SciELO Preprints

Publication status: This preprint has not been published elsewhere.

# Sustainable coating technology to enhance tomato seed quality

Vitória Gouveia Resta, Jordana Nogueira Laite de Araujo, Natalia de Camargo Lima Beluci, André Luiz Martinez Oliveira, Suzana Mali

https://doi.org/10.1590/0103-8478cr20250490

Submitted on: 2026-11-11
Posted on: 2026-11-11 (version 1)
(YYYY-MM-DD)

SciELO Preprints - This document is a preprint and its current status is available at: https://doi.org/10.1590/0103-8478cr20250490

Ciência Rural, Santa Maria, v.57:1, e20250490, 2027 http://doi.org/10.1590/0103-8478cr20250490

ISSNe 1678-4596
BIOLOGY

# Sustainable coating technology to enhance tomato seed quality

**Vitória Gouveia Resta[1] (https://orcid.org/0000-0002-0588-9668)**
**Jordana Nogueira Laite de Araujo[1] (https://orcid.org/0009-0007-8668-2477)**
**Natalia de Camargo Lima Beluci[1*] (https://orcid.org/0000-0002-4080-4404)**
**André Luiz Martinez Oliveira[1] (https://orcid.org/0000-0003-1555-202X)**
**Suzana Mali[1] (https://orcid.org/0000-0003-4601-1568)**

[1]Departamento de Bioquímica e Biotecnologia, Centro de Ciências Exatas (CCE), Universidade Estadual de Londrina (UEL), 86051-990, Londrina, PR, Brasil. E-mail: natalia.beluci@gmail.com. *Corresponding author.

## Tecnologia sustentável de revestimento para melhorar a qualidade de sementes de tomate

**Received 09.12.25 Approved 08.20.26 Returned by the author xx.xx.xx**
**CR-2025-0490.R1**
**Editors: Alessandro Dal'Col Lúcio Geri Eduardo Meneghello**

SciELO Preprints - This document is a preprint and its current status is available at: https://doi.org/10.1590/0103-8478cr20250490

Ciência Rural, Santa Maria, v.57:1, e20250490, 2027 http://doi.org/10.1590/0103-8478cr20250490
ISSNe 1678-4596
BIOLOGY

# Sustainable coating technology to enhance tomato seed quality

**Vitória Gouveia Resta[1] Jordana Nogueira Laite de Araujo[1] Natalia de Camargo Lima Beluci[1*] André Luiz Martinez Oliveira[1] Suzana Mali[1]**

[1]Departamento de Bioquímica e Biotecnologia, Centro de Ciências Exatas (CCE), Universidade Estadual de Londrina (UEL), 86051-990, Londrina, PR, Brasil. E-mail: natalia.beluci@gmail.com. *Corresponding author.

**ABSTRACT**: This study developed and characterized a low-cost biodegradable polymeric matrix based on cassava starch, gelatin, and oat hulls for coating tomato seeds. The coated seeds were characterized by their production yield, pH, density, mass distribution, moisture content, solubility, water absorption, and water adsorption capacity. The coating process resulted in seeds with different shapes, lower densities, and higher masses than uncoated seeds. The pH of the coated seeds ranged from 6.09 to 6.55, and the moisture contents ranged from 7.68 to 9.08%.The highest proportions of starch resulted in more brittle and soluble coated seeds, which were difficult to handle, while the higher gelatin content resulted in harder and smaller ones. The S50G50 formulation (50% starch, 50% gelatin) demonstrated superior properties, offering benefits such as higher production yields, easier handling, lower solubility, and higher water absorption capacity. Coated seeds showed 76% germination, compared to 85% for uncoated seeds, with no statistically significant difference according to the t-test ($P > 0.05$). This indicated that the biodegradable polymeric matrix preserves seed viability and is effective for the intended application. The paper highlighted the potential of utilizing a biodegradable polymeric matrix to improve the quality and management of tomato seeds, providing a promising approach to sustainable agricultural practices.
**Key words**: seeds quality, biodegradable, starch, gelatin, oat hulls.

## Tecnologia sustentável de revestimento para melhorar a qualidade de sementes de tomate

**RESUMO**: O objetivo deste estudo foi desenvolver e caracterizar uma matriz polimérica biodegradável de baixo custo, baseada em amido de mandioca, gelatina e cascas de aveia, para a revestimento de sementes de tomate. Para realizar o objetivo, as sementes revestidas foram caracterizadas quanto ao rendimento de produção, ao pH, a densidade, a distribuição de massa, ao teor de umidade, a solubilidade, a absorção de água e a capacidade de adsorção de água. Os resultados revelam que o processo de revestimento resultou em sementes com diferentes formatos, menores densidades e massas superiores às sementes não revestidas. O pH das sementes variou de 6,09 a 6,55, e os teores de umidade variaram de 7,68% a 9,08%. Além disso, as maiores proporções de amido resultaram em sementes revestidas mais frágeis e solúveis (difíceis de manusear), enquanto o maior teor de gelatina resultou em sementes revestidas mais duras e menores. A formulação com 50% de amido e 50% de gelatina (S50G50) demonstrou propriedades superiores às demais, oferecendo benefícios como maiores rendimentos de produção, manuseio facilitado, menor solubilidade e maior capacidade de absorção de água. Do mesmo modo, as sementes revestidas apresentaram 76% de germinação, em comparação com 85% das sementes não revestidas, sem diferença estatisticamente significativa de acordo com o teste t ($P > 0,05$). Isso indica que a matriz polimérica biodegradável preserva a viabilidade das sementes e é eficaz para a aplicação pretendida. Portanto, o estudo destaca o potencial do uso de uma matriz polimérica biodegradável para melhorar a qualidade e o manejo das sementes de tomate, oferecendo uma abordagem promissora para práticas agrícolas sustentáveis.
**Palavras-chave**: qualidade das sementes, biodegradáveis, amido, gelatina, cascas de aveia.

## INTRODUCTION

The global population's rapid growth, from 1.7 billion in 1900 to about 8.1 billion in 2024, has severely degraded agricultural lands (QIU et al., 2020). With food production expected to rise by 70% to 100% by 2050, and limited agrarian expansion, the core challenge is to produce enough quality food without harming soil and ecosystems (VERCELHEZE et al., 2019). This urgent need underscores the importance of precision agriculture technologies for sustainable agricultural intensification (BARNES et al., 2019).

Current farming methods, which rely heavily on fertilizers, pesticides, and animal waste, harm the environment by polluting air, soil, and water and reducing biodiversity. This necessitates new agricultural strategies with reduced environmental footprints (MA, 2019). The unsustainability of conventional practices and future climate scenarios further drive the search for environmentally friendly alternatives to boost agricultural production (ROCHA et al., 2019).

Tomato (*Lycopersicon esculentum Mill.*) is a globally cultivated fruit, holding substantial

Received 09.12.25 Approved 08.20.26 Returned by the author xx.xx.xx
CR-2025-0490.R1
Editors: Alessandro Dal'Col Lúcio Geri Eduardo Meneghello

SciELO Preprints - This document is a preprint and its current status is available at: https://doi.org/10.1590/0103-8478cr20250490



## INTRODUCTION

The global population's rapid growth, from 1.7 billion in 1900 to about 8.1 billion in 2024, has severely degraded agricultural lands (QIU et al., 2020). With food production expected to rise by 70% to 100% by 2050, and limited agrarian expansion, the core challenge is to produce enough quality food without harming soil and ecosystems (VERCELHEZE et al., 2019). This urgent need underscores the importance of precision agriculture technologies for sustainable agricultural intensification (BARNES et al., 2019).

Current farming methods, which rely heavily on fertilizers, pesticides, and animal waste, harm the environment by polluting air, soil, and water and reducing biodiversity. This necessitates new agricultural strategies with reduced environmental footprints (MA, 2019). The unsustainability of conventional practices and future climate scenarios further drive the search for environmentally friendly alternatives to boost agricultural production (ROCHA et al., 2019).

Tomato (*Lycopersicon esculentum Mill.*) is a globally cultivated fruit, holding substantial commercial and socioeconomic importance (MUSTAFA et al., 2025; DE CARVALHO et al., 2019). Its tiny seeds; however, pose challenges for direct sowing due to their small size, shape, weight, non-uniform germination, susceptibility to pests and microorganisms, and dormancy (GOVINDEN-SOULANGE & LEVANTARD, 2008). Large-scale tomato cultivation often relies on pesticides to ensure high productivity and quality (DE CARVALHO et al., 2019).

Coating technology can offer a solution by covering seeds with inert material, optimizing planting by homogenizing seed size, and protecting them from physical damage (AMIRKHANI et al., 2016; GÁLVEZ et al., 2019). Standard coating techniques include film coating (applying a thin layer), encrusting (increasing size while retaining original shape), and pelleting (standardizing seeds to a nearly spherical shape) (JAVED et al., 2022).

Coating is particularly beneficial for tiny seeds, as it increases their size, simplifying field planting (MA, 2019). Additionally, coated materials can serve as carriers for fungicides, insecticides, nutrients, and growth regulators. However, it is essential to understand the dynamics and interaction between the polymer matrix and seeds, as the coating can act as a barrier to water diffusion, potentially reducing seed germination and seedling emergence. (PIRZADA et al., 2020).

In pursuit of sustainable agriculture, various biopolymers are being explored for seed coating to replace synthetic polymers (ACCINELLI et al., 2018; GIRARDI et al., 2018; VERCELHEZE et al., 2019; WU et al., 2012). These biopolymers offer a lower environmental impact and produce non-toxic residues upon biodegradation in soil (PIRZADA et al., 2020). Despite the importance of seed coating technologies, much of the research and development is limited by the commercial and confidential nature of most processes, with a substantial portion of methods in scientific studies being outsourced to private companies (PEDRINI et al., 2017, 2018). This highlighted the need for more detailed studies on polymeric matrices to understand their behavior under varying humidity conditions.

Addressing the handling challenges associated with the small size of tomato seeds and the growing demand for eco-friendly alternatives to synthetic polymers, this study developed and characterized a low-cost biodegradable polymeric matrix based on cassava starch, gelatin, and oat hulls for coating tomato seeds. The goal was to standardize seed shape and increase mass to enhance handleability and planting precision, while evaluating the matrix's viability as a potential carrier for bioactive compounds. Finally, this research provided a sustainable technological approach to improve seed quality and support the intensification of sustainable agricultural practices.

## MATERIALS AND METHODS

### *Coating formulations*

The polymeric matrix for coating the seeds was produced from a mixture of two biopolymers, cassava starch and gelatin, in varying proportions. Initially, polymeric matrices were made from gel solutions (3% w/w) of starch and gelatin in different proportions. The samples were denoted as SxGy, where x and y represent the amount of starch (%) and gelatin (%).

Gelatin was hydrated in distilled water at room temperature for 1 h and then solubilized at 55 °C for 30 min. Cassava starch was heated to 90 °C for 10 min. Finally, gelatin and starch were mixed under continuous agitation in a water bath (Marconi MA 127, Brazil) at 90 °C for 30 min until a homogeneous mixture was obtained. In the second step, other components were incorporated into the prepared gel solutions (g/100 mL of the gel solution) with fixed amounts: rock phosphate (4 g), PBS buffer (8.2 mL), oat hulls (15 g), glycerol (1 g), and neem oil (10 drops).

The pastes were then manually transferred

SciELO Preprints - This document is a preprint and its current status is available at: https://doi.org/10.1590/0103-8478cr20250490



to silicone molds containing the tomato seeds and dried in an oven at 30 °C with air circulation (Marconi MA 035, Brazil) for 24 h, resulting in coated seeds with a spherical shape approximately 8 mm in diameter. The seeds were kept at a relative humidity (RH) of 58-60% in an incubator-type B.O.D. (Marconi MA 415, Brazil) containing a saturated sodium bromide solution at 25 °C for at least 48 h before characterization.

The pH of the coated seeds was determined with a potentiometer (Digimed DM20, Brazil) at room temperature. The moisture content of the coated seeds was determined for each formulation by drying in an air-circulating oven (Marconi MA 035, Brazil) at 105 °C until a constant weight was reached.

*Characterization of the coated seeds*

*Production yield*

The production yield (%) was calculated from the relationship between the number of whole coated seeds and the total coated seeds produced. For each formulation, 382 samples were made. Coated seeds that were not whole and had defective upper or lower parts or holes in their structure were discarded.

*Density and mass distribution*

The seed density was determined by calculating the ratio between the weight (g) and the volume ($cm^3$) of the coated and uncoated seeds using the method adapted from SILVA & MARCOS FILHO (1982). The tests were performed in quintuplicate.

For mass distribution analysis, 100 coated and uncoated seeds were weighed individually, both with and without coatings, on an analytical balance (Shimadzu AX220, Japan).

*Solubility*

The coated samples (0.5 g) were added to 100 mL Erlenmeyer flasks containing 80 mL of distilled water and stirred slowly for 4 and 24 h at 25 °C in an orbital incubator. Afterward, the samples were removed and dried in an air-circulating oven (Marconi MA 035, Brazil) at 60 °C for 24 h to determine the mass of the non-solubilized material (final weight). The solubility was expressed as the percentage of solubilized dry material. The analyses were performed in triplicate.

*Water absorption capacity*

The water absorption capacity of the samples was determined according to ABNT NBR NM ISO 535 (ABNT, 2011). Samples of the coated seeds (0.5 g) were weighed and submerged in 100 mL of distilled water at room temperature. The specimens were placed in contact with water for different periods (1, 5, 10, 15, 20, 25, and 30 min), and then the excess water was removed with paper towels. The samples were weighed to obtain the mass increment resulting from water absorption. The tests were performed in triplicate.

*Moisture adsorption isotherms*

The coated samples (0.5 g) were pre-dried for 24 h in a ventilated oven at 50 °C (Marconi - MA 035, Brazil) and then placed at 25 °C in desiccators containing different saturated solutions of salts providing specific relative humidity (RH): magnesium chloride ($MgCl_2$) 38% RH; potassium carbonate ($K_2CO_3$) 46% RH; sodium bromide (NaBr) 60% RH; sodium chloride (NaCl) 75% RH; and barium chloride ($BaCl_2$) 90% RH (MALI et al., 2005) The equilibrium moisture content of each sample was calculated as the increase in dry mass for each RH after 7 days, which was determined by oven drying at 105 °C (Marconi—MA 035, Brazil).

The equilibrium moisture content of each sample was plotted as a function of relative humidity (RH), and the experimental data were fitted using the Guggenheim-Anderson-de-Boer (GAB) model (BELUCI et al., 2023), determined by nonlinear regression using Statistica software 7.0 (StatSoft, Oklahoma, USA). The isotherm model of GAB can be expressed by equation 1:

$$M = \frac{C.k.m_0.a_w}{[(1 - k.a_w).(1 - k.a_w + C.k.a_w)]} \quad (1)$$

where M is the moisture content of the equilibrium at a given water activity ($a_w$ = RH/100), $m_0$ is the monolayer value (g water / g solids), and C and K are the GAB constants. All tests were performed in triplicate.

*Moisture adsorption kinetics*

The samples (0.5 g) were pre-dried for 24 h in a ventilated oven at 50 °C (Marconi - MA 035, Brazil) and then placed in desiccators containing different saturated solutions of salts (magnesium chloride ($MgCl_2$) 38% RH; sodium bromide (NaBr) 60% RH, and barium chloride ($BaCl_2$) 90% RH). Samples stored at 38 and 58% RH were weighed after 2, 4, 6, 8, 23, 21, 27, 41, 37 and 71 h, and samples stored at 90% RH were weighed after 2, 4, 6, 8, 23, 21, 27, 41, 37, 53, 71, 121, 149, 168 and 180 h. The moisture adsorption data were adjusted according to a mathematical model and estimation methods suggested by PELEG (1988):

$$M_{(t)} = M_0 + \left(\frac{t}{(k_1 + k_2 t)}\right) \quad (2)$$

SciELO Preprints - This document is a preprint and its current status is available at: https://doi.org/10.1590/0103-8478cr20250490



where $M_{(t)}$ is the moisture after time t, $M_0$ is the initial moisture, $k_1$ is the Peleg rate constant (h/(g water / g solids), and $k_2$ is the Peleg capacity constant (g water / g solids). All tests were performed in triplicate.

*Germination*

A germination test (BRASIL, 2020) was conducted to assess the physiological quality of the seeds and compare the performance of uncoated and coated seeds. Four replications of 50 seeds each were placed in disposable trays containing sand and soil (1:1) as a substrate. Seeds were sown in longitudinal grooves 5 cm deep. The trays were maintained in BOD chambers at 20 ± 2 °C for 14 days with an adjusted photoperiod of 12 h. The evaluations and counts of the normal seedlings were performed on the 14th day after sowing. The results are expressed as percentages.

## RESULTS AND DISCUSSION

*General characteristics, production yield, pH, and moisture content of the coated seeds*

During their preparation, all formulations resulted in a viscous paste that was easy to handle, transfer to the silicon mold, and facilitated the covering of the seed. Formulations with a higher proportion of gelatin resulted in more viscous matrices after cooling, which dried quickly in the molds and did not disintegrate. Formulations with higher percentages of starch exhibited lower viscosity during preparation, and after drying, they became more brittle; the higher the proportion of starch, the more brittle the coated seeds became. The formulation with 50% starch and 50% gelatin (S50G50) resulted in an easier-to-handle paste that filled the molds to cover the seeds. Figure 1 illustrates the developed formulations, and table 1 presents the yields of coated seeds, pH, and moisture content.

Formulations produced with the pure polymers (S100 and G100) resulted in coated seeds that differed greatly from each other and from the different formulations. The formulation with 100% starch (S100) yielded more brittle coated seeds that quickly disintegrated upon handling, resulting in the lowest production yield (65.10%). Although, the formulation with 100% gelatin (G100) yielded a high production rate (98.17%), it resulted in smaller and harder coated seeds compared to those produced by the other formulations.

Formulations S25G75 and S33G67, with yields of 69.10% and 75.91%, respectively, exhibited defects in the coated seeds base and format. As those formulations contained higher proportions of gelatin, the paste's thicker consistency may have affected its distribution in the molds.

The S50G50 formulation (50% starch and 50% gelatin) yielded the highest production rates, and the coated seeds remained intact when handled. The characteristics obtained from the different formulations suggested that the incorporated starch and gelatin resulted in pastes with varied consistency and polymeric matrices after drying, leading to coated seeds with distinct handling characteristics.

AL-HASSAN & NORZIAH (2012) reported that changing the ratio of starch and gelatin can modify the strength and extensibility of starch-gelatin films and that films with higher starch proportions are more brittle. SOLIMAN et al. (2014) studied several proportions of starch

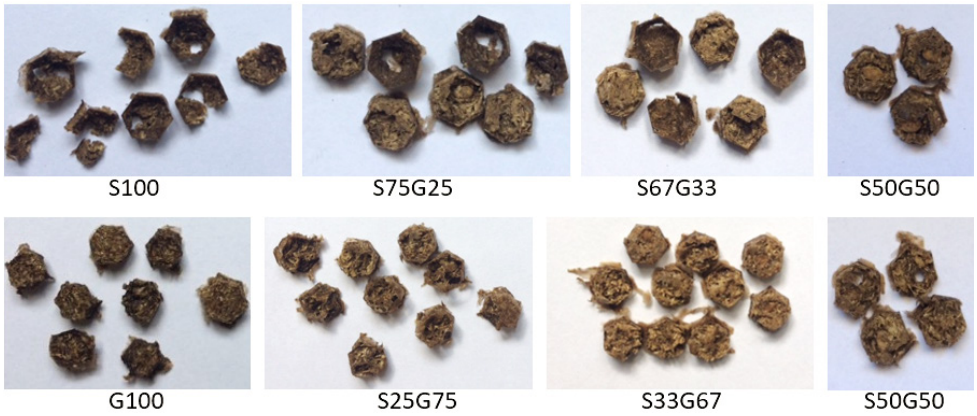



Figure 1 - Visual appearance of tomato seeds after the coating process.

SciELO Preprints - This document is a preprint and its current status is available at: https://doi.org/10.1590/0103-8478cr20250490



Table 1 - Production yield, pH, and moisture content of coated seeds.

| Formulation | Yield (%)* | pH* | Moisture (%)* |
|---|---|---|---|
| S100 | 65.71[d] | 6.55 ± 0.03[a] | 7.68 ± 0.08[b] |
| G100 | 98.17[a] | 6.09 ± 0.02[d] | 9.08 ± 0.10[a] |
| S75G25 | 91.10[b] | 6.24 ± 0.04[b] | 7.86 ± 0.23[ab] |
| S25G75 | 69.10[d] | 6.13 ± 0.01[cd] | 9.14 ± 0.14[a] |
| S33G67 | 75.91[a] | 6.16 ± 0.01[c] | 8.77 ± 0.57[a] |
| S67G33 | 98.43[a] | 6.16 ± 0.01[c] | 8.03 ± 0.21[a] |
| S50G50 | 99.00[a] | 6.17 ± 0.03[c] | 8.43 ± 0.30[a] |

*Different letters in the same column indicate significant differences (P ≤ 0,05 between means (Tukey test).

and gelatin to obtain films, and they reported that a better combination of morphological and mechanical properties was obtained when starch and gelatin were mixed in a 1:1 proportion. The authors attributed this result to the interactions between starch and gelatin. These polymers can interact to produce matrices for film and coating applications, and the hydroxyl groups in the starch macromolecule could interact with carboxyl, amino, and/or hydroxyl groups on the gelatin chains via hydrogen bonding.

The pH analysis showed that, regardless of the difference in the formulation composition, the pH values of the samples were very similar and close to neutral, which is an attractive characteristic of the produced material, considering that it could be used as a polymeric matrix for the immobilization of nutrients and/or microorganisms in future applications. The results varied from 6.09 to 6.55 (Table 1), and a difference was observed between formulations G100 and S100, which were prepared using only gelatin and starch, respectively, as the polymer matrix. Formulations containing both polymers, starch, and gelatin (S75G25, S25G75, S33G67, S67G33, and S50G50) showed slight variation in their pH values, which ranged from 6.11 to 6.25, indicating greater homogeneity of the pH values in these formulations than of those found between formulations containing only one type of polymer. These results are consistent with those obtained by VERCELHEZE et al. (2019), who reported pH values between 5.5 and 6.1 for starch-gelatin-polyvinyl alcohol coatings on maize seeds.

The moisture content of the coated tomato seeds ranged from 7.68 to 9.08%, except for the S100 formulation, which showed the lowest moisture value (7.68%). The values of the other samples did not differ significantly (Table 1). These results are very satisfactory because, at this moisture level, the coated seeds are stable for storage. Moisture content is considered one of the most critical factors influencing seed viability during storage; generally, the storage life decreases if the moisture content increases. High moisture content (≥ 13%) results in mold growth, while very low moisture content (< 4%) can result in the extreme desiccation of seeds; thus, moisture contents between 5 and 13% are generally regarded as safe for the storage of most seeds (FAO, 2018). It is essential to note that the coated seeds were stored at an RH of 58 - 60% at 25 °C for 48 h before their characterization. Thus, the moisture contents (Table 1) corresponded to those of the coated seeds under these conditions. The variation in moisture content as a function of RH is discussed later through the moisture sorption isotherm results.

*Seed density and mass distribution*

The results of the density and mass distribution of uncoated and coated seeds are shown in table 2.

The difference between the density of

Table 2 - Results of density and mass distribution of uncoated and coated seeds.

| Formulation | Density (g/cm$^3$)* | Mass distribution (g)* |
|---|---|---|
| Uncoatedseeds | 0.3778[a] | 0.0028 ± 0.0010[c] |
| S100 | 0.1696[cd] | 0.0610 ± 0.0028[b] |
| G100 | 0.2559[b] | 0.0760 ± 0.0030[a] |
| S75G25 | 0.1574[d] | 0.0695 ± 0.0029[a] |
| S25G75 | 0.1743[cd] | 0.0736 ± 0.0031[a] |
| S33G67 | 0.1788[c] | 0.0776 ± 0.0041[a] |
| S67G33 | 0.1802[c] | 0.0749 ± 0.0027[a] |
| S50G50 | 0.1798[c] | 0.0739 ± 0.0025[a] |

*Different letters in the same column indicate significant differences (P ≤ 0.05) between means (Tukey test).

SciELO Preprints - This document is a preprint and its current status is available at: https://doi.org/10.1590/0103-8478cr20250490



uncoated and coated seeds was remarkable, and the densities of the coated seeds varied from 0.1574 to 0.2559 g/cm$^3$. The uncoated seeds had a density of 0.3778 g/cm$^3$, indicating that the method used for coating significantly decreased the seed density. According to GOVINDEN-SOULANGE & LEVANTARD (2008), seed coating results in seeds with different shapes, lower densities, and higher masses (JAVED et al., 2022) reported that the primary purpose of coating is to increase the apparent size and weight of the seeds and change the shape of the seeds for precision planting.

There was no considerable difference in the densities of the coated seeds between the formulations (S100, S25G75, S33G67, S67G33, and S50G50); however, differences in the density values were more pronounced in the formulations with higher proportions of starch or gelatin.

Formulations S75G25 and S100 showed the lowest density values, 0.1574 g/cm$^3$ and 0.1696 g/cm$^3$, respectively, while the highest density was observed for G100 (0.2559 g/cm$^3$). The highest density is likely related to the highest viscosity of the paste in the G100 formulation, which resulted in shrunken and smaller coated seeds after drying. According to (FAKHOURY et al., 2012). The chemical structure of gelatin does not allow for the formation of organized matrices, unlike starch, resulting in less organized matrices with a higher water sorption capacity.

Uncoated seeds had a mean mass of 0.0028 g, a lower value than that of coated seeds, with mean mass values ranging from 0.0610 to 0.0776 g. The largest variations in mass were observed in the formulations with the highest starch content. Formulations S75G25 and S100 had lower values of 0.0610 and 0.0695 g, respectively, compared to the uncoated seeds. The difference in mass values is likely related to the type and proportion of polymer used in the coating formulation. Starch has a smaller water retention capacity than gelatin, resulting in a lower final weight of the produced coated seeds. In contrast, gelatin favors water retention, thereby increasing the weight of the coated seeds, as observed in the density analysis. According to PESKE & NOVEMBRE (2011), coating results in seeds with a higher weight, which is affected by the materials used to coat the seed.

Table 3 - Solubility of coated seeds.

| Formulation | Solubility 4h (%)* | Solubility 24 h (%)* |
|---|---|---|
| S100 | 35.3 ± 0.029$^{a}$ | 42.8 ± 0.006$^{a}$ |
| G100 | 20.1 ± 0.004$^{c}$ | 34.4 ± 0.002$^{d}$ |
| S75G25 | 30.4 ± 0.006$^{ab}$ | 38.7 ± 0.007$^{abc}$ |
| S25G75 | 24.0 ± 0.002$^{bc}$ | 34.0 ± 0.005$^{d}$ |
| S33G67 | 23.9 ± 0.009$^{bc}$ | 35.2 ± 0.004$^{cd}$ |
| S67G33 | 28.5 ± 0.004$^{ab}$ | 40.3 ± 0.025$^{ab}$ |
| S50G50 | 26.1 ± 0.005$^{bc}$ | 36.8 ± 0.007$^{bcd}$ |

*Different letters in the same column indicate significant differences (P ≤ 0,05) between means (Tukey test).

*Solubility*

Table 3 shows the results of coated seed solubility. These values represent the quantity of mass solubilized after immersing the different formulations in distilled water and stirring for 4 h and 24 h. All samples subjected to longer stirring times (24 h) had significantly higher solubility values than those stirred for only 4 h.

The samples subjected to agitation for 4 h showed values ranging from 20.1 to 35.4%,

Table 4 - The water absorption capacity of coated seeds.

| | Water absorption capacity (%)* | | | | | | |
|---|---|---|---|---|---|---|---|
| Formulation | 1 min | 5 min | 10 min | 15 min | 20 min | 25 min | 30 min |
| S100 | - | - | - | - | - | - | - |
| G100 | 20 ± 0.007$^{c}$ | 24 ± 0.005$^{c}$ | 40 ± 0.006$^{d}$ | 48 ± 0.008$^{b}$ | 57 ± 0.072$^{b}$ | 54 ± 0.043$^{c}$ | 61 ± 0.022$^{bc}$ |
| S75G25 | 47 ± 0.059$^{a}$ | 51 ± 0.013$^{a}$ | 58 ± 0.040$^{bc}$ | 75 ± 0.026$^{a}$ | 66 ± 0.016$^{b}$ | 55 ± 0.046$^{c}$ | 52 ± 0.030$^{c}$ |
| S25G75 | 30 ± 0.007$^{bc}$ | 38 ± 0.012$^{b}$ | 61 ± 0.016$^{b}$ | 74 ± 0.031$^{a}$ | 81 ± 0.039$^{ab}$ | 83 ± 0.048$^{ab}$ | 97 ± 0.052$^{a}$ |
| S33G67 | 42 ± 0.036$^{ab}$ | 47 ± 0.006$^{ab}$ | 74 ± 0.023$^{a}$ | 82 ± 0.044$^{a}$ | 92 ± 0.004$^{a}$ | 88 ± 0.001$^{a}$ | 92 ± 0.050$^{a}$ |
| S67G33 | 37 ± 0.004$^{ab}$ | 47 ± 0.050$^{ab}$ | 47 ± 0.013$^{cd}$ | 55 ± 0.008$^{b}$ | 61 ± 0.036$^{b}$ | 66 ± 0.028$^{bc}$ | 60 ± 0.039$^{bc}$ |
| S50G50 | 41 ± 0.017$^{ab}$ | 50 ± 0.034$^{ab}$ | 67 ± 0.013$^{ab}$ | 74 ± 0.027$^{a}$ | 74 ± 0.020$^{ab}$ | 78 ± 0.033$^{ab}$ | 80 ± 0.044$^{ab}$ |

*Different letters in the same column indicate significant difference (P ≤ 0.05) between means (Tukey test).

SciELO Preprints - This document is a preprint and its current status is available at: https://doi.org/10.1590/0103-8478cr20250490



and after 24 h of stirring, the values ranged from 34.4 to 42.7%. Formulations S100 and S75 had the highest values after 4 and 24 h, without a significant difference between them. In contrast, the lowest percentages (with no significant difference between them) were obtained for the G100, S25G75, S33G67, and S50G50 formulations at both agitation times. The different proportions of starch and gelatin affected the solubility of the coated seeds, and higher levels of starch in the formulation increased the solubility. In contrast, formulations with higher levels of gelatin had lower solubility values.

*Water absorption capacity*

The results of the water absorption capacity analysis are shown in table 4. Formulation S100 completely disintegrated at all tested times, rendering it impossible to determine the water absorption capacity of this sample. Overall, for all the samples, the longer the period of analysis was, the higher the values of water absorption capacity (Table 4), except for formulation S75G25, which, along with the sample prepared with 100% starch (S100), was solubilized after 20 min of analysis, resulting in mass loss.

Overall, the water absorption capacity of formulations S33G67 and S50G50 was higher at all tested time points, and it was similar to the values of formulation S25G75 at the last four time points of the analysis (Table 4). The lower values were observed in the G100 formulation at all points tested.

Notably, the behavior of the formulations produced with pure polymers was different: formulation S100 (100% starch) completely dissolved after the first minute of immersion, whereas formulation G100 (100% gelatin) exhibited a low water absorption capacity at all tested time points. These results are consistent with the subjective evaluation and the density analysis of both samples. Formulation S100 was brittle when handled and did not remain intact when immersed in water. In contrast, formulation G100 resulted in smaller and denser coated seeds that shrank during drying and exhibited a low swelling capacity when submerged in water.

According to VERCELHEZE et al. (2019), it is crucial to correlate the water absorption capacity of different coatings with the respective solubility. A seed coated with an absorbent material can increase the water content used for germination; however, a readily soluble coating may not enhance this function, even if the seeds exhibit high water absorption capacity values. Considering this, the sample with the optimal combination of properties (lower solubility and higher WAC values) was the S50G50 formulation, which also had the highest production yield among all samples (Table 1).

Several authors reported combining starch and gelatin to develop different biodegradable materials (AL-HASSAN & NORZIAH, 2012; FAKHOURY et al., 2012; SOLIMAN et al., 2014; VERCELHEZE et al., 2019; ZHANG et al., 2023). These materials generally exhibited improved mechanical and morphological properties compared to those obtained from pure polymers, which was attributed to the interactions between starch and gelatin (polymer-polymer), thereby reinforcing the polymeric matrix. Hydroxyl groups on starch can interact with carboxyl, amino, and/or hydroxyl groups on gelatin chains via hydrogen bonding, resulting in a stable network with a higher capacity for water retention. Water availability is a limiting factor in the germination of seeds (BADEK et al., 2006; BLUNK et al., 2020), and water absorption is related to the interaction of the hydrophilic groups of starch and gelatin with water molecules (polymer-water) in the three-dimensional polymeric network.

*Moisture adsorption isotherms*

Water sorption isotherm equations help predict the water sorption properties of materials; however, they provide little insight into the interaction between water and the material components. The Guggenheim, Anderson, and Boer (GAB) isotherm equation has been widely used as a representative model of the hydration process to describe the water sorption behavior of food products (BELUCI

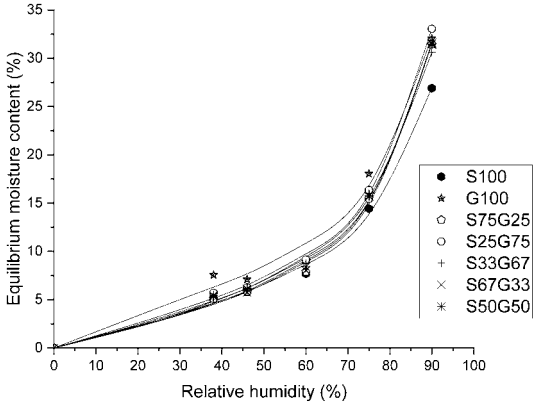



Figure 2 - Moisture sorption isotherm behavior in coated tomato seeds.

SciELO Preprints - This document is a preprint and its current status is available at: https://doi.org/10.1590/0103-8478cr20250490



Table 5 - GAB model parameters for coated seeds.

| Formulation | ----------GAB model parameters---------- | | | |
|---|---|---|---|---|
| | $m_0$ | C | K | $R^2$ |
| S100 | 4.89 | 3.0956 | 0.9220 | 0.99 |
| G100 | 5.29 | 3.9920 | 0.9322 | 0.99 |
| S75G25 | 5.18 | 2.2879 | 0.9416 | 0.99 |
| S25G75 | 5.37 | 2.8960 | 0.9413 | 0.99 |
| S33G67 | 5.94 | 2.1017 | 0.9155 | 0.99 |
| S67G33 | 5.31 | 2.2837 | 0.9385 | 0.99 |
| S50G50 | 5.18 | 2.9797 | 0.9393 | 0.99 |

et al., 2023). Figure 2 shows the moisture sorption isotherms of coated seeds, and table 5 shows the GAB model parameters.

Formulation S100 had the lowest monolayer value (4.89 g water/g solids), while the highest monolayer value (5.94 g water/g solids) was observed in S33G67. The monolayer value indicates the maximum amount of water that can be adsorbed in a single layer per gram of dry material and is a measure of the number of adsorption sites (MALI et al., 2005).

The C parameter is related to the difference in magnitude between the upper layers and the monolayer (MALI et al., 2005). This parameter decreased with the association of polymers, and formulations with 100% starch or gelatin (S100 and G100) showed the highest values. The K parameter values were independent of the formulation composition.

The moisture sorption isotherms exhibited a sigmoidal shape, influenced by the concentration of starch and gelatin in the formulation. The presence of gelatin increased the coated seeds moisture affinity, and under most RH conditions, formulation G100 had a higher capacity to adsorb water, which could be related to the fact that gelatin is more hygroscopic than starch and has a large number of hydrophilic amino acids capable of interacting with water. It was shown that films produced by blending starch and gelatin that contain more protein are most likely to be hygroscopic and absorb more water molecules from the environment (SOLIMAN et al., 2014).

*Moisture adsorption kinetics*

The moisture adsorption curves of the coated seeds are shown in figure 3, and the Peleg parameters (PELEG, 1988) $k_1$ and $k_2$ are shown in table 6.

For all formulations under the three RH conditions evaluated, the moisture adsorption was more rapid during the initial stages of the analysis. Small amounts of water were adsorbed over time until a plateau was reached, indicating that the seeds had equilibrated at the respective RH of the medium. At the end of the analysis, the coated seeds adsorbed higher moisture values at a higher RH of the medium.

It was observed that the moisture equilibrium time was influenced by the storage RH and the concentrations of starch and gelatin in the formulation. Coated seeds stored at 90% RH needed more time to reach equilibrium, and all formulations reached equilibrium almost simultaneously (Figure 3).

The Peleg constant parameters ($k_1$ and $k_2$) are related to mass transfer and maximum water adsorption capacity, respectively. The lower the $k_1$ is, the higher the initial water adsorption rate, and the lower the $k_2$ is, the higher the adsorption capacity (MALI et al., 2005). Formulation S100 exhibited higher initial water adsorption rates at 38% and 60% RH, reaching a plateau close to 5% moisture content. In contrast, other formulations and G100 had higher initial water adsorption rates at 90% RH. Considering the adsorption capacity, a higher value was observed in formulation G100 at 38% RH and in G100 and S25G75 at 60% and 90% RH, respectively.

Molecular differences between starch and gelatin are likely responsible for the difference in the sorption rates. According to the kinetics and isotherm results, the presence of gelatin in the formulation increased the material's affinity for water. Additionally, it was observed that starch resulted in faster water adsorption but with a lower water content. Most likely, starch's lower capacity to interact with water compared with gelatin is related to starch-starch intermolecular interactions in the polymeric matrix (MALI et al., 2005).

*Germination tests*

Germination tests were carried out only for

SciELO Preprints - This document is a preprint and its current status is available at: https://doi.org/10.1590/0103-8478cr20250490



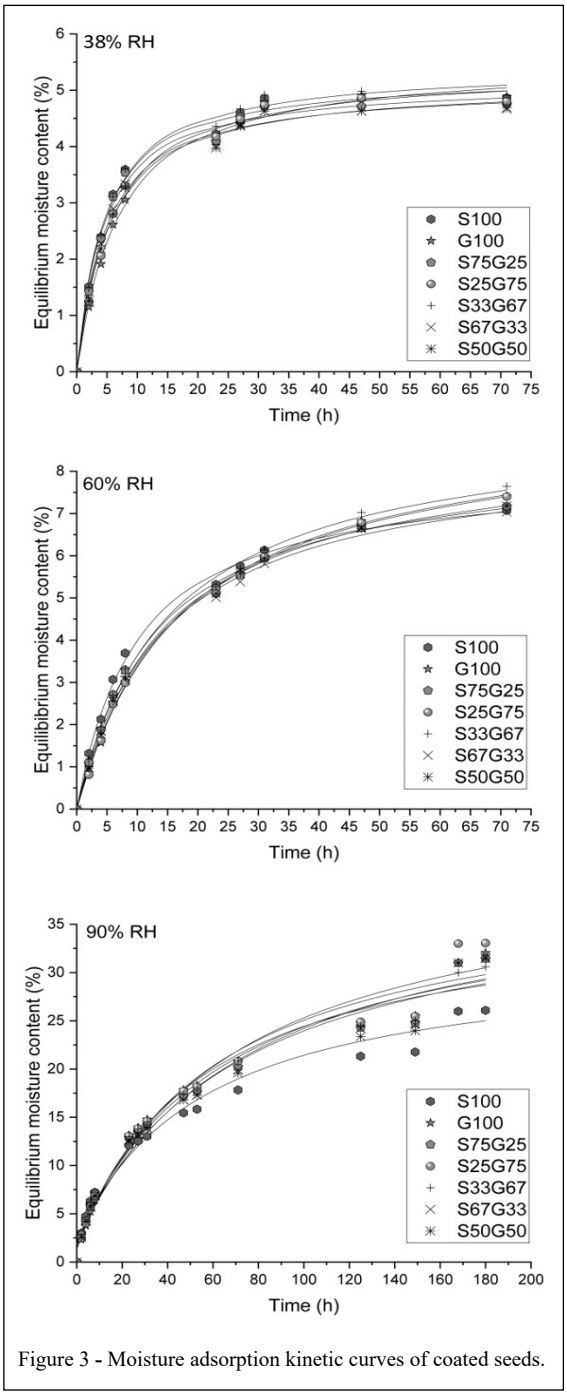



Figure 3 - Moisture adsorption kinetic curves of coated seeds.

the formulation produced with 50% starch and 50% gelatin (S50G50) because this formulation resulted in the best combination of properties (higher production yields, easier handling, lower solubility, and higher water absorption capacity). The germination percentage of the uncoated seeds after 14 days was 85 ± 8%, while the coated samples exhibited a germination of 76 ± 5%. A statistical analysis (Student's t-test, $P > 0.05$) confirmed that the difference between the two groups was not significant. This finding is crucial as it demonstrates that while the S50G50 formulation provides the benefits of coating (e.g., easier handling, higher yields), it does not compromise the fundamental viability of seeds. Notably, the germination percentage

SciELO Preprints - This document is a preprint and its current status is available at: https://doi.org/10.1590/0103-8478cr20250490



Table 6 - PELEG model parameters for coated seeds.

| Formulation | Peleg model parameters | | | | | |
|---|---|---|---|---|---|---|
| | 20% RH | | 60% RH | | 90% RH | |
| | $K_1$ | $K_2$ | $K_1$ | $K_2$ | $K_1$ | $K_2$ |
| S100 | 2920 | 0.187 | 4605 | 0.124 | 6682 | 0.034 |
| G100 | 4414 | 0.179 | 6710 | 0.108 | 5674 | 0.026 |
| S75G25 | 2952 | 0.191 | 5704 | 0.118 | 6399 | 0.027 |
| S25G75 | 3711 | 0.183 | 6701 | 0.108 | 6259 | 0.025 |
| S33G67 | 2976 | 0.183 | 6284 | 0.110 | 6599 | 0.028 |
| S67G33 | 3282 | 0.194 | 6253 | 0.118 | 6894 | 0.026 |
| S50G50 | 3533 | 0.192 | 6159 | 0.115 | 6749 | 0.027 |

For all calculated models $R^2 \geq 0.98$.

of the coated seeds remains above the minimum of 75% required by the Ministry of Agriculture, Livestock, and Food Supply in Brazil (MAPA, 1986) for the distribution, transport, and trade of tomato seeds throughout the Brazilian territory.

## CONCLUSION

This study examined the effect of varying starch and gelatin proportions on the properties of coated tomato seeds, aiming to develop a sustainable and cost-effective alternative for seed enhancement. Coating consistently altered seed shape, decreased density, and increased weight. The coated seeds' pH (6.09-6.55) suggests their potential as polymeric matrices for immobilizing nutrients or microorganisms, while their moisture content (7.68-9.08%) ensures safe storage. We found that higher starch content led to brittle, hard-to-handle coated seeds, making them unsuitable for practical applications. Conversely, formulations with more gelatin resulted in harder, denser coated seeds with superior water absorption capabilities.

The S50G50 formulation was the optimal choice, striking a balance between high production yields, easy handling, lower solubility, and superior water absorption. Although, this formulation led to a slightly reduced germination rate (76%) compared to uncoated seeds (85%), this difference was not statistically significant, and the final germination rate still met the minimum standards for commercial use. This study successfully demonstrated the potential of sustainable seed technologies, but further research is needed to optimize the formulation and unlock the full agricultural potential of these coated seeds.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

## ACKNOWLEDGMENTS

This research was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) - Finance Code 001, which awarded a scholarship to Victória G. Resta. The authors also thank the bibliographic resources provided through the CAPES Journals Portal, which were essential for the development of this research. – Finance code 001."

## DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

## AUTHORS' CONTRIBUTIONS

All authors contributed equally to the conception and writing of the manuscript. All authors critically reviewed the manuscript and approved the final version.

## DELCARATION OF USE OF ARTIFICIAL INTELLIGENCE

During the preparation of this manuscript, the authors used artificial intelligence tools to assist with English language translation and language editing. The authors reviewed and edited all AI-assisted content and take full responsibility for the final

SciELO Preprints - This document is a preprint and its current status is available at: https://doi.org/10.1590/0103-8478cr20250490



content of the manuscript.

## REFERENCES


ABNT – Associação Brasileira de Normas Técnicas. **ABNT NBR NM ISO 535**:1999 Versão Corrigida: 2011. 2011. Available from: <https://www.abntcatalogo.com.br/norma.aspx?ID=88326>. Accessed: Jun. 17, 2024.

ACCINELLI, C. et al. Biological control of aflatoxin production in corn using non-aflatoxigenic Aspergillus flavus administered as a bioplastic-based seed coating. **Crop Protection**, v.107, p.87–92, 2018. Available from: <https://doi.org/10.1016/J.CROPRO.2018.02.004>. Accessed: Jun. 01, 2024. doi: 10.1016/j.cropro.2018.02.004.

AL-HASSAN, A. A.; NORZIAH, M. H. Starch–gelatin edible films: water vapor permeability and mechanical properties as affected by plasticizers. **Food Hydrocolloids**, v.26, n.1, p.108–117, 2012. Available from: <https://doi.org/10.1016/J.FOODHYD.2011.04.015>. Accessed: Jul. 11, 2024, doi: 10.1016/j.foodhyd.2011.04.015.

AMIRKHANI, M. et al. Investigation of soy protein–based Biostimulant Seed Coating for Broccoli Seedling and Plant Growth Enhancement. **HortScience**, v.51, n.9, p.1121–1126, 2016. Available from: <https://doi.org/10.21273/HORTSCI10913-16>. Accessed: Jul. 10, 2024. doi: 10.21273/HORTSCI10913-16.

BADEK, B. et al. Effects of water supply methods and seed moisture content on germination of China aster (*Callistephus chinensis*) and tomato (*Lycopersicon esculentun* Mill.) seeds. **European Journal of Agronomy**, v.24, n.1, p.45–51, 2006. Available from: <https://doi.org/10.1016/J.EJA.2005.04.004>. Accessed: Jul. 01, 2024, doi: 10.1016/j.eja.2005.04.004.

BARNES, A. et al. Influencing incentives for precision agricultural technologies within European arable farming systems. **Environmental Science & Policy**, v.93, p.66–74, 2019. Available from: <https://doi.org/10.1016/J.ENVSCI.2018.12.014>. Accessed: Jul. 02, 2024. doi: 10.1016/j.envsci.2018.12.014.

BLUNK, S. et al. Impact of fruit orientation and pelleting material on water uptake and germination performance in artificial substrate for sugar beet. **PloS one**, v.15, n.5, 2020. Available from: <https://doi.org/10.1371/JOURNAL.PONE.0232875>. Accessed: Jul. 05, 2024. doi: 10.1371/journal.pone.0232875.

BRASIL. **Ministério da agricultura, pecuária e abastecimento, regras para análise de sementes**, 2020. Available from: <https://repositorio-dspace.agricultura.gov.br/handle/1/423>. Accessed: Jun. 17, 2023.

BELUCI, N. C. L. et al. Tailored biodegradable films via extrusion blow molding using PBS, PBAT, and TPS. **Journal of Applied Polymer Science**, p.e54820, 2023. Available from: <https://doi.org/10.1002/APP.54820>. Accessed: Jun. 01, 2024. doi: 10.1002/app.54820.

DE CARVALHO, É. et al. Development and evaluation of a remotely controlled and monitored self-propelled sprayer in tomato crops. **Revista Ciência Agronômica**, v.50, n.1, p.8, 2019. Available from: <https://doi.org/10.5935/1806-6690.20190002>. Accessed: Aug. 01, 2024. doi: 10.5935/1806-6690.20190002.

FAKHOURY, F. et al. Edible films made from blends of manioc starch and gelatin – influence of different types of plasticizer and different levels of macromolecules on their properties. **LWT**, v.49, n.1, p.149–154, 2012. Available from: <https://doi.org/10.1016/J.LWT.2012.04.017>. Accessed: Jun. 11, 2024, doi: 10.1016/j.lwt.2012.04.017.

FAO. **Seeds Toolkit - Module 6**: Seed storage. FAO, Rome, Italy, 2018.

GÁLVEZ, A. et al. Effect of different surfactants on germination and root elongation of two horticultural crops: implications for seed coating. **New Zealand Journal of Crop and Horticultural Science**, v.47, n.2, p.83–98, 2019. Available from: <https://doi.org/10.1080/01140671.2018.1538051>. Accessed: Jun. 14, 2024. doi: 10.1080/01140671.2018.1538051.

GIRARDI, N. S. et al. Microencapsulation of *Peumusboldus* essential oil and its impact on peanut seed quality preservation. **Industrial Crops and Products**, v.114, p.108–114, 2018. Available from: <https://doi.org/10.1016/J.INDCROP.2018.01.036>. Accessed: Jun. 12, 2024. doi: 10.1016/j.indcrop.2018.01.036.

GOVINDEN-SOULANGE, J.; LEVANTARD, M. Comparative studies of seed priming and pelleting on percentage and meantime to germination of seeds of tomato (*Lycopersicon esculentum* Mill.). **African Journal of Agricultural Research**, v.3, n.10, p.725–731, 2008. Available from: <https://doi.org/10.5897/AJAR.9000117>. Accessed: Aug. 12, 2024, doi: 10.5897/AJAR.9000117.

JAVED, T. et al. Seed coating technology: An innovative and sustainable approach for improving seed quality and crop performance**. Journal of the Saudi Society of Agricultural Sciences**, v.21, n.8, p.536–545, 2022. Available from: <https://doi.org/10.1016/J.JSSAS.2022.03.003>. Accessed: Aug. 01, 2024. doi: 10.1016/j.jssas.2022.03.003.

MA, Y. Seed coating with beneficial microorganisms for precision agriculture. **Biotechnology Advances**, v.37, n.7, p.107423, 2019. Available from: <https://doi.org/10.1016/J.BIOTECHADV.2019.107423>. Accessed: Jun. 10, doi: 10.1016/j.biotechadv.2019.107423.

MALI, S. et al. Water sorption and mechanical properties of cassava starch films and their relation to plasticizing effect. **Carbohydrate Polymers**, v.60, n.3, 2005. Available from: <https://doi.org/10.1016/j.carbpol.2005.01.003>. Accessed: Jun. 20, 2024. doi: 10.1016/j.carbpol.2005.01.003.

MAPA. Ministério da Agricultura, Pecuária e Abastecimento. **Portaria número 457 de 18 de dezembro de 1986**. Publicada no DOU 23/12/1986, n.245, seção 1, p.19.653. 1986. Available from: <https://www.gov.br/agricultura/pt-br/assuntos/insumos-agropecuarios/insumos-agricolas/sementes-e-mudas/publicacoes-sementes-e-mudas/PortariaN457de18dedezembrode1986.pdf>. Accessed: Jun. 01, 2024.

MUSTAFA, M. et al. Sustainable responses to open field tomato (*Solanum lycopersicum* L.) stress impacts. **Journal of Agriculture and Food Research**, v.21, p.101825, 2025. Available from: <https://doi.org/10.1016/J.JAFR.2025.101825>. Accessed: Jun. 20, 2024. doi: 10.1016/j.jafr.2025.101825.

PEDRINI, S. et al. Protocol Development Tool (PDT) for seed encrusting and pelleting. **Seed Science and Technology**, v.46,

SciELO Preprints - This document is a preprint and its current status is available at: https://doi.org/10.1590/0103-8478cr20250490



n.2, p.393–405, 2018. Available from: <https://doi.org/10.15258/SST.2018.46.2.21>. Accessed: Jun. 19, 2024. doi: 10.15258/sst.2018.46.2.21.

PEDRINI, S. et al. Seed coating: science or marketing spin? **Trends in Plant Science**, v.22, n.2, p.106–116, 2017. Available from: <https://doi.org/10.1016/J.TPLANTS.2016.11.002>. Accessed: Jun. 15, 2024. doi: 10.1016/j.tplants.2016.11.002.

PELEG, M. An empirical model for the description of moisture sorption curves. **Journal of Food Science**, v.53, n.4, p.1216–1217, 1988. Available from: <https://doi.org/10.1111/j.1365-2621.1988.tb13565.x>. Accessed: Jun. 22, 2024. doi: 10.1111/j.1365-2621.1988.tb13565.x.

PESKE, F. B, NOVEMBRE, A. D. L. C. Pearl millet seed pelleting. **Revista Brasileira de Sementes**, v.33, n.2, p.352–362, 2011. Available from: <https://doi.org/10.1590/S0101-31222011000200018>Accessed: Jun. 18, 2024. doi: 0.1590/S0101-31222011000200018.

PIRZADA, T. et al. Recent advances in biodegradable matrices for active ingredient release in crop protection: Towards attaining sustainability in agriculture. **Current Opinion in Colloid & Interface Science**, v. 48, p. 121–136, 2020. Available from: <https://doi.org/10.1016/J.COCIS.2020.05.002>. Accessed: doi: 10.1016/j.cocis.2020.05.002.

QIU, Y. et al. Biostimulant seed coating treatments to improve cover crop germination and seedling growth. **Agronomy**, v.10, n.2, p.154, 2020. Available from: <https://doi.org/10.3390/AGRONOMY10020154>. Accessed: Jun. 15, 2024. doi: 10.3390/agronomy10020154.

ROCHA, I. et al. Seed coating: a tool for delivering beneficial microbes to agricultural crops. **Frontiers in Plant Science**, v.10, p.485509, 2019. Available from: <https://doi.org/10.3389/fpls.2019.01357>. Accessed: Jun. 17, 2024. doi: 10.3389/fpls.2019.01357.

This preprint was submitted under the following conditions:

- The authors declare that the necessary Terms of Free and Informed Consent of participants or patients in the research were obtained and are described in the manuscript, when applicable.
- The authors declare that the preparation of the manuscript followed the ethical norms of scientific communication.
- The authors declare that they are aware that they are solely responsible for the content of the preprint and that the deposit in SciELO Preprints does not mean any commitment on the part of SciELO, except its preservation and dissemination.
- The authors declare that the data, applications, and other content underlying the manuscript are referenced.
- The deposited manuscript is in PDF format.
- The authors declare that the research that originated the manuscript followed good ethical practices and that the necessary approvals from research ethics committees, when applicable, are described in the manuscript.
- The authors declare that once a manuscript is posted on the SciELO Preprints server, it can only be taken down on request to the SciELO Preprints server Editorial Secretariat, who will post a retraction notice in its place.
- The authors agree that the approved manuscript will be made available under a Creative Commons CC-BY license.
- The submitting author declares that the contributions of all authors and conflict of interest statement are included explicitly and in specific sections of the manuscript.
- The authors declare that the manuscript was not deposited and/or previously made available on another preprint server or published by a journal.
- If the manuscript is being reviewed or being prepared for publishing but not yet published by a journal, the authors declare that they have received authorization from the journal to make this deposit.
- The submitting author declares that all authors of the manuscript agree with the submission to SciELO Preprints.