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Production and quality of sunflower and Paiaguas palisadegrass silage in monocropped and intercropping in different forage systems

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ABSTRACT. The objective of this study was to evaluate dry mass production, fermentative parameters and chemical and bromatological composition of sunflower silage and Paiaguas palisadegrass silage in monocropped and intercropping in different forage systems. The experimental design consisted of randomized blocks, with four replicates. The treatments consisted of silage forage systems: sunflower monocropped; Paiaguas palisadegrass monocropped; sunflower row-intercropped with Paiaguas palisadegrass; sunflower inter-row intercropped with Paiaguas palisadegrass; and sunflower oversown and intercropped with Paiaguas palisadegrass, totalizing 20 experimental silos. Sunflower and Paiaguas palisadegrass were harvested at 110 days after planting at 20 cm from the soil for silage, using brush cutter. The silos were opened after 53 days of fermentation. The rows and inter-row intercropped systems contributed to increase the mass production of the ensiled material. The monocropped sunflower silage had higher values of pH, ethereal extract and acid detergent fiber and lower values of titratable acidity and dry matter, crude protein, neutral detergent fiber and *in vitro* dry matter digestibility values. The silages of the sunflower intercropped with Paiaguas palisadegrass in forage systems of crop-livestock integration presented better fermentative and bromatological characteristics, guaranteeing an adequate fermentative process and nutritional quality. In this way, the intercropping of these two forages potentiates the production of silage for feeding of ruminants during the period of forage shortage.

Keywords: *Brachiaria brizantha;* Ensilage; *Helianthus annuus L;* crop-livestock integration.

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Introduction

The seasonality of forage grass production due to edaphic inefficient conditions in part of the year demands planning and execution of specific practices, aiming to keep the forage alive through hard days. The use of silage has been an efficient solution, allowing good bulky material, that is also used for ruminants nutrition (Pereira et al., 2007).

Nowadays, annual crops are used as an alternative for the use in crop-livestock integration system. Among those cultures, the sunflower (*Helianthus annuus L.)* is in the spotlight, the plant is adapted to temperate, tropical and subtropical climate, possessing a fast cycle of production, high efficiency with water available in the ground and, even, good tolerance for high band of temperatures. All of these features are explanations for the use of sunflowers in culture process of silage. (Santos et al., 2012).

The use of the sunflower in the silage after the principal culture harvest is recommended in places where water deficiency turns impossible the cultivation of traditional cultures used on this process. Therefore, the sunflower in the shape of silage is an interesting alternative for production of good quality bulky, consequently, it allows animal production during all the year.

Among the forage used in integration systems, or intercropping of cultures in Cerrado region, *Brachiaria brizantha* cv. BRS Paiaguas is a great option, the plant attends all the requirements needed in different systems of production, encompassing different technological levels (Costa et al., 2016). Besides that, the forage has been used for the production of silage in integrated systems, allowing great results (Santos et al., 2016; Costa et al., 2018; Souza et al., 2019; Oliveira et al., 2020).

Cruvinel et al. (2017) reported that the silage of additive sunflowers with tropical forages are able to bring great benefits to the quality of the silage, for example, decrease in the content of ethereal extract, in the fibers of acid detergents, lignin, in addition to the production of silage in the off season, with good quality and with sufficient amount for nutritional maintenance of ruminants.

However, not much is known about this seeding form of the sunflower rows intercropped with Paiaguas palisadegrass for the production of silage. Therefore, the goal was to evaluate the production of dry mass, fermentative parameters and chemical-bromatological composition of sunflowers silage, monocropped Paiaguas palisadegrass and the intercropping in different forage systems.

Material and methods

The experiment was conducted in the field (17°48' S; 50°55' W; and 748 m altitude) at the Federal Institute of Goiás (Instituto Federal Goiano) in the municipality of Rio Verde, Goiás in the 2014 offseason on a dystroferric Red Latosol soil.

Soil samples were collected from the 0-20 cm layer to assess the physical and chemical characteristics of the experimental area prior to planting the forage systems. The following values were obtained: clay, 520 g kg^{-1}; silt, 150 g kg^{-1}; sand, 330 g kg^{-1}; pH in $CaCl_2$: 5.02; Ca: 4.62; Mg: 1.24; Al: 0.01; Al+H: 6.00; K_2O: 0.63; cation exchange capacity (CEC): 12.52 in $cmol_c$ dm^{-3}; P: 8.43 g dm^{-3}; Cu: 3.5 g dm^{-3}; Zn: 4.1 g dm^{-3}; Fe: 34.0 g dm^{-3}; and organic matter (O.M.): 36.76 g dm^{-3}.

The experimental design consisted of randomized blocks, with four replicates. The treatments consisted of silage forage systems: sunflower monocropped; Paiaguas palisadegrass monocropped; sunflower row-intercropped with Paiaguas palisadegrass; sunflower inter-row intercropped with Paiaguas palisadegrass; and sunflower oversown and intercropped with Paiaguas palisadegrass, totalizing 20 experimental silos. Charrua (triple, semi-early, black-achene hybrid with high oil content) was the sunflower cultivar.

Tillage was performed by weed desiccation using the herbicide glyphosate at a dose of 1.680 g active ingredient (a.i.) ha^{-1} glyphosate in a volume of 150 L broth ha^{-1}. Disking was performed at 40 cm 20 days after desiccation using a disk harrow to remove the seed bank of colonião grass and weeds in the area.

A week before planting, 1.0 t ha^{-1} limestone filler was applied, and the second disking operation was performed at 20 cm followed by leveling. Subsequently, sowing furrows were opened using a planter, and the sowing furrows of Paiaguas palisadegrass in sunflower inter-rows and oversown plots were manually opened using hoes.

Sowing was performed on February 17, 2014 using 80 kg ha^{-1} P_2O_5, 20 kg ha^{-1} FTE BR 12 and 1.5 kg boron and triple super phosphate, frits and boric acid as sources. The sunflowers were sown to a depth of 3 cm in the row, inter-row and oversown intercropping and monocropping. The Paiaguas palisadegrass was sown to a depth of 6 cm in the row intercropping and to a depth of 40 cm from the sunflower row in the inter-row intercropping. In the oversown intercropping, Paiaguas palisadegrass was sown 15 days after the emergence of sunflowers in the inter-rows at 40 cm. Seeds were 6 used per meter of sunflower and pure and viable Paiaguas palisadegrass seeds at 5 kg ha^{-1} were used. The plots consisted of eight rows 3.0 m long in all forage systems.

Manual weeding was performed weekly up to 50 days after emergence (DAE) for weed control. Pest control was manually performed on 03/25/2014 by applying the insecticides Losban (contact) and Nomolt (physiological) at doses of 120 and 7.5 g a.i. ha^{-1} to control the sunflower patch (*Chlosyne lacinia saundersii*) and southern armyworm (*Spodoptera eridania*), respectively, and the fungicide Prior extra on 04/07/2014 at a dose of 60+24 g a.i. ha^{-1} to control sunflower leaf blight (*Alternaria helianthi*) and powdery mildew (*Erysiphe cichoracearum*).

For the ensilage, the sunflower and the Paiaguas palisadegrass were harvested after 110 days of seeding in a 20 cm part of the solo, using a brush cutter. Subsequently, the material was chopped, in a slitting static machine, and turned into particles of 10 to 30 mm.

Then, the material was stored in experimental silos of PVC, which measured 10 cm of diameter and 40 cm of length. After that, it was compacted in an iron pendulum, closed with PVC lids and sealed with duct tape in order to preclude air entrance. Next, the experimental silos were kept in a closed area in room temperature.

Silos were opened after 53 days of fermentation. The top and the bottom silage from each silo was discarded. The central portion was homogenized and placed on plastic trays. Part of the fresh silage after opening the silos was separated to be analyzed for pH and buffering capacity (eq.mg HCL 100 g^{-1} DM).

After this procedure, a sample of the silage was taken and divided into two parts. The first one was packed in plastic bags and frozen. For the determination of ammonia nitrogen ($N\text{-}NH_3$ g kg^{-1} N), the samples were thawed for juice extraction (Bolsen, Lin, & Brent, 1992). The organic acids were determined in a Shimadzu, SPD-10A VP, high performance liquid chromatograph (HPLC), coupled to ultraviolet detector (UV), at a wavelength of 210 nm, according to Kung Júniorr. and Shaver (2001).

The other part of the silage with approximately 500 g was weighed and taken to a forced ventilation oven at 55°C for 72 hours, and then ground in mill with a 1 mm sieve, and stored in plastic containers.

The chemical analysis was performed to determine dry matter (DM), mineral matter (MM), crude protein (CP) obtained by determination of total N using the micro-Kjeldahl technique and the fixed conversion factor (6.25); ether extract (EE) (Association of Official Analytical Chemists [AOAC], 1990). Neutral detergent fiber (NDF) was determined according to Mertens (2002); acid detergent fiber (ADF) (AOAC, 1990) and lignin. Total digestible nutrients (NDT) were obtained using the equation (% NDT = 105.2 - 0.68 (% NDF)). For in vitro dry matter digestibility (IVDMD), we adopted the technique described by Tilley and Terry (1963), adapted for artificial rumen developed by ANKON® using the Daisy incubator from Ankom Technology.

Chemical-bromatological were carried out for fresh sunflower and Paiaguas palisadegrass in monocropped and intercropped in different forage systems, prior to ensiling, according to the methodologies described above (Table 1).

The results were tested by analysis of variance, using the R program (version R-3.1.1) through the ExpDes package (Ferreira, Cavalcanti, & Nogueira, 2014), and Tukey's test for means comparison. Probability level of 5% was considered significant to test.

Table 1. Chemical-bromatological composition (g kg^{-1} MS) of the sunflower and Paiaguas palisadegrass monocropped and intercropped in different forage systems.

Composition	Sunflower monocropped	Paiaguas palisadegrass monocropped	Sunflower x Paiaguas palisadegrass in rows	Sunflower x Paiaguas palisadegrass in inter-rows	Sunflower x Paiaguas palisadegrass in oversown
DM	225	340	275	295	268
BC	45,3	305	383	361	319
CP	103	136	135	130	118
NDF	515	691	608	595	583
ADF	478	418	435	439	455
EE	128	30	82	73	103
MM	18	35	26	23	20
TDN	682	552	605	612	668
IVDMD	539	570	559	558	530

DM: dry matter; BC: buffering capacity; CP: crude protein; NDF: Neutral detergent fiber; ADF: acid detergent fiber; EE: ethereal extract; MM: mineral matter; TDN: total digestible nutrients; IVDMD: In vitro dry matter digestibility.

Results and discussion

The dry matter (DM) production was affected ($p < 0.05$) by forage systems. The biggest production was obtained by the silage of the sunflower inter-row intercropped with Paiaguas palisadegrass intercropping, followed by the forage systems in rows and the sunflower monocropped (Table 2). However, the lowest production of DM was obtained by Paiaguas palisadegrass monocropped forage system, demonstrating that the intercropping has contributed for the rise of DM production in 110.6; 127.9 and 48.9%, in the rows, inter-rows and oversown intercropped, respectively. Several studies have evidenced the benefits of producing silages from intercropping systems (Ribeiro et al., 2017; Cruvinel et al., 2017; Souza et al., 2019; Oliveira et al., 2020).

It is important to emphasize that the intercropped of sunflower with Paiaguas palisadegrass in oversown, proportion was only of 10.93%, in which there was the lowest yield of MS ha^{-1}. This result is caused by the competition for plants, for water, light and nutrient, besides the sunflower morphology, which caused a bigger shading on Paiaguas palisadegrass, damaging the development of the plant. This indicated that this way of planting is not adequate for sunflower intercropping for the silage production.

The values of titratable acidity, buffering capacity, pH, DM, $N\text{-}NH_3/NT$, lactic acid EE, CP, TDN, NDF, ADF and the IVDMD of the silages were affected ($p < 0.05$) by forage systems. However, for the values of acetic acid, butyric acid, propionic acid, the MM contents did not have a meaningful effect ($p > 0.05$) among the silages of forage systems.

Table 2. Dry matter production (t ha^{-1}) and proportion (%) of the ensiled material of forages in different forage systems.

Forage systems	Dry matter production	Sunflower proportion	Paiaguas palisadegrass proportion
Monocropped sunflower	22.16 ab	100	0
Monocropped Paiaguas palisadegrass	11.36 c	0	100
Sunflower x Paiaguas palisadegrass in rows	23.93 ab	81.56	18.44
Sunflower x Paiaguas palisadegrass in inter-rows	25.89 a	78.61	21.39
Sunflower x Paiaguas palisadegrass in oversown	16.92 bc	89.07	10.93
CV (%)		17.23	

Mean values followed by different letters, are significantly different by Tukey's test at 5% probability.

Monocropped sunflower and the intercropped in the oversown forage systems, there were lower values of titratable acidity (TA), differentiating itself from the silage of monocropped Paiaguas palisadegrass (Table 3). The titratable acidity may aid in the general aspect of the fermentative quality of silage, which influences the taste, odor, color and stability (Silva & Queiroz, 2002). Monocropped sunflower silage and the intercropped of Paiaguas palisadegrass in oversown presented high values ($p < 0.05$) of the buffer capacity, as a result the ensilage showed lower values of buffering capacity (Table 3).

Table 3. Titratable acidity (TA), buffering capacity (BC) and pH of the silage in different forage systems.

Forage systems	TA	BC (eq.mg g^{-1} MS)	pH
Monocropped sunflower	8.20 c	46.12 a	5.02 a
Monocropped Paiaguas palisadegrass	15.90 a	30.22 b	4.25 b
Sunflower x Paiaguas palisadegrass in rows	11.87 bc	42.22 ab	4.32 b
Sunflower x Paiaguas palisadegrass in inter-rows	13.02 b	37.90 ab	4.57 b
Sunflower x Paiaguas palisadegrass in oversown	9.17 c	45.90 a	4.97 ab
CV (%)	10.90	14.13	5.82

Mean values followed by different letters, are significantly different by Tukey's test at 5% probability.

Lower pH values of in silages of monocropped Paiaguas palisadegrass and of the intercropped in rows sunflowers (Table 3) were observed. Therefore, those values are inside the appropriate standard for a good fermentation, which is from 3.8 to 4.2 according to Tomich et al. (2004).

The DM content obtained for monocropped sunflower silage was the lowest compared to other forage systems ($p < 0.05$) (Table 4). According to Oliveira et al. (2010) the content of DM from monocropped sunflower silage is usually found, due to the fact that the structure of the plant shows a high level of humidity.

The silage intercropping systems contributed to increase DM content of the silage, because of Paiaguas palisadegrass showed a higher level of DM, since it was harvested during 110 days of growing, with a content of 340 g kg^{-1} (Table 1), balancing the DM content of the sunflower. Similar results were obtained by Cruvinel et al. (2017), who verified that the addition of Marandu palisadegrass; Xaraes palisadegrass; Piata palisadegrass e Paiaguas palisadegrass, in sunflower silage helped to raise DM content of the silage.

Monocropped sunflower silage and intercropped in the oversown presented higher values of $N-NH_3/NT$ (Table 4). The highest and the lowest values of DM were obtained in these forage systems. Considering the proposal of Ferrari Júnior and Lavezzo (2001) silages can be classified as desirable, if NH_3-N value is less than 100 g kg^{-1} total nitrogen.

Table 4. Dry matter (DM) and ammonia nitrogen ($N-NH_3$) of the silage in different forage systems.

Forage Systems	DM (g kg^{-1} DM)	$N-NH_3$ (total N %)
Monocropped sunflower	240.2 b	5.21 a
Monocropped Paiaguas palisadegrass	331.6 a	3.92 ab
Sunflower x Paiaguas palisadegrass in rows	287.9 a	2.93 b
Sunflower x Paiaguas palisadegrass in inter-rows	291.0 a	2.95 b
Sunflower x Paiaguas palisadegrass in oversown	294.3 a	4.46 a
CV (%)	6.36	18.35

Mean values followed by different letters, are significantly different by Tukey's test at 5% probability.

The highest content of lactic acid ($p < 0.05$) was the one obtained in monocropped sunflower silage (Table 5). This result shows the importance of the intercropping of sunflower and Paiaguas palisadegrass in the production of lactic acid. However, the other organic acids were not affected ($p > 0.05$) by forage systems.

The content of acetic acid is related to the values of pH, since the shorter values of pH the lower content of acetic acid. This way, well preserved silages must show a low content of that acid. In general, the average of the contents obtained in the study analyzed (9.9 a 13.7 g kg^{-1} DM) are lower than the limit of 20.0 g kg^{-1} and according to Kung Júnior and Shaver (2001), it is the reference to classify silages as "high-quality" ones.

Butyric acid contents present an average value of 0.2 g kg^{-1} DM. Besides, Souza et al. (2005) reported that the values vary between 0.0 to 3.0 g kg^{-1} DM for all analyzed cultivars of sunflower; those results are close to the ones found on this work.

Considering the fermentative parameters, it is possible to infer that the silages of intercropped systems produced silages with adequate fermentation for the conservation of stored forage.

Table 5. Organic acids (g kg^{-1} DM) of silage in different forage systems.

Forage Systems	Lactic	Acetic	Propionic	Butyric
Monocropped sunflower	30.1 a	13.7	2.2	0.2
Monocropped Paiaguas palisadegrass	17.9 b	9.9	1.7	0.2
Sunflower x Paiaguas palisadegrass in rows	27.7 ab	10.9	1.9	0.3
Sunflower x Paiaguas palisadegrass in inter-rows	23.8 ab	12.5	2.3	0.2
Sunflower x Paiaguas palisadegrass in oversown	21.7 ab	11.5	1.8	0.2
CV (%)	17.93	17.87	16.24	21.78

Mean values followed by different letters, are significantly different by Tukey's test at 5% probability.

Assessing EE contents, it is possible to conclude in Table 6 that monocropped sunflower silage presented the highest value (135.2 g kg^{-1} DM), followed by the intercropped in oversown (109.4 g kg^{-1} DM). Possibly, this result can be explained by the participation of sections in the silage of sunflower, resulting in a bigger amount of grease. The lowest value of EE was obtained in monocropped Paiaguas silage (29.3 g kg^{-1} DM).

Sunflower intercropped to Paiaguas palisadegrass in rows and inter-rows forage systems helped to reduce EE contents, getting the average of 75.4 g kg^{-1} DM. Viana et al. (2012) reported that the sunflower silage presents a higher energetic value compared to the sorghum Sudan and the fodder sorghum, explained by the presence of the ethereal extract.

On the other hand, it is important to highlight that the sunflower silage must not be given as the only bulky for cattle diet, because of the high level of EE, which must be controlled. Higher levels than 70.0 g kg^{-1} DM on their diet can reduce the digestion of the fiber explained by the deterrent of micro-organisms adhesion to food particles or by the toxic effect on cellulolytic bacteria. Besides that, too much grease on their diet can cause the reduction of dry matter ingestion and of passage rate (Sullivan, Bernard, Amos, & Jenkins, 2004).

Aiming to avoid the bad impacts caused by the high content of EE in exclusive silage of sunflower, the silage produced by the sunflower intercropped to tropical forages can be an alternative to well-quality silage production.

For CP contents, there was a meaningful effect ($p > 0.05$) only between the silage of sunflower and Paiaguas palisadegrass, which presented the highest value. This result is caused by the morphology of Paiaguas palisadegrass, which presents a great relation to foliar lamina: thatch (Costa et al., 2016; Santos et al., 2016), contributing for a better quality of the forage. However, in intercropped systems, the contents of CP were similar varying from 116.1 to 119.5 g kg^{-1} DM.

All the silages in forage systems presented contents of CP higher than the minimum, level of 70.0 g kg^{-1} DM, possible to keep proper functioning of ruminal microbiota (Lazzarini et al., 2009).

Table 6. Ethereal extract (EE), crude protein (CP), total digestible nutrients (TDN) and mineral matter (MM) (g kg^{-1} DM) of the silage in different forage systems.

Forage Systems	EE	CP	TDN	MM
Monocropped sunflower	135.2 a	108.9 b	668.9 a	29.1
Monocropped Paiaguas palisadegrass	29.3 c	122.3 a	533.4 b	17.4
Sunflower x Paiaguas palisadegrass in rows	74.6 b	119.5 ab	603.8 a	21.7
Sunflower x Paiaguas palisadegrass in inter-rows	76.2 b	115.6 ab	626.5 a	21.9
Sunflower x Paiaguas palisadegrass in oversown	109.4 a	116.1 ab	636.2 a	24.1
CV (%)	16.05	5.33	4.70	29.94

Mean values followed by different letters, are significantly different by Tukey's test at 5% probability.

Considering the contents of TDN, the silage of monocropped sunflower presented the highest level, differing from the silage of monocropped Paiaguas palisadegrass (Table 4). This result can be related to the high contents of EE on sunflower, which helped to elevate food energy. TDN content is important, once energy and the protein are the most limiting factors for ruminants (Oliveira et al., 2010). The increase of TDN contents in silages can promote a better use of the forage by the ruminants, allowing higher consumption of energy, and, as a consequence, a better performance of the animals.

There was not any significant difference for MM contents ($p < 0.05$) among the silages of the forage systems (Table 6). It is possible to emphasize that MM content reports just an indicative of the quantity of minerals in the sample. High levels of MM can be resulted by high content of silica, which can not have an utilization by the animals.

Studying NDF contents, the silage of monocropped Paiaguas palisadegrass showed the highest value. In contrast, it showed the smallest level of ADF, which explains the good relation foliar lamina: thatch of this forage. According to Sampaio et al. (2009), fodders high contents of ADF are associate to a lower digestibility (Table 7). These results indicates that the fodder used in the experiments analyzed on this article is one of the best plants for the silage of intercropped sunflower, because it reduces the fibrous fractions of this farming, especially lignin contents (Cruvinel et al., 2017).

Lower results were reported by Viana et al. (2012), during the evaluation of the fractionation of the corn, Sudan grass, fodder sorghum and sunflower silage carbohydrates and proteins. The authors obtained NDF contents of 418.0 g kg^{-1} DM and ADF of 33.2 g kg^{-1} DM.

Table 7. Neutral detergent fiber (NDF), acid detergent fiber (ADF) and digestibility *in vitro* of the dry matter (IVDMD) (g kg^{-1} DM) of the silage in different forage systems.

Forage Systems	NDF	ADF	IVDMD
Monocropped sunflower	510.8 c	460.5 a	513.0 b
Monocropped Paiaguas palisadegrass	688.6 a	411.9 b	581.0 a
Sunflower x Paiaguas palisadegrass in rows	603.7 b	438.6 ab	564.7 a
Sunflower x Paiaguas palisadegrass in inter-rows	594.6 b	436.7 ab	565.8 a
Sunflower x Paiaguas palisadegrass in oversown	548.9 bc	451.4 ab	521.3 b
CV (%)	6.44	4.55	5.78

Mean values followed by different letters, are significantly different by Tukey's test at 5% probability.

The silage of monocropped Paiaguas palisadegrass and intercropped Paiaguas palisadegrass in rows and inter-rows have shown the highest values of IVDMD ($p < 0.05$), differing from monocropped sunflower silage and intercropped Paiaguas palisadegrass in oversown (Table 7). The contents of IVDMD obtained in this monocropped sunflower silage study were higher than the ones found by Tomich et al. (2004), that obtained an average value of 49.8%.

The increase of IVDMD rates of monocropped Paiaguas palisadegrass are relevant, because it shows the potential of this fodder used for increasing of digestibility of intercropped silages, elevating their nutritive values. The rise of digestibility is probably associated to the modifications in the chemical fraction of ADF contents. This effect would allow the provision of promptly digestible carbohydrates for the rumens microorganisms (Fernandes et al., 2002; Cruvinel et al., 2017).

Conclusion

In-rows and inter-rows intercropped systems contributed for the increasement of ensilage mass material production. The intercropping silage of the sunflowers with Paiaguas palisadegrass in the cattle raising integration of fodder systems showed the best fermentative and bromatological characteristics, assuring an adequate fermentative process and nutritional quality. So, the intercropping of those fodders enhance silage production used for feeding ruminants during the shortage period of fodder.

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