

Seed longevity differs in *Astronium fraxinifolium* Schott from two geographic regions in Brazil

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ABSTRACT: The objective of this work was to evaluate the longevity of *Astronium fraxinifolium* Schott seeds collected in the states of Goiás and Minas Gerais in Brazil and analyse its association with local weather conditions during the vegetative and reproductive phases (temperature, precipitation and altitude) and seed oil content. Longevity was tested in a controlled ageing test at a constant temperature of 45 °C and relative humidity (RH) of 60, 65 or 70%, followed by germination. Seed longevity was inferior in seeds collected in the state of Minas Gerais and superior in seeds collected in the state of Goiás. There was a significant positive correlation between seed longevity and temperature and a significant negative correlation between seed longevity and altitude. No correlation was found between rainfall and seed longevity. In addition, we found a significant negative correlation between seed longevity and oil content, which was associated with an increase in malondialdehyde (MDA) content. Thus, the influence of the maternal environment during seed production should be considered during seed collection for improved ex situ conservation of *A. fraxinifolium* seeds.

Key words: ex situ conservation; rainfall; seed storage; temperature

A longevidade de sementes difere em *Astronium fraxinifolium* Schott de duas regiões geográficas do Brasil

RESUMO: O objetivo deste trabalho foi avaliar a longevidade de sementes de *Astronium fraxinifolium* Schott coletadas nos estados de Goiás e Minas Gerais, no Brasil, e analisar a associação com as condições climáticas locais (temperatura, precipitação e altitude) e teor de óleo da semente. A longevidade foi testada através de um teste de envelhecimento controlado a uma temperatura constante de 45 °C e umidade relativa (UR) de 60, 65 e 70%, seguido de germinação. A longevidade das sementes foi inferior nas sementes coletadas no Estado de Minas Gerais e superior nas sementes coletadas no Estado de Goiás. Houve correlação significativa e positiva da longevidade das sementes com a temperatura e correlação significativa e negativa com a altitude. Não foi encontrada correlação entre a precipitação e a longevidade das sementes. Além disso, encontramos uma correlação significativa e negativa da longevidade das sementes e do teor de óleo, que foi associada a um aumento no conteúdo de malonaldeído (MDA). Assim, a influência do ambiente materno durante a produção de sementes pode ser considerada durante a coleta de sementes para melhor conservação ex situ de sementes de *A. fraxinifolium*.

Palavras-chave: conservação ex situ; precipitação; armazenamento de sementes; temperatura

Introduction

Seed longevity is important for *ex situ* conservation and the survival of plant populations in their natural environment. Seed longevity is defined as the time required for seeds to decline in viability by one sigma during dry storage and is considered an important trait for ecology, agronomy and economy (Sano et al., 2016). Studies have revealed considerable long-term longevity for seeds of *Cassia multijuga* collected in 1776, which presented 100% germination in 1934 and thus high viability after 158 years, as well as *Cassia bicuscularis*, with high viability after 115 years, and *Mimosa glomerata*, with high variability after 81 years, among others (Bewley et al., 2013). Extreme long-term seed longevities have been reported for sacred lotus (*Nelumbo nucifera*) (nearly 1,300 years) (Shen-Miller, 2002) and for *Phoenix dactylifera* (>2,000 years) (Sallon et al., 2008), whereas other species such as onion and pepper show relatively short longevity (Sano et al., 2016). Additionally, some species possess seeds with poor longevity, such as *Inga vera* (Faria et al., 2006).

During seed development, longevity is progressively acquired during late maturation, increasing until reaching a maximum before or close to the dry state. Several studies have been carried out to evaluate the correlations between seed dry storage time and seed mass, oil content, and carbohydrate composition and taxonomy and climate (Probert et al., 2009). Walters et al. (2005) suggested taxonomic and climatic effects on interspecific differences in longevity. According to these authors, seeds of species from cold and temperate climates have shorter longevity than seeds of species from hot and arid climates (McDonald, 1999; Kranner et al., 2010; Walters et al., 2010). For example, heat during seed development, such as temperatures varying from 30 to 33 °C, improved longevity in soybean seeds (Basso, 2018). However, higher temperatures (24-26 °C) influenced the duration of the maturation period of the seeds, in turn negatively affecting the acquisition of longevity in *Medicago truncatula* seeds (Righetti et al., 2015).

In addition, the seed properties such as lipid composition, initial viability, maturation stage, seed mass, oil content, and carbohydrate composition that affect seed longevity are strongly influenced by the environmental conditions during seed development and maturation. Conditions such as the relative humidity and air temperature during storage and the degree of infection by microorganisms and insects also influence longevity (Bewley et al., 2013). For instance, oil content may influence seed longevity. According to Sharma et al. (2013), soybean seeds from basal positions showed more deteriorative changes during storage than those from apical positions, which might be related to the higher lipid content in seeds from the basal portion of the soybean stem axis than in those from the apical portion. It is believed that lipid peroxidation is the main cause of seed deterioration in dry seeds during storage, which in turn influences longevity (Bewley et al., 2013). Despite the numerous studies in this area, there is a lack of studies considering the influence of the environment on seed longevity in tree seeds from Brazilian biomes.

The species *Astronium fraxinifolium* Schott belongs to the family Anacardiaceae, occurring in Mexico and part of Central America, Argentina, Bolivia, Brazil and Paraguay (IBGE, 2002; Lorenzi, 2014). It is a tree that produces large quantities of seeds that are easily dispersed by wind. The seeds are non-endospermic and show rapid and uniform germination.

The objective of this work was to evaluate the longevity of *A. fraxinifolium* seeds from the states of Goiás and Minas Gerais in Brazil and to verify whether seed longevity was related to the environment during the vegetative and reproductive phases (temperature, precipitation and altitude) and to oil content.

Materials and Methods

Mature fruits of *A. fraxinifolium* were collected in 2013 in two geographic regions of Brazil. The trees were located in the counties of Alto Paraíso de Goiás (GO2), Cavalcante (GO1), Colinas do Sul (GO3) and Niquelândia (GO4, GO5 and GO6) in the state of Goiás and in the counties of Montes Claros (MG2 and MG3), Mirabela (MG1) and Lontra (MG4) in the state of Minas Gerais. The trees were identified and geo-referenced. The reproductive phase in *A. fraxinifolium* occurs from July until October. Seeds were collected from a total of ten accessions, and each accession corresponded to one tree. Next, the seeds were placed in 1-litre glass bottles with a sealed cap containing silica gel and stored at an 18% relative humidity and a temperature of 5 °C until the start of experiments. The water content of the seeds during accelerating ageing experiments was determined in an oven at 105 ± 3 °C for 24 hours, with two replicates of 25 seeds each, and calculated on a fresh weight basis (Brasil, 2009). Seed germination was tested using rolled filter paper moistened with distilled water, with four replicates of 25 seeds. The paper rolls were placed in an incubator with a constant temperature of 30 °C and a daily photoperiod of eight hours under white-light, tubular, fluorescent lamps (20WT1) with a measured fluence rate of $30 \mu\text{mol m}^{-2} \text{s}^{-1}$. Seeds were considered germinated when the primary root showed a length of 2 mm or more. The seed longevity of ageing seeds was assessed by placing dried seeds in 500-ml glass bottles hermetically sealed over a solution of lithium chloride at a constant temperature of 45 °C and relative humidity (RH) of 60, 65 or 70%. We added 60, 55 and 50 grams of LiCl to 200 ml of deionized water to achieve the 60, 65 and 70% RH, respectively (Golden & Hay, 2008). After different periods of time, seeds were imbibed as described above, and their viability was assessed using the germination assay described above. The viability data were then transformed into probits. A probit unit is equivalent to one standard deviation of the normal distribution of seed decay over time (Ellis & Roberts, 1980). Then, the values of sigma and P_{50} were calculated for each relative humidity. Sigma refers to the time required for viability to drop by one probit. P_{50} is defined as the time (in days) at which a stored seed lot loses 50% of its viability during storage.

The geographical coordinates, altitude (m), mean annual temperatures (°C) and mean precipitation (mm) for the collection site of each accession are presented in Table 1. The altitude, mean annual temperature and annual precipitation were based on data obtained in 2013. The oil content was determined according to the Am 5-04 method (AOCS, 2005) with Ankon equipment. Lipid peroxidation was determined by measuring the malondialdehyde content (MDA) in four replicates of 25 non-aged or aged seeds. The seeds were aged at a 60% relative humidity and temperature of 45 °C for twenty-one or thirty-one days. The extraction of malondialdehyde was performed according to Cakmak & Horst (1991). The MDA content was expressed in nmol g⁻¹ fresh weight.

The experimental design was entirely randomized. For the variables sigma and P₅₀, the factorial scheme was 10 x 3, with the first factor representing the 10 accessions and the second factor representing the 3 relative humidities (60, 65 and 70%). To evaluate the influence of the environmental conditions on longevity, Pearson correlation analysis was performed using the log₁₀-transformed P₅₀ data versus temperature, precipitation, oil content and latitude. For the MDA evaluation, the scheme was 10 x 3, with the first factor representing the 10 accessions and the second factor representing without ageing or with ageing for 21 or 31 days. The seed oil content data of the 10 accessions were evaluated at a relative humidity of 65%. The sigma, P₅₀, MDA and oil content data were evaluated for normality, tested with analysis of variance and subjected to post hoc comparisons with Tukey's test. Data that did not follow a normal distribution were square-root transformed to meet the assumptions of the analysis.

Results and Discussion

The geographical coordinates, altitude, mean temperature, average precipitation (during the vegetative and reproductive phases) and oil content of the seeds of each accession are presented in Table 1. The weather conditions used are from 2013.

Ageing at 45 °C and a relative humidity of 60, 65 or 70% resulted in a significant decrease in seed viability for all ten accessions (Figure 1). In general, in all accelerated ageing conditions studied (60, 65 and 70% RH), the accessions collected in the state of Goiás always showed higher seed longevity than the accessions collected in the state of Minas Gerais (Figure 1 and Table 2 and Table 3). The difference in seed longevity between the accessions may be due to the environment, which may have influenced the seeds before harvest.

Our results showed that longevity was significantly positively correlated with local temperature ($r = 0.48$ and $p < 0.01$) (Figure 2). The mean annual temperatures from the areas where the seeds were collected were 24.8 °C for the state of Goiás and 22.0 °C for the state of Minas Gerais (Table 1). Thus, longevity was affected by the higher temperature in the state of Goiás. We also found a significant but negative correlation between longevity and altitude ($r = -0.44$ and $p < 0.02$) (Figure 2). The mean altitude in the state of Minas Gerais was approximately 790 metres, while in the state of Goiás, the mean altitude was approximately 550 metres (Table 1). However, we did not find a significant correlation between rainfall and longevity ($r = 0.23$ and $p \geq 0.27$) (data not shown). The water content of the seeds from all accessions collected during the accelerated ageing experiments varied from 8.0 to 9.2% on a fresh weight basis (data not shown).

Seeds from the state of Minas Gerais had a higher oil content than seeds from the state of Goiás (Table 1). We found a negative correlation between oil content and seed longevity (Figure 2). Thus, lipid composition may influence the seed longevity of *A. fraxinifolium* seeds since fatty acids contribute to lipid peroxidation. The results for malondialdehyde (MDA) are presented in Table 4. It was verified that ageing for 21 and 31 days at 45 °C and a 60% RH significantly increased the MDA values. Of the four accessions from Minas Gerais, accession MG 2 presented the greatest increase in MDA content. Of the six accessions from Goiás, accessions GO 3 and GO 6 exhibited the greatest increase in MDA content after 31 days of ageing.

Table 1. The names and details of collection sites of the 10 accessions of *A. fraxinifolium* from the states of Goiás and Minas Gerais, namely, the geographical coordinates, altitude, annual mean temperature and annual mean precipitation from the year 2013 and oil content.

Accession	Geographical coordinates	Altitude (m)	Mean temp. (°C)	Mean rainfall (mm)	Oil content* (%)
GO 1	14°00'50"S - 47°46'51"W	547	25.00	1546	31
GO 2	14°13'38"S - 47°55'23"W	594	24.70	1577	30
GO 3	14°11'45"S - 48°05'41"W	470	25.30	1576	27
GO 4	14°59'05"S - 48°40'42"W	526	24.90	1471	33
GO 5	14°39'32"S - 48°35'21"W	601	24.60	1609	29
GO 6	14°57'58"S - 48°39'49"W	557	24.70	1487	32
Averages		550	24.87	1544	30.3b
MG 1	16°16'48"S - 44°09'14"W	822	21.80	1067	32
MG 2	16°45'38"S - 43°53'02"W	662	22.60	1061	31
MG 3	16°51'15"S - 44°03'45"W	897	21.30	1272	31
MG 4	15°52'23"S - 44°18'07"W	777	22.40	1016	32
Averages		789	22.02	1104	31.5a

*For oil content, different lowercase letters in the column indicate statistically significant differences. The F test was applied at a 1% probability level.

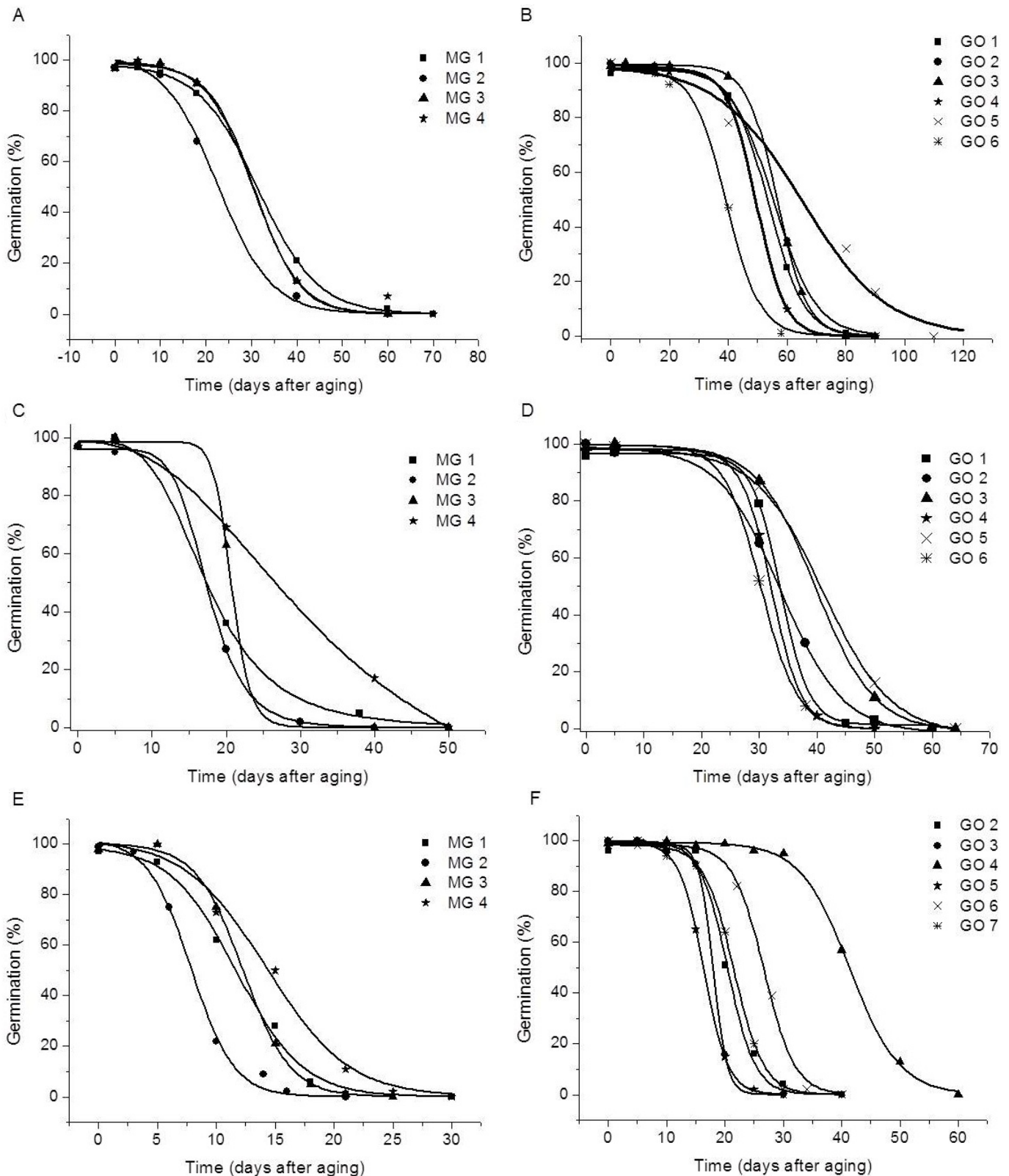


Figure 1. Changes in the germination percentage of *A. fraxinifolium* seeds collected in the states of Goiás and Minas Gerais. **A, C** and **E** are seeds from the state of Minas Gerais stored at 45 °C with an RH of 60, 65 and 70%, respectively. **B, D** and **F** are seeds from the state of Goiás stored at 45 °C with an RH of 60, 65 and 70%, respectively.

Seed longevity is important for *ex situ* conservation and the survival of plant populations in their natural environment. However, seed longevity is strongly influenced by environmental cues perceived by both the parent plant and

zygote (Leprince et al., 2017). Thus, in this study, we attempted to show the differences in seed longevity of *A. fraxinifolium* collected in two geographical regions of Brazil. This work also aimed to study the influence of the environment and oil content

Table 2. Values of sigma and P_{50} , in days, for the 10 accessions of *A. fraxinifolium* at three levels of RH (60, 65 and 70%).

Accession	60% RH		65% RH		70% RH	
	Sigma	P_{50}	Sigma	P_{50}	Sigma	P_{50}
GO 1	11.98 bA	49.4 bcA	10.05 abA	29.0 cB	4.08 bB	21.8 bcC
GO 2	11.81 bA	49.6 bcA	9.12 abcB	29.8 bcB	3.96 bC	17.8 cdeC
GO 3	9.84 bA	53.5 bA	9.31 abA	37.5 aB	8.01 aA	41.1 aB
GO 4	11.42 bA	46.4 cA	8.15 abcB	27.1 cdB	3.37 bC	16.8 cdefC
GO 5	17.65 aA	69.5 aA	10.97 aB	35.3 abB	4.82 abC	24.5 bC
GO 6	10.58 bA	36.4 dA	7.31 bcB	26.6 cdB	5.05 abB	20.3 bcdC
MG 1	11.90 bA	30.7 deA	7.35 bcB	25.7 cdB	4.01 bC	11.8 fgC
MG 2	9.91 bA	26.9 eA	5.74 cB	15.6 eB	3.17 bB	8.8 gC
MG 3	8.92 bA	32.1 deA	5.67 cB	22.2 dB	2.74 bC	12.7 efgC
MG 4	11.10 bA	36.1 dA	8.37 abcB	25.4 cdB	4.06 bC	15.6 defC

Significant differences are indicated by lowercase letters in the columns and uppercase letters in the rows. Averages followed by the same letter do not differ statistically. Tukey's test was applied at a 5% probability. CV% for sigma = 19.24, and CV% for P_{50} = 8.64.

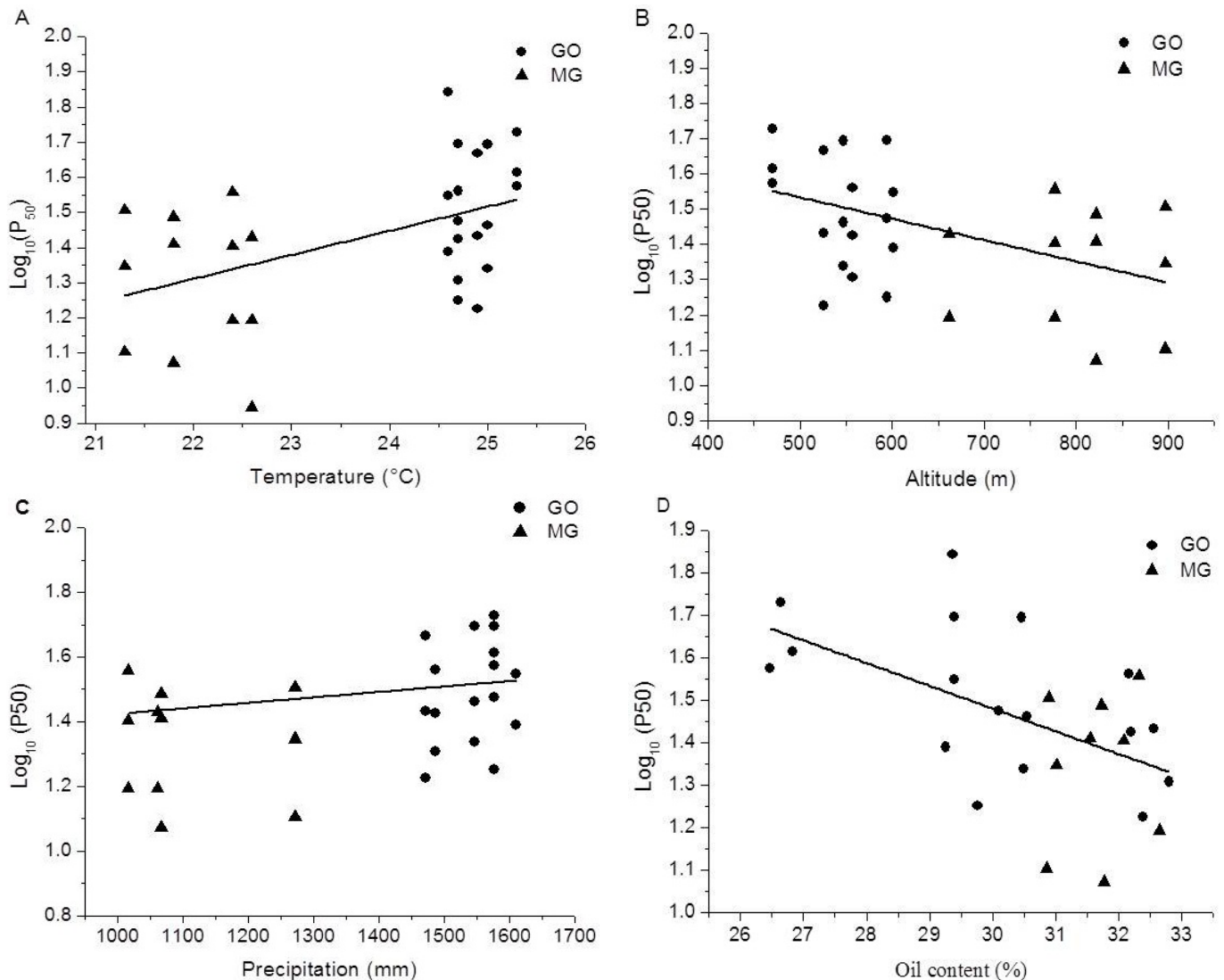


Figure 2. Pearson correlations of the \log_{10} of P_{50} . **A**, Mean annual temperature; **B**, Altitude; **C**, Precipitation; and **D**, Oil content. The temperature data are from the collection sites in the states of Minas Gerais and Goiás in 2013.

on seed longevity. We found that seed viability decreased with an increase in storage duration in *A. fraxinifolium* and that longevity was influenced by the environment and seed oil content. Our results confirmed a positive influence of temperature on seed longevity of *A. fraxinifolium* collected in the state of Goiás. In the same state, the average temperature

in the year of seed production was almost 3 °C higher than that experienced by seeds collected in the state of Minas Gerais. No positive influence of precipitation or altitude on seed longevity was found. An influence of the environment on seed longevity was previously shown by Probert et al. (2009), who studied the seed longevity of 195 wild species from

Table 3. Values of sigma and P₅₀ for the 10 accessions of *A. fraxinifolium* at three levels of relative humidity (60, 65 and 70%).

	UR	Locations	
		GO	MG
Sigma	60%	12.21 A	10.46 A
	65%	9.15 A	6.78 B
	70%	4.88 A	3.50 B
P ₅₀	60%	48.10 A	31.45 B
	65%	30.88 A	22.22 B
	70%	23.72 A	12.23 B

Averages followed by the same letter in a row do not differ statistically. Tukey's test was applied at a 5% probability. CV% for sigma = 19.24, and CV% for P₅₀ = 8.64.

Table 4. Malondialdehyde content (nmol g⁻¹ fresh weight) of *A. fraxinifolium* seeds without ageing and after ageing for 21 and 31 days at a 60% RH and 45 °C.

Accession	No ageing	21 days of ageing days	31 days of ageing
GO 1	23.4 abA	23.9 cdeA	25.5 bA
GO 2	23.0 abB	36.0 aA	35.6 aA
GO 3	23.9 abB	31.9 abA	28.1 bAB
GO 4	15.5 cB	30.3 abcA	26.2 bA
GO 5	28.8 aA	22.9 deB	30.6 abA
GO 6	19.0 bcB	22.2 deAB	25.8 bA
MG 1	24.3 abB	24.4 cdeB	30.0 abA
MG 2	23.3 abB	20.3 eB	31.4 abA
MG 3	20.1 bcB	28.2 bcdA	26.2 bA
MG 4	20.1 bcC	32.2 abA	26.1 bB

Significant differences are indicated by lowercase letters in the columns and uppercase letters in the rows. Averages followed by the same letter do not differ statistically. Tukey's test was applied at a 5% probability. CV% = 11.79.

environments ranging from tropical forests to cold deserts. Thus, seed longevity seems to depend on maternal factors before harvest. For instance, Kochanek et al. (2011), working with *Plantago cunninghamii*, a wild species, found that the pre-zygotic environment resulted in a highly plastic parental response that was passed on to offspring seeds and changed their longevity by more than a factor of 2. Thus, the pre-zygotic growth environment modulated seed longevity via a parental effect. However, we should not exclude that other factors, such as differences in soil nutrient composition, the amount of light, and soil structure, especially with regard to the water content in the soil, as well as gas exchange properties, relative air humidity, and genetic factors, may also influence the seed longevity of *A. fraxinifolium*.

Lipid peroxidation has been widely reported as one of the main drivers of oilseed deterioration during the ageing process (Bhanuprakash et al., 2010). During seed deterioration, lipid peroxidation increases, resulting in damage to the cell membrane and the consequent generation of toxic sub-products (Schwember & Bradford, 2010). MDA is a short-chain aldehyde, and its concentration has been used to estimate the lipid peroxidation intensity in biological systems (Lima Abdalla, 2001). Here, we found a correlation between oil content and longevity. Seeds from the state of Goiás had a lower oil content and superior longevity, while seeds from the

state of Minas Gerais showed a higher oil content and inferior longevity. The production of MDA was also inferior in seeds produced in the state of Goiás. Therefore, the MDA content is positively associated with seed longevity and seems to be promising for evaluating the beginning of the deterioration process during storage in seeds of *A. fraxinifolium*. However, more experiments are required to confirm this.

Conclusion

The environmental conditions during vegetative or reproductive phases were correlated with the longevity of *Astronium fraxinifolium* seeds. Seed longevity was inferior in seeds collected in the state of Minas Gerais and superior in seeds collected in the state of Goiás.

Based on the correlations found in this work, we suggest that the influence of the environment on the seed longevity of *Astronium fraxinifolium* should be considered when collecting seeds for *ex situ* conservation.

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