

Original Article

## Film coating of *Enterolobium schomburgkii* (Benth.) Benth seeds

Revestimento em filme de sementes de *Enterolobium schomburgkii* (Benth.) Benth

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### Abstract

The growing demand for native seeds in forest restoration projects highlights the importance of technical and technological knowledge in the propagation and maintenance of forest species. Seed coating can facilitate direct seeding of these species. However, although the polymer polyvinyl alcohol (PVA) and the plasticizer glycerol have been studied for coating agricultural seeds, there is a lack of information about their behavior in forest species. Therefore, the objective of this research is to evaluate the applicability of film coating using polyvinyl alcohol and glycerol on forest seeds, specifically *Enterolobium schomburgkii*, and evaluate its influence on germination. The first experiment determined a suitable formulation for coating, for which three concentrations of PVA (1%, 3% and 5%) and glycerol (10%, 20% and 30%) were evaluated. To evaluate the effect of coatings on germination, a control was included, totaling 40 plots. Thickness, water vapor permeability, solubility and germination tests were carried out. The combination of 5% PVA and 10% glycerol was appropriate for coating *E. schomburgkii* seeds due to its properties and lack of deleterious effect on germination.

**Keywords:** polymer, polyvinyl alcohol, orelha-de-macaco, direct sowing, storage.

### Resumo

A crescente demanda por sementes nativas em projetos de restauração florestal destaca a importância do conhecimento técnico e tecnológico na propagação e manutenção de espécies florestais. O revestimento de sementes pode facilitar a semeadura direta dessas espécies. No entanto, apesar do polímero álcool polivinílico (PVA) e o plastificante glicerol serem estudados para revestimento de sementes agrícolas, há falta de informações sobre seu comportamento em espécies florestais. Portanto, o objetivo desta pesquisa é avaliar a aplicabilidade de revestimento em filme com uso de álcool polivinílico e glicerol em sementes florestais, especificamente *Enterolobium schomburgkii* e avaliar sua influência na germinação. O primeiro experimentou determinou a formulação adequada para revestimento, avaliando três concentrações de PVA (1%, 3% e 5%) e de glicerol (10%, 20% e 30%). Para avaliar o efeito dos revestimentos na germinação foi incluída uma testemunha, totalizando 40 parcelas. Conduziu-se testes de espessura, permeabilidade ao vapor d'água, solubilidade e germinação. A combinação de 5% de PVA e 10% de glicerol foi apropriada para o revestimento de sementes de *E. schomburgkii* devido a suas propriedades e ausência de efeito deletério a germinação.

**Palavras-chave:** polímero, álcool polivinílico, orelha-de-macaco, semeadura direta, reflorestamento.

## 1. Introduction

Brazil has one of the largest vegetation covers in the world, 40% of which are located in public domain conservation areas or on indigenous lands. The Amazon concentrates 91% of these areas. However, despite the 22.3% reduction in deforestation in 2023, compared to 2022,

there was still an alarming loss of 9,001 km<sup>2</sup> of vegetation cover in the Amazon (Soares-Filho, 2014; INPE, 2023).

To protect what remains of the country's vegetation cover, legal instruments were updated to provide greater security for biodiversity. Law No. 12,651, of the so-called

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“Forest Code”, contains instruments such as the National Plan for the Recovery of Native Vegetation (Planaveg), which provides measures for the recovery of at least 12 million hectares of native vegetation by 2030 (Brasil, 2012, 2017).

To restore an ecosystem, it is essential to use key species, that is, those that occur naturally in it, in order to provide the appropriate community structure and promote an increase in the number of native species (SER, 2010; Salomão et al., 2013).

The species *Enterolobium schomburgkii* Benth (Benth.), popularly known as monkey ear, is native to the Amazon and is distributed from Central America to the Amazon, extending to the south of Brazil, Argentina, Uruguay, Paraguay. It has a multitude of uses such as civil construction, traditional medicine, shading pastures, afforestation and recovery of degraded areas. Its use is recommended in forest restoration projects due to its ability to associate with nitrogen-fixing bacteria, good ecological suitability and establishment in reforestation (Allen and Allen, 1981; Zenid et al., 2009; Salomão et al., 2014; Nogueira et al., 2015; Campos Filho and Sartorelli, 2016; Lorenzi, 2016; Mojena et al., 2016; Fernandes, 2023; Morim et al., 2023).

Restoration requires technical knowledge about the propagation and maintenance of forest species. However, seed-linked technology receives little attention in forest restoration due to the costs of researching and adapting existing technologies for more diverse and complex forest species, initial equipment costs, and obstacles in scaling these technologies (BenDor et al., 2015; Nevill et al., 2018; Cross et al., 2020; Pedrini and Dixon, 2020).

The application of priming, coating and conditioning techniques, originating in agriculture and adapted for ecological restoration, offers promising prospects. Considering that seeds are often scarce resources in forest restoration programs, it is imperative to develop technologies that promote the quality, resilience and reliability of native seed lots. However, despite the significant impact of seed coating, most methodologies and protocols remain confidential, under the exclusive control of large seed companies. Furthermore, seed coating, widely used in the agricultural industry, has been limited to experimental testing on forest species (Howard, 2009; Pedrini and Dixon, 2020; Brown et al., 2021).

In the context of ecological restoration projects, seed coating is applicable to forest species in the practice of direct seeding. In this scenario, the inclusion of a wide diversity of species becomes not only recommended, but essential for the success of the project (Oliveira and Vieira, 2010).

Seed coating is characterized by the application of an exogenous substance to the surface of the seed to modify its properties or deliver bioactive ingredients. For the coating, seeds are covered with substances that act as adhesives, which adhere to the surface and can carry nutrients, growth regulators, protectors, individuals that form symbiosis, without changing their original form. Generally, coatings based on adhesive films result in an increase in seed weight of up to 2% (Santos, 2016; Pedrini et al., 2017; Hu and Guan, 2018; Sun et al., 2022).

Coating materials are selected according to their stability and durability, mechanical flexibility, adhesiveness,

ability to modulate gas exchange and effectiveness of compartmentalizing, preserving and sustaining the release of active agents. Polyvinyl alcohol is a synthetic, non-toxic and biodegradable polymer, with high tensile and compression strength, adhesion properties and good flexibility (Wang et al., 2014; Mali et al., 2019; Vercelheze et al., 2019; Sun et al., 2022).

When coating seeds, it is recommended that adhesive materials are water-soluble, remain dry and non-sticky when dehydrated, act at low concentrations, among other characteristics. Because it has desirable characteristics, polyvinyl alcohol is one of the recommended materials for seed coating (Giménez-Sampaio and Sampaio, 2009; Nascimento et al., 2009).

Glycerol is a plasticizer with a wide range of uses in the pharmaceutical, cosmetics and food industries. Glycerol has the ability to alter some characteristics of coating films such as wettability, water barrier properties, flexibility and solubility of polymeric films (Lim and Wan, 1994; Müller et al., 2008; Tan et al., 2013; Chandrika et al., 2019).

Therefore, the objective of this research is to evaluate the applicability of film coating using polyvinyl alcohol and glycerol on forest seeds, specifically *Enterolobium schomburgkii*, and evaluate its influence on germination and storage.

## 2. Material and Methods

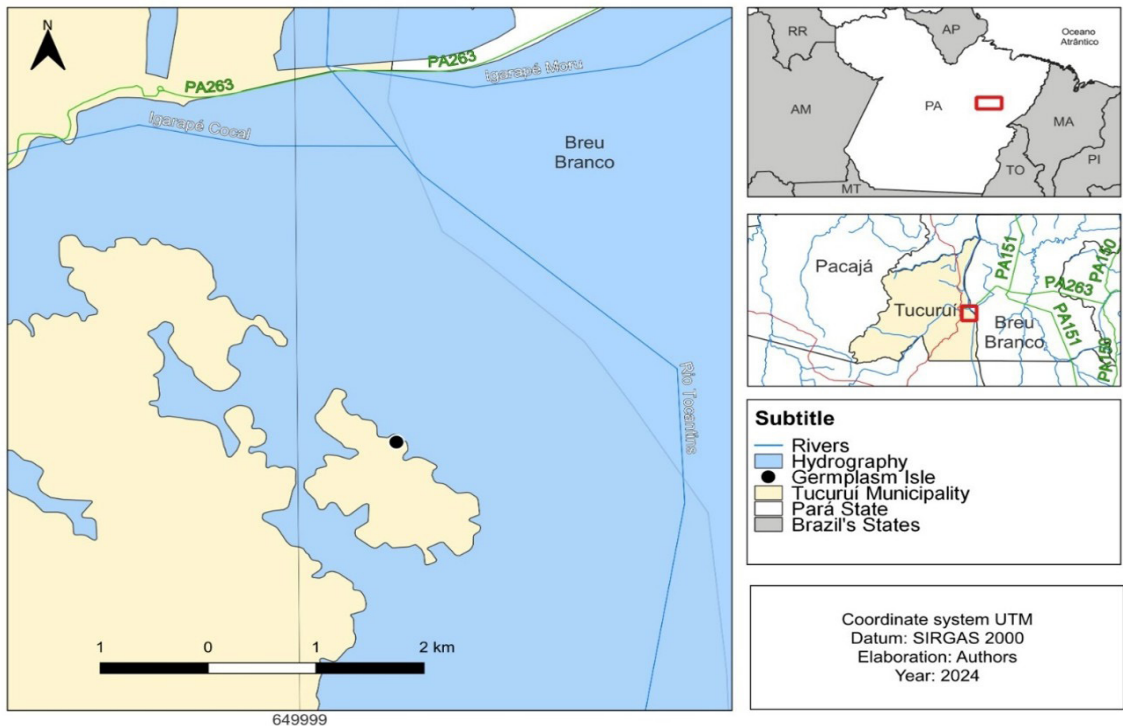
### 2.1. Material

The experiment was conducted at the Seed Laboratory (LABSEM) of the Universidade Federal Rural da Amazônia, Belém campus, state of Pará. The *E. schomburgkii* seeds used were collected in matrices located on the Germoplasma Island of Eletrobrás in the municipality of Tucuruí – PA (Figure 1). The batch was stored for two months in a semi-permeable plastic bag located in a refrigerated room at  $20\text{ °C} \pm 2\text{ °C}$  and 50% relative humidity. The polymer for coating used was polyvinyl alcohol (PVA) for synthesis (P.S) ACS Científica and the plasticizer was double-distilled glycerin P.A from ACS Científica.

### 2.2. Methods

To evaluate the film characteristics, such as thickness, water solubility, water vapor permeability, and for the evaluation of the physiological quality of seeds a completely randomized design was used in a  $3 \times 3 + 1$  factorial scheme, with three replicates. The treatments consisted of three concentrations of PVA (1%, 3% and 5%), three concentrations of Glycerol (10%, 20% and 30%) and a control treatment (No coating).

To evaluate the use of PVA and glycerol in the coating formulation, three concentrations of PVA (1%, 3% and 5%) and three concentrations of glycerol (10%, 20% and 30% in relation to the polymer concentration). Film-forming solutions were obtained by heating the solutions for 30 minutes, under constant stirring, in a water bath set at a temperature of  $95\text{ °C}$ , resulting in the complete dissolution of the polymer and plasticizer (Vercelheze et al., 2019).



**Figure 1.** Location map of the seed collection site -Tucuruí Germplasm Island - PA.

To analyze the properties of the formulations, 20 mL of solution was pipetted into petri dishes and dried using the casting method (evaporation of the solvent) in an oven at 50 °C for 24 hours to form the film to be analyzed (Müller et al., 2008; Vercelheze et al., 2019).

To evaluate the effect of coating on the germination of *E. schomburgkii*, seeds previously aseptic in a 5% sodium hypochlorite solution for three minutes. In addition, 100 seeds were coated in 10 mL of the film-forming solution. Then, placed to dry in a ventilated place at room temperature for 2 hours and then in BOD (Biochemical Oxygen Demand) at 25 °C for 24 hours until completely dry.

### 2.2.1. Coating characterization

#### 2.2.1.1. Thickness

The thickness was determined with the aid of a digital caliper with an accuracy of 0.01 mm. Thickness assessments were carried out in the central part and at the four ends of three film samples, the result consisted of the average of the evaluated points, expressed in millimeters (mm) (Oliveira et al., 2012).

#### 2.2.2. Water vapor permeability

The water vapor permeability rate was determined according to the method proposed by Gontard et al. (1992), based on the ASTM E96-80 test (ASTM, 1989). The films were fixed in permeability cells containing silica gel at the base, maintaining a distance greater than 6,0 mm between the film and the desiccant. The cells were then placed in a desiccator containing distilled water at the base and

stored in BOD at 25 °C. Cell weight was recorded at 24-hour intervals for seven days on a precision scale. The water vapor permeability rate was calculated using Equation 1.

$$Tva = \frac{g}{tA} \quad (1)$$

where: A: is the permeation area (m<sup>2</sup>); g/t: is the angular coefficient of the linear regression equation between the points of weight gain and time, in the constant regime (Sobral, 2000).

Then, water vapor permeability (Pva) was calculated using Equation 2:

$$Pva = \frac{g}{tA} \cdot \frac{x}{DP} \quad (2)$$

where: x: is the average thickness of the films (mm); DP: is the difference in vapor pressure between the environment containing silica gel (0) and containing pure distilled water (3,169 kPa, at 25 °C).

#### 2.2.3. Germination test

The test consisted of four replicates of 25 seeds, sown on a roll of germitest paper (28 × 38 cm), moistened with distilled water in a proportion of 2.5 times its dry weight. The rolls were placed in thin polyethylene bags and in a BOD germination chamber regulated at a temperature of 25 °C, with the first count at three days and the last at 15 days after sowing (DAS). The botanical parameters of emission of the primary root at 2 mm and technical parameters of normal seedling formation for germination were considered (Brasil, 2013).

Due to the physical dormancy present in the seeds, before preparing the germination test, a procedure was carried out to break dormancy, using mechanical scarification with sandpaper on the part opposite the hilum (Souza and Varela, 1989; Brasil, 2009).

#### 2.2.4. Analysis of vigor and morphological parameters of the seedlings

The development of the seedlings was measured with a graduated ruler (cm), the roots and aerial parts were measured, then they were packed in kraft paper bags and dried in an oven at 65 °C, until they reached a constant weight. Subsequently, the samples were weighed on a precision balance with an accuracy of 0.001 g.

#### 2.2.5. Statistical analysis

The data pertaining to thickness, water vapor permeability and solubility of the coatings were subjected to the Shapiro-Wilk normality test and homoscedasticity of the data by the Bartlett test. When not normal, the data were transformed by box-cox and subjected to the test of Jarque-Bera normality and Breusch Pagan homoscedasticity test and then subjected to analysis of variance and test of means.

Data from germination tests were transformed according to  $\text{Arcsen } \sqrt{x/100}$ . Then assessed for normality using the Shapiro-Wilk test and homoscedasticity using Bartlett test and compared in relation to the control group using the Dunnett test. The combinations were also compared with each other using the Tukey test at a 5% probability level. The software used was RStudio 2023.12.

### 3. Results

The result of the analysis of variance for the properties of the coating films indicated statistical significance by the F test ( $p \leq 0.05$ ) as a function of the PVA factor for all characteristics. The glycerol factor had no effect on the thickness variable. The concentration of PVA, glycerol and the interaction between these factors influenced the water vapor permeability of the coating films (Table 1).

Regarding thickness, the use of 1% PVA concentration, regardless of the plasticizer concentration, resulted in very thin coating films. However, the application of 3% and 5% PVA in the coating formulation resulted in a thickness between 0.14 mm and 0.17 mm.

In general, the higher PVA content contributed significantly to the greater permeability, which was also observed with the increase in glycerol, although slightly smaller. An exception occurred with the increase from 20% to 30% of glycerol at a concentration of 5% PVA, which resulted in more than double the gain in permeability (Table 2).

The solubility of coating films reduced with increasing PVA concentration in the formulation. The formulations containing 5% PVA had lower solubility rates, however, it was possible to observe an increase in solubility with an increase in the glycerol content.

Thickness and water vapor permeability increased linearly with increasing PVA, while there was a reduction in solubility with increasing polymer concentration in the

solution. The presence of glycerol caused a strong increase in permeability to water vapor and increased the solubility of films containing 5% PVA (Figure 2).

The polymer affected the emission of the primary root, however, with no significant difference according to the F test ( $p \geq 0.05$ ) compared to the control. Also considering the emission of the primary root, parameters such as GSI and AGT were influenced by the presence of PVA, glycerol,

**Table 1.** Analysis of variance of the analyzed characteristics of the coating films resulting from the combination of different concentrations of polyvinyl alcohol and glycerol.

Variation factor	D.F	QM		
		Thickness (mm)	Solubility in water (%)	Water vapor permeability (%)
PVA (P)	2	0.0136 *	6845.1 *	18,504,721.4 *
Glycerol (G)	2	0.0001 <sup>ns</sup>	326.0 *	2,253,043.6 *
P*G	4	0.0005 <sup>ns</sup>	305.7 *	1,669,548.3 *
Error	18	0.004	742.4	7240.7
CV%	-	15.2	9.58	6.07

\*Significant at 5% probability using the F test. <sup>ns</sup>Not significant; D.F: Degree of Freedom.

**Table 2.** Thickness, solubility and water vapor permeability of coating films resulting from the combination of different concentrations of polyvinyl alcohol and glycerol.

	Thickness (mm)		
	Glycerol (%)		
PVA (%)	10	20	30
1	0.07 Ba	0.08 Ba	0.09 Ba
3	0.14 Aa	0.014 Aa	0.12 Aba
5	0.17 Aa	0.15 Aa	0.15 Aa
	Water vapor permeability (g.h <sup>-1</sup> .m <sup>-2</sup> )		
PVA (%)	10	20	30
1	104.68 Cb	188.90 Cab	298.40 Ca
3	858.60 Bb	1,125.70 Ba	1,071.50 Ba
5	2,181.10 Ab	2,230.10 Ab	4,551.30 Aa
	Solubility in water (%)		
PVA (%)	10	20	30
1	100.00 Aa	100.00 Aa	100.00 Aa
3	82.61 Bb	91.16 Ba	87.94 Bab
5	58.61 Cb	66.85 Cab	74.13 Ca

Means followed by the same uppercase letter in the columns and lowercase letter in the rows do not differ according to the Tukey test at 5% probability.

the combination of factors and differed from the control (Table 3).

When considering the formation of normal seedlings, it is observed that the use of PVA did not influence the parameters evaluated, however, the glycerol factor provided a difference for GSI and AGT and there was statistical significance compared to the control group.

Dunnet's test to compare coated seeds with the control group indicated that there was no effect of the coating on the germination and dry mass of *E. schomburgkii* seedlings. In relation to GSI, AGT and root and shoot length, all combinations did not differ statistically from the control or negatively influenced the observed variables, except for the formulation of 5% PVA and 10% glycerol where there was promotion of root length and statistical distinction from the control group (Table 4).

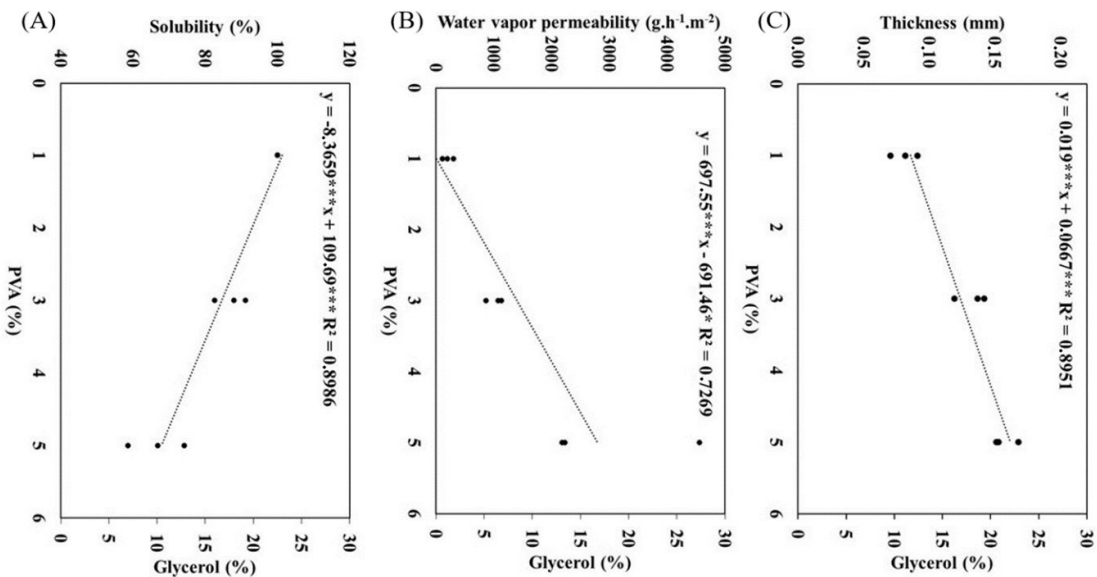
In summary, the analysis of germination parameters indicated little influence of the coating in relation to

the control. Germination, regardless of the parameter considered, was not affected by the increase in the concentration of PVA or glycerol, and it can be considered that for *E. schomburgkii* the use of PVA up to 5% and glycerol up to 30% does not harm the germination of the species.

When comparing the different formulations, there was no pattern of behavior observed regarding the concentration of PVA or glycerol, indicating that there was no effect related to the different concentrations of polymer and plasticizer on seedling development (Table 5).

#### 4. Discussion

The use of 3% and 5% concentrations of PVA stabilized the thickness of the coating films. Among the physical attributes of the coating films applied to seeds, the thickness of the films stands out, which can impact the germination and development of seedlings. Coatings that are too thick



**Figure 2.** Regression analysis for solubility (A), water vapor permeability (B) and thickness (C) of coating films.

**Table 3.** Analysis of variance for Germination, Germination Speed Index (GSI) and Average Germination Time (AGT) of *E. schomburgkii* seeds coated with different combinations of polyvinyl alcohol and glycerol.

Variation factor	QM						
	D.F	Root emission			Normal seedling		
		G	GSI	AGT	G	GSI	AGT
PVA (P)	2	0.029 *	1.012 *	0.472 *	0.015 <sup>ns</sup>	0.018 <sup>ns</sup>	0.012 <sup>ns</sup>
Glycerol (G)	2	0.011 <sup>ns</sup>	0.782 *	0.281 *	0.012 <sup>ns</sup>	0.081 *	0.749 *
P*G	4	0.005 <sup>ns</sup>	1.473 *	0.706 *	0.001 <sup>ns</sup>	0.010 <sup>ns</sup>	0.387 *
Control x Common	1	0.027 <sup>ns</sup>	14.691 *	7.500 *	0.018 <sup>ns</sup>	0.195 *	1.004 *
Error	30	0.007	0.209	0.042	0.013	0.021	0.114
CV (%)	-	6.620	6.940	5.650	9.140	6.730	3.170

\*Significant at 5% probability using the F test. <sup>ns</sup>Not significant; D.F: Degree of Freedom.

**Table 4.** Germination (G), Germination Speed Index (GSI), Average Germination Time (AGT) and biometric variables of *E. schomburgkii* seedlings after coating compared with the control using the Dunnett test.

PVA × glycerol concentration	Variables						
	G (%)	GSI	AGT (days)	CR (cm)	CPA (cm)	MSR (g)	MSPA (g)
1% PVA + 10% G	92 <sup>ns</sup>	2.26 <sup>ns</sup>	10.38 <sup>ns</sup>	5.35 <sup>ns</sup>	6.26 <sup>-</sup>	0.0023 <sup>ns</sup>	0.014 <sup>ns</sup>
1% PVA + 20% G	90 <sup>ns</sup>	2.12 <sup>ns</sup>	10.84 <sup>ns</sup>	4.04 <sup>ns</sup>	5.58 <sup>-</sup>	0.0021 <sup>ns</sup>	0.015 <sup>ns</sup>
1% PVA + 30% G	91 <sup>ns</sup>	2.16 <sup>ns</sup>	10.77 <sup>ns</sup>	4.18 <sup>ns</sup>	5.86 <sup>-</sup>	0.0020 <sup>ns</sup>	0.015 <sup>ns</sup>
3% PVA + 10% G	90 <sup>ns</sup>	2.14 <sup>ns</sup>	10.79 <sup>ns</sup>	3.73 <sup>ns</sup>	6.13 <sup>-</sup>	0.0022 <sup>ns</sup>	0.015 <sup>ns</sup>
3% PVA + 20% G	85 <sup>ns</sup>	2.00 <sup>-</sup>	10.89 <sup>+</sup>	4.89 <sup>ns</sup>	6.33 <sup>-</sup>	0.0028 <sup>ns</sup>	0.016 <sup>ns</sup>
3% PVA + 30% G	88 <sup>ns</sup>	2.16 <sup>ns</sup>	10.35 <sup>ns</sup>	3.95 <sup>ns</sup>	6.70 <sup>ns</sup>	0.0025 <sup>ns</sup>	0.015 <sup>ns</sup>
5% PVA + 10% G	92 <sup>ns</sup>	2.17 <sup>ns</sup>	10.93 <sup>+</sup>	5.97 <sup>+</sup>	6.85 <sup>ns</sup>	0.0030 <sup>ns</sup>	0.015 <sup>ns</sup>
5% PVA + 20% G	87 <sup>ns</sup>	2.01 <sup>-</sup>	11.09 <sup>+</sup>	2.63 <sup>-</sup>	5.50 <sup>-</sup>	0.0021 <sup>ns</sup>	0.015 <sup>ns</sup>
5% PVA + 30% G	89 <sup>ns</sup>	2.23 <sup>ns</sup>	10.16 <sup>ns</sup>	5.38 <sup>ns</sup>	6.43 <sup>ns</sup>	0.0029 <sup>ns</sup>	0.015 <sup>ns</sup>
Control	94	2.37	10.17	4.26	7.01	0.00252	0.0159
CV (%)	9.14	6.73	3.17	13.78	5.1	12.31	3.54

Legend: + Significant and superior to the witness, according to the Dunnett test, at a 5% probability level; -: Significant and lower than the witness, according to the Dunnett test, at a 5% probability level. <sup>ns</sup>Not significant, according to the Dunnett test, at a 5% probability level. Seedling radicle length (CR); Length of the aerial part of the seedling (CPA); Seedling height; Total dry matter (MSR) and shoot dry matter (MSPA).

**Table 5.** Development variables of *E. schomburgkii* seedlings coated with different combinations of polyvinyl alcohol and glycerol compared by the Tukey test at 5% probability.

	RL (cm)			SL (cm)		
	Glycerol (%)			Glycerol (%)		
PVA (%)	10	20	30	10	20	30
1	5.20 Aa	4.04 Ba	4.18 ABb	6.26 Ba	5.58 Bb	5.86 Bab
3	3.80 Bb	4.89 Aa	3.95 ABb	6.13 Bb	6.33 Aab	6.70 Aa
5	5.97 Aa	2.79 Bb	5.38 Aa	6.85 Aa	5.50 Bb	6.43 Aa
		RDM (mg)		SDM (mg)		
PVA (%)	10	20	30	10	20	30
1	2.31 Ba	2.19 Ba	2.05 Ba	14.92 Aa	15.02 Ba	15.87 Aa
3	2.21 Bb	2.83 Aa	2.52 ABab	15.15 Ab	16.45 Aa	15.50 Aab
5	3.09 Aa	2.14 Bb	3.00 Aa	15.25 Aa	15.2 Ba	15.42 Aa
		TL (cm)		TDM (mg)		
PVA (%)	10	20	30	10	20	30
1	11.46 Aa	9.62 Bb	10.05 Bab	17.24 Aa	17.21 Ba	17.93 Aa
3	9.93 Ba	11.23 Aa	10.65 Aba	17.36 Ab	19.28 Aa	18.02 Ab
5	12.83 Aa	8.29 Bb	11.82 Aa	18.34 Aa	17.34 Ba	18.42 Aa

Means followed by the same uppercase letter in the columns and lowercase letter in the rows do not differ according to the Tukey test at 5% probability. Root length (RL) (cm), Shoot length (SL) (cm), Root dry mass (RDM) (mg), Shoot dry mass (SDM) (mg), Total length (TL) (cm) and Total dry mass (TDM) (mg).

can be harmful, causing seed delays, abnormalities or toxicity, while coatings that are too thin can disintegrate before sowing or not contain enough active ingredients (Qiu et al., 2020).

The thickness of the films is influenced by the content added to the polymeric matrix, such as anthocyanins, betalains, nano-titania particles, cellulose and in general,

this influence varies according to the material added. However, the fluctuation in plasticizer percentage did not influence the thickness of the coating films (Zhai et al., 2017; Lin et al., 2018; Cazón et al., 2019; Qin et al., 2020; Abedi-Firoozjah et al., 2023; Petry et al., 2024). This result is similar to that found by Petry et al. (2024) for the effect of sorbitol plasticizer on PVA films.

In general, the higher PVA content contributed significantly to the greater permeability, which was also observed with the increase in glycerol, although with slightly smaller increases. It is important to observe the water vapor permeability of the films in order to guarantee the hydration of the seed and thus enable the germination process to begin. The calculation of water vapor permeability is essential to determine the rate of moisture penetration through the polymeric matrix, which can influence the water content of seeds (Oliveira et al., 2009; Taylor, 2020; Abedi-Firoozjah et al., 2023).

The conservation of stored seeds is linked to their water content, which tends to come into balance with the humidity of the storage environment. Thus, the hygroscopicity of the coating material affects the conservation of physiological quality, since if the material is highly hygroscopic it can act as a "bridge", absorbing moisture from the environment and transferring it to the seed (Silva, 1997).

PVA is a hydrophilic synthetic polymer, therefore increasing its concentration, in addition to increasing thickness, can increase water vapor permeability, which occurred in this study. The regression analysis pertinent to the permeability of the films indicates a linear growth trend when using 5% PVA and higher doses of glycerol (Faria et al., 2012; Kahvand and Fasihi, 2019).

The reduction in the solubility of polymeric films observed when the PVA concentration increased indicates a positive effect on the permanence of the coating. The solubility of PVA films in seed coatings is a point of concern, as soil moisture can lead to dissolution of the polymer fibers, accelerating the release of active ingredients. PVA is a hydrophilic polymer sold with a high degree of hydrolysis (>98.5%), therefore, the presence of free hydroxyl groups in the polymer chain allows them to form a bond with water molecules, increasing permeability to water vapor, solubility and swelling of films (Hassan and Peppas, 2000; Jain et al., 2017; Pirzada et al., 2020).

The use of coating did not affect the germination of the species when compared to the control group or between formulations. In the literature there is a variable response to the isolated effect of PVA on seed germination. The use of 3% PVA in seeds of two corn genotypes did not affect germination. The hydrophilic nature of PVA is credited for increasing the germination of mung beans and peanuts. Coating soybean seeds with PVA associated with the rhizobacteria *Pantoea agglomerans* promoted greater germination, because PVA is a biodegradable polymer, it serves as food for rhizobacteria (De Gregorio et al., 2017; Vercelheze et al., 2019; Raja et al., 2021).

The presence of the coating can impose mechanical restrictions, decreasing not only the germination rate, but also the subsequent development of the seedlings. Furthermore, components present in the coating can also negatively influence germination. Thus, it is possible to infer that the use of PVA coating does not restrict the germination process, however, it can cause a reduction shoot length (Sung and Chiu, 1995; Pilar-Izquierdo et al., 2012).

The application of PVA to *E. schomburgkii* seeds did not include the use of active ingredients such as beneficial microorganisms, nutrients or hormones, thus, there was little or no positive effect in relation to the control, in

addition to that observed in the combination of 5% PVA and 10% of glycerol.

The isolated impact of PVA on seedling growth is little explored in the literature, being commonly linked to beneficial microorganisms and nutrients. The use of PVA coating with the rhizobacteria *P. agglomerans* resulted in an increase in root length and dry mass, possibly due to greater colonization of the bacteria in the PVA, which acted as a substrate and nourished it.

The hydrophilic property of water absorption and retention of the PVA polymer and the nutrition of microorganisms was also linked to greater emergence, root length, aerial part and vigor of peanut seedlings coated with PVA nanofibers and nitrogen-fixing bacteria *Methylobacterium aminovorans*. Application of PVA coating with nutrients resulted in increased germination, plant height, grain yield and crop yield in *Vigna radiata* (De Gregorio et al., 2017; Mohanraj et al., 2022; Mukiri et al., 2022).

According to Vercelheze et al. (2019), films with high permeability to water vapor, indicating the potential to supply water, low solubility, uniform distribution in the seeds and no deleterious effect related to germination, are interesting for seed coating. Thus, considering the observed properties of low solubility, good water vapor permeability, absence of deleterious effect on germination and promotion of root and shoot length, as well as root dry mass, the combination of 5% PVA and 10% glycerol was more suitable for coating *E. schomburgkii* seeds.

## 5. Conclusion

The increase in PVA content in the formulations resulted in an increase in the thickness and permeability of the polymer films. On the other hand, solubility decreased with increasing PVA concentrations. The formulation of 5% PVA and 10% glycerol was more suitable for coating *E. schomburgkii* seeds due to its low solubility, good water vapor permeability and absence of harmful effects on the species' germination.

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## Data Availability Statement

The entire data set that supports the results of this study was published in the article itself.

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