A. Goudégnon, K. V. Salako, G. N. Gouwakinnou, M. Oumorou
Data Curation	E. O. A. Goudégnon, K. V. Salako
Formal Analysis	E. O. A. Goudégnon, K. V. Salako, R. Tohoun, K. Gandji
Funding Acquisition	E. O. A. Goudégnon, K. V. Salako, M. Oumorou
Investigation	E. O. A. Goudégnon
Methodology	E. O. A. Goudégnon, K. V. Salako, K. Gandji, G. N. Gouwakinnou, M. Oumorou
Project Administration	E. O. A. Goudégnon, M. Oumorou
Resources	G. N. Gouwakinnou, M. Oumorou
Software	K. V. Salako, G. N. Gouwakinnou, R. Tohoun, E. O. A. Goudégnon, K. Gandji
Supervision	G. N. Gouwakinnou, M. Oumorou
Validation	E. O. A. Goudégnon, K. V. Salako, G. N. Gouwakinnou, M. Oumorou
Visualization	E. O. A. Goudégnon, R. Tohoun, K. V. Salako, K. Gandji, G. N. Gouwakinnou, M. Oumorou
Writing – Original Draft Preparation	E. O. A. Goudégnon, R. Tohoun, K. V. Salako, K. Gandji, G. N. Gouwakinnou, M. Oumorou
Writing – Review & Editing	K. Gandji, E. O. A. Goudégnon, K. V. Salako.

Cirad - Campus international de Baillarguet,
34398 Montpellier Cedex 5, France
Contact : bft@cirad.fr - ISSN : L-0006-579X