DOI: 10.1590/1809-6891v24e-74185E

Ciência Animal Brasileira
Brazilian Animal Science

e-ISSN 1809-6891

Section: Animal science
Research article

Sealing strategies in corn silage and sheep performance in feedlots

Estratégias de vedação na ensilagem de milho e desempenho de ovinos em confinamento

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Abstract

The objective of this study was to evaluate the effects of different sealing strategies on aerobic stability and feed value of corn silage supplied to finishing lambs. The treatments were set up according to the silo sealing strategy: BP (black polyethylene film), BP + Bagasse (black polyethylene film + sugarcane bagasse) and BP + Silostop (Silostop® Orange oxygen barrier film + black polyethylene film). Six lambs per treatment were used, totaling 18 animals in an experimental period of 63 days. The silage from LP treatment presented the highest aerobic stability, however with lower dry matter digestibility coefficients. No significant differences were detected among treatments for intake and performance of lambs. But for final body weight, weight gain, daily average gain, feed efficiency and dry matter intake, the best results, in absolute value, were found for lambs fed with silage from LP + Bagasse treatment. The silage sealed exclusively with black polyethylene film showed greater aerobic stability. The different sealing strategies used in this experiment did not influence the performance of finishing Dorper x Santa Inês lambs.

Keywords: aerobic deterioration; carcass; digestibility; weight gain

Resumo

Objetivou-se avaliar os efeitos de diferentes estratégias de vedação sobre a estabilidade aeróbia e o valor alimentício da silagem de milho fornecida para cordeiros em terminação. Os tratamentos foram definidos de acordo com a estratégia de vedação do silo: LP (lona preta de polietileno), LP + Bagaço (lona preta de polietileno + bagaço de cana) e LP + Silostop (lona preta de polietileno + filme de barreira de oxigênio Silostop® Orange). Foram utilizados seis cordeiros por tratamento, totalizando 18 animais, em um período experimental de 63 dias. A silagem do tratamento LP apresentou maior estabilidade aeróbia, porém proporcionou menor coeficiente de digestibilidade da matéria seca. Não foi observada diferença significativa entre os tratamentos para o consumo e desempenho dos cordeiros. Todavia, para o peso corporal final, ganho de peso, ganho médio diário, eficiência alimentar e consumo de matéria seca, os melhores resultados, em valor absoluto, foram encontrados para os cordeiros alimentados com dieta à base da silagem coberta com LP + Bagaço. A silagem vedada exclusivamente com a lona preta de polietileno apresentou maior estabilidade aeróbia. As diferentes estratégias de vedação utilizadas nesse experimento não influenciaram o desempenho de cordeiros Dorper x Santa Inês em terminação.

Palavras-chave: carcaça; deterioração aeróbia; digestibilidade; ganho de peso

1. Introduction

Whole-plant corn silage has been widely used in ruminant feeding,[1] mainly because it provides a high content of total digestible nutrients and high voluntary intake, consisting of a good option for roughage feed for finishing lambs.[2] However, processes that lead to nutrient losses may occur in the most diverse magnitudes during the forage fermentation period, and the degree of anaerobiosis that occurs inside the silo is the factor that has a direct influence on silage preservation.[3,4] The presence of oxygen favors the development of undesirable microorganisms, resulting in nutrient losses, a decrease in hygienic quality, a reduction in the silage feed value,[5,6] and a reduction of intake by animals.[7]

In this context, the plastic film used to seal silos makes a significant contribution, as it is used to reduce the penetration of air from the external environment into the silo. Traditionally, polyethylene film has been the most used material for sealing horizontal silos,[8] mainly due to its low cost and mechanical characteristics.[9] However, the polyethylene polymer is not a material totally impermeable to oxygen diffusion, and, therefore, it does not completely prevent the entrance of oxygen into the silo.[10,11] Thus, even with good sealing conditions, the use

Received: October 2, 2022. Accepted: December 14, 2022. Published: January 23, 2023..

of polyethylene films may not prevent the penetration of oxygen into the peripheral areas of the silo, and these regions may be exposed to deterioration.

Therefore, alternatives have been sought in recent years to contain losses during silage storage through the use of plastic films with lower oxygen permeability.(12) Amaral et al.(8) point out the importance of plastic film quality but its protection with some other material can bring benefits, reducing the incidence of sunlight and gas exchange with the environment, in addition to causing adhesion between the film and ensiled mass, making it difficult for oxygen to move through the mass.

However, although several studies have been developed(9,11,13) aiming to evaluate different plastic films in the sealing stage, few evaluations have been directed to the effects generated in the performance of animals fed these silages. Most studies aim to evaluate the qualitative and quantitative losses of silages in terms of storage time. In this context, this study was developed to evaluate the effects of different sealing strategies on silage aerobic stability and the performance of finishing lambs.

2. Material and methods

The experiment was conducted on the Experimental Farm of Iguatemi (FEI) (23°25′38″ South; 51°56′15″ West) and the Laboratory of Food Analysis and Animal Nutrition (LANA), both belonging to the State University of Maringá, Maringá, Paraná, Brazil. The corn crop (hybrid DKB 177) was sown on FEI and ensiled when it reached 29% dry matter, on average. The plants were harvested with a JF92 Z10 forage harvester set to cut with a theoretical particle size of 10 mm. The forage was compacted in a trench-type horizontal silo, with dimensions of 4.85 m wide x 18 m long and 1.6 m deep (volume of 139.68 m^3). Immediately after the supply and compaction stages, the silo was divided transversely into three equal parts (46.56 m^3) and three different sealing strategies were used, consisting of the following treatments:

1) 200-µm black polyethylene film (BP).

2) 200-µm black polyethylene film with the addition of a ~10 cm high layer of sugarcane bagasse along its entire length (BP + Bagasse).

3) 45-µm oxygen barrier film (Silostop® Orange), covered with a 200-µm black polyethylene film (BP + Silostop).

The silo was opened after 200 days of storage and the upper stratum material (depth of 0–50 cm) from the different sealing strategies was relocated into plastic barrel silos with a capacity of approximately 150 L (seven barrels for each treatment). The silage was compacted in the silos by human trampling to reach a density of approximately 600 kg/m^3. Subsequently, the silos were sealed using films and adhesive tapes and remained in a covered shed for 20 days. After this procedure, the silage from the plastic barrels began to be used to feed the finishing lambs.

Animal performance was evaluated using 18 Dorper x Santa Inês crossbred lambs (12 males and 6 females) with an average initial live weight (ILW) of 21.4 kg (±2.27 kg), distributed in complete blocks according to ILW and sex (n = 6 animals/treatment). Thus, 4 blocks were composed of males and 2 blocks were composed of females, and the animals of each block presented homogeneous ILW. The animals were housed in individual suspended covered stalls (0.60 x 0.90 m) with a slatted floor and provided with individual feeding and drinking troughs. The use of animals in the research complied with the specifications and precautions imposed by the Council for Ethics and Animal Protection (CEUA/UEM No. 4411180917).

The animals remained in the experimental period for 63 days until they reached an average slaughter weight of ~35 kg. Diets were composed of corn silage (CS), rehydrated corn + soybean (20%) high-moisture grain silage (CSHMGS), rehydrated corn grain silage (CHMGS), and mineral supplement (Table 1), formulated according to NRC (2007)(14) for a daily average weight gain of 200 g, considering a roughage to concentrate ratio of 40:60, based on dry matter (DM) (Table 2).

Table 1. Chemical composition (based on DM) of experimental diet ingredients

Ingredient*	DM	MM	CP	NDF	EE	ADF	NFC	TDN
CS–BP	26.41	4.10	8.72	52.06	2.85	30.79	32.22	64.91
CS–BP + Bagasse	25.96	3.98	8.47	51.28	2.94	29.22	35.59	66.13
CS–BP + Silostop	26.43	4.22	8.11	51.76	3.17	29.57	35.00	65.86
CSHMGS	65.60	2.49	15.81	14.27	6.94	3.72	63.61	86.02
CHMGS	65.12	1.49	8.81	10.00	5.96	2.01	75.19	87.33

*CS–BP: corn silage sealed with 200-µm black polyethylene film; CS–BP + Bagasse: corn silage sealed with 200-µm black polyethylene canvas + sugarcane bagasse; CS–BP + Silostop: corn silage sealed with Silostop® Orange + 200-µm black polyethylene film; CSHMGS: rehydrated corn + soybean (20%) grain silage; CHMGS: rehydrated corn grain silage; MS: dry matter; MM: mineral matter; CP: crude protein; NDF: neutral detergent fiber; EE: ether extract; ADF: acid detergent fiber; NFC: non-fibrous carbohydrates; TDN: total digestible nutrients.

Table 2. Experimental diets formulated with corn silage distributed according to the type of coverage received: 200-µm black polyethylene film (BP), 200-µm black polyethylene film + sugarcane bagasse (PP + Bagasse), and 200-µm black polyethylene film + Silostop® Orange (BP + Silostop)

Diet* (% DM)	Silo sealing strategies		
	BP	BP + Bagasse	BP + Silostop
CS	40.0	40.0	40.0
CSHMGS	42.51	42.51	42.51
CHMGS	14.17	14.17	14.17
[1]Mineral supplement	3.32	3.32	3.32
Nutrients in the diets*			
DM, % NM	47.7	47.5	47.7
MM, % DM	2.9	2.9	3.0
CP, % DM	11.5	11.4	11.2
NDF, % DM	28.3	28.0	28.2
EE, % DM	4.9	5.0	5.01
ADF, % DM	14.2	13.6	13.7

*CS: corn silage; CSHMGS: rehydrated corn + soybean (20%) grain silage; CHMGS: rehydrated corn grain silage; DM: dry matter; NM: natural matter; MM: mineral matter; CP: crude protein; NDF: neutral detergent fiber; EE: ether extract; ADF: acid detergent fiber; NFC: non-fibrous carbohydrates; TDN: total digestible nutrients. [1]Guarantee levels per kg of product: Na: 147.00 g; Ca: 120.00 g; P: 87.00 g; S: 18.00 g; Zn: 3800.00 mg; Fe: 1800.00 mg; Mn: 1300.00 mg; F: 870.00 mg; Cu: 590.00 mg; Mo: 300.00 mg; I: 80.00 mg; Co: 40.00 mg; Cr: 20.00 mg; Se: 15.00 mg.

The diet was provided twice a day, at 8:00 am and 4:00 pm, and leftovers were collected before the morning feeding to quantify the material consumed individually by the animals. The amount of diet provided was calculated to allow approximately 10% leftovers, and water was provided ad libitum. Weekly, samples of feed and leftovers were collected and stored at −20 °C for further chemical analyses. The animals were weighed at the beginning of the experimental period, every 21 days, and on the day of slaughter, always preceded by a solid diet fasting for 16 hours. Weight gain (WG) assessment was calculated as the difference between ILW and final live weight (FLW); the daily average gain was obtained by the difference between FLW and ILW divided by the number of days of the experimental period; and feeding efficiency was obtained through the relationship between the WG and DM intake.

The animals were slaughtered in accordance with the rules of the Regulation of Industrial and Sanitary Inspection for Products of Animal Origin– RIISPOA.[15] After evisceration, the hot carcass was weighed to obtain the hot carcass yield (HCY), where HCY = ((hot carcass weight/live weight at slaughter) x100). The carcasses were then refrigerated at a temperature of 4 °C for 24 hours. Subsequently, they were weighed again to determine the cold carcass yield (CCY), where CCY = ((cold carcass weight/live weight at slaughter) x 100).

Feces were collected from the 29th to 31st experimental days directly from the rectal ampulla of the animals to determine the in vivo digestibility of nutrients, according to Huhtanen et al.[16] In addition, samples of feed and leftovers were collected and stored at −20 °C for further laboratory analysis. Fecal output estimation was performed using indigestible neutral detergent fiber (iNDF) as an internal indicator.[17]

At the end of the experiment, all samples (feed, leftovers, and feces) were pre-dried in a forced-air circulation oven at 55 °C for approximately 72 hours and then ground in a Willey mill with a 1-mm opening sieve. Subsequently, the contents of dry matter (DM), mineral matter (MM), crude protein (CP), and ether extract (EE) were determined according to AOAC.[18] Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined according to Van Soest et al.[19] and total digestible nutrients (TDN) were estimated using the equation TDN = 88.9 − (0.779 x %ADF).[20] Total carbohydrates (TC) were calculated according to the methodology described by Sniffen et al.,[21] in which TC = 100 − (%CP + %EE + %MM), and non-fibrous carbohydrates (NFC) were obtained by subtracting NDF (corrected for its MM and PB content) − TC. The equation proposed by Merchen[22] was used to calculate nutrient digestibility: Digestibility (%) = [(Ni − Nf) / Ni] x 100, where Ni is the ingested nutrient and Nf is the fecal nutrient.

Samples of 2.5 kg of silages were collected from each treatment, with four replications, packed without compaction in plastic buckets without lids, and randomly distributed in a room with controlled temperature (24 °C ± 1 °C) for 144 hours to evaluate some parameters of aerobic stability. Silage temperatures were measured every 15 minutes using data loggers (Novus Tagtemp®) inserted in the center of mass of each bucket. The room temperature was measured using data loggers placed next to the buckets. Samples were collected on the first day of the aerobic stability study to determine lactic acid and ammonia. The lactic acid concentration was determined using the spectrophotometric method (565 nm) of Pryce[23] and ammonia according to Chaney and Marbach.[24]

The variables assessed during the aerobic stability test were aerobic stability, calculated as the time, in hours, for the silages to present a temperature 2 °C higher than the room temperature after opening the silo;[25] maximum temperature reached by the mass, in °C; and temperature accumulation in 6 days of aerobic exposure (Σ6d). Another parameter used to evaluate the aerobic stability of silages was pH, through a daily collection of samples from buckets. The readings were performed using a digital pH meter, calibrated with pH 4.0 and 7.0 buffer solutions, with the pH reading being performed via infusion of 10 g of silage sample in 100 mL of distilled water. A complete block design with randomized treatment was used to evaluate animal performance. The experimental data were subjected to analysis of variance and their means compared by the Tukey's test (α = 0.05), using the PROC MIXED of SAS.[26] The experimental design used in the assessment of aerobic stability was completely randomized and the experimental data were subjected to analysis of variance and their means compared by the Tukey's test (α = 0.05), using the PROC MIXED of the SAS software.[26]

3. Results and discussion

The silage sealed with BP showed a higher $N–NH_3$ value (P<0.05), while the silage sealed with BP + Bagasse and BP + Silostop showed similarity between their values. In turn, lactic acid contents were lower in the silage sealed with BP (Table 3).

Table 3. Ammoniacal nitrogen ($N–NH_3$, in % of total nitrogen – %TN), lactic acid (%DM), aerobic stability (AS), maximum temperature (t °C max), and accumulated temperature (Σ6d, in °C) of corn silages sealed with 200-µm black polyethylene film (BP), 200-µm black polyethylene film + sugarcane bagasse (BP + Bagasse), and 45-µm Silostop® Orange oxygen barrier film + 200-µm black polyethylene film (BP + Silostop)

Variable	Silo sealing strategies			Mean	SEM*	P-value
	BP	BP + Bagasse	BP + Silostop			
$N–NH_3$ (%TN)	2.85[a]	2.07[b]	2.00[b]	2.30	0.41	0.004
Lactic acid (% DM)	2.07[c]	3.00[b]	3.10[a]	2.72	0.03	<0.001
AS (hours)	76.35[a]	74.00[b]	71.00[b]	73.77	4.96	0.024
t °C max.	30.95[c]	35.87[b]	38.10[a]	34.97	0.90	<0.001
Σ6d (°C)	10.67[c]	23.07[b]	27.25[a]	10.88	1.26	<0.001

*SEM: standard error of the mean. Different means on the same row differ from each other by Tukey's test (α = 0.05).

According to McDonald et al.,[27] poorly preserved silages have $N–NH_3$ contents higher than 10%. Thus, the values observed in the present study are characteristic of the typical fermentation profile of good-quality corn silages, indicating low proteolytic activity of clostridia. Kung et al.[28] pointed out that the desirable fermentation profile does not always avoid losses after opening the silos but increases them in some cases. According to Weinberg and Muck,[29] silages that present better fermentation patterns, characterized by high concentration and predominance of lactic acid, as well as the presence of residual sugars, are more affected by aerobic deterioration. The results observed in the present study corroborate that mentioned literature, as silages sealed with BP + Bagasse and BP + Silostop, which showed higher contents of lactic acid, thus providing higher amounts of substrates available for consumption by microorganisms in the aerobic phase, resulted in lower aerobic stability (Table 3).

The silage sealed with BP + Silostop showed a higher maximum temperature (38.10 °C) than the other silages, resulting in a higher temperature accumulation for 144 hours (27.25 °C) (P<0.05), which is an indication of greater microbial activity (Table 3). On the other hand, the silage sealed only with BP showed lower temperature values over the time of aerobic exposure (Figure 1A). The increase in silage temperature is the result of the balance between the rate of heat produced by microbial activity and heat losses by conduction, radiation, evaporation, and convection and is directly related to DM oxidation, which causes losses in the form of carbon dioxide (CO_2).[30]

All average pH values were similar to each other (P>0.05) and showed a pH below 4.2 at the beginning of the period of exposure to air regardless of the type of seal used, demonstrating good acidification for corn silage. The silages presented an increase in pH values with the advancement in aerobic exposure time (Figure 1B), probably due to the lactic acid degradation by aerobic microorganisms, especially yeasts, to obtain energy,[31] and the loss of other organic acids by volatilization,[32] intensifying the silage deterioration process.

Regarding lamb performance (Table 4), the variables were not influenced (P>0.05) by the type of sealing. The similarity between the animal responses can be attributed, among other factors, to the similarity regarding the chemical composition of the experimental diets (Table 2). Thus, the magnitude of changes in the chemical composition of the evaluated silages (Table 1) was not enough to change the lamb performance.

The DAG reached with the three diets was 251 g/day, which is higher than the 200 g/day predicted in the diet formulation. Lambs fed silage from the BP + Bagasse treatment showed a higher DAG of 21 and 17 g/day than lambs fed diets with silage from treatments with BP and BP + Silostop, respectively (Table 4), although there was no statistical difference, which can guarantee a better economic return. This behavior may have been a consequence of the higher DMI by animals in the BP + Bagasse treatment (Table 5) than animals fed silages of the other treatments although without statistical difference.

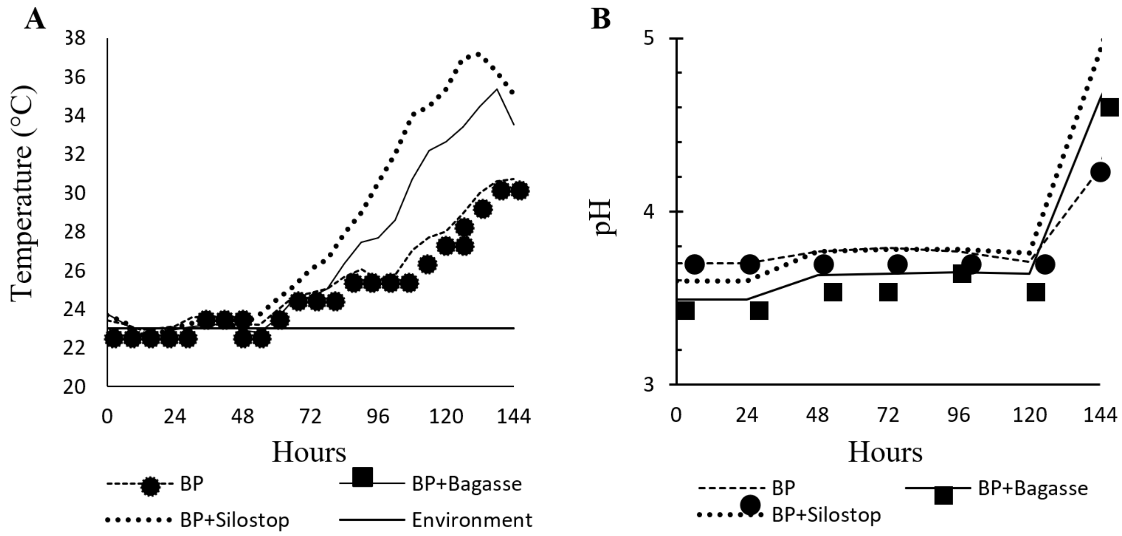

Figure 1. Temporal behavior of silages under aerobic conditions regarding temperature (A) and pH (B).

Table 4. Performance of Dorper x Santa Inês lambs fed corn silage sealed with 200-µm black polyethylene film (BP), 200-µm black polyethylene film + sugarcane bagasse (BP + Bagasse), 45-µm Silostop® Orange oxygen barrier film + 200-µm black polyethylene film (BP + Silostop)

Variable*	Silo sealing strategies			Mean	SEM	P-value
	BP	BP + Bagasse	BP + Silostop			
FBW (kg)	34.31	36.56	36.18	35.68	6.97	0.328
WG (kg)	14.01	14.95	13.73	14.23	2.10	0.354
DAG (g/day)	242.00	263.00	246.00	251.00	0.83	0.490
FE	0.199	0.211	0.208	0.206	0.01	0.332
Intake (% LW)	3.22	3.28	3.12	3.20	0.07	0.626
HCY (%)	49.46	49.28	49.08	49.27	1.44	0.860
CCY (%)	49.06	48.56	48.00	48.63	1.78	0.605

*FBW: final body weight; WG: weight gain – 63 days; DAG: daily average gain; DMI: dry matter intake; FE: feed efficiency; HCY: hot carcass yield; CCY: cold carcass yield. SEM: standard error of the mean.

Table 5. Nutrient intake of Dorper x Santa Inês lambs fed corn silage sealed with 200-µm black polyethylene film (BP), 200-µm black polyethylene film + sugarcane bagasse (BP + Bagasse), 45-µm Silostop® Orange oxygen barrier film + 200 µm black polyethylene film (BP + Silostop)

Variable*	Silo sealing strategies			Mean	SEM	P-value
	BP	BP + Bagasse	BP + Silostop			
		Nutrient intake (g day^{-1})				
DM	1155	1262	1164	1193	0.01	0.267
OM	1124	1225	1132	1160	1.02	0.273
NDF	305	342	313	320	3.87	0.149
CP	139	148	136	141	1.35	0.545
EE	62	66	63	64	2.68	0.407
		Nutrient digestibility coefficients (%)				
DM	70.73^{b}	74.5^{a}	74.45^{a}	73.24	3.05	0.034
OM	73.70	76.77	76.63	75.70	2.58	0.060
NDF	36.56	44.82	43.30	41.56	1.82	0.083
CP	60.86	64.35	65.09	63.43	0.35	0.386

*DM: dry matter; OM: organic matter; NDF: neutral detergent fiber; CP: crude protein; EE: ether extract. SEM: standard error of the mean. Different means on the same row differ from each other by Tukey's test (α = 0.05).

There was a trend towards lower FE for animals fed silage sealed with BP alone and it can be explained by the lower apparent digestibility coefficients of DM (P<0.05; Table 5), influencing the use of nutrients by the animals. In short, this would be the result of higher nutrient losses in the silage covered only with BP. Likewise, carcass yield (Table 4) was not influenced by the type of sealing on the silages (P>0.05), with mean values of 49.27% for HCY and 48.63% for CCY.

Intake variables were not influenced by experimental diets (P>0.05). However, lambs fed silage sealed with BP + Bagasse tended to intake more of all nutrients (P>0.05; Table 5). DMI is important in the performance of feedlot ruminants, as it is considered a determinant of the supply of nutrients needed to meet the maintenance and weight gain requirements of animals.[33] According to Mertens,[34] 60 to 90% of differences in animal performance are a function of intake. The present study showed that although there was no significant difference, lambs fed silage sealed with BP + Bagasse had higher absolute values of DMI, FBW, WG, DAG, and FE, corroborating the authors' assertion.

Regarding the apparent digestibility coefficients of nutrients, only dry matter digestibility coefficient (DMDC) was influenced by the type of seal used in the silages. DMDC was lower (P<0.05; Table 5) when BP was used alone, which may be associated with a higher ADF content and lower NFC content of the silage sealed with BP (Table 1). DMDC was superior for silages sealed with BP associated with bagasse or Silostop® (Table 5), but it was not enough to significantly influence animal performance (Table 4).

4. Conclusion

Silage sealed exclusively with black polyethylene film showed higher aerobic stability. The different sealing strategies used in this experiment did not influence the performance of Dorper x Santa Inês lambs under finishing. Thus, the choice of the best sealing strategy should be based on the production costs incurred at the time of ensiling.

Declaration of conflict of interest

The authors declare that there are no conflicts of interest.

Author contributions

Research: K. C. Scheidt, T. G. Diaz, J. Machado e M. P. Osmari. *Project management:* J. L. P. Daniel e C. C. Jobim.

Acknowledgments

The authors would like to thank the Coordination for the Improvement of Higher Education Personnel (CAPES) for granting the scholarship to the first author.

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