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Production and quality of forage oats harvested at different developmental stages

Produção e qualidade de aveias forrageiras colhidas em diferentes fases do desenvolvimento

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Highlights

Oat intercropping showed a higher morphological composition of leaves.
The TamGau intercropping system showed lower mean values for NDF, ADF, and LDA.
Greater ruminal degradation after 168 hours for the TamGau system at pre-flowering.

Abstract

This study aimed to evaluate the productive and bromatological characteristics of white and black forage oats grown either in monocropping or intercropping systems, and harvested according to the following treatment designations: TamPic: 90% GMX Tambo white oats + 10% GMX Picasso black oats; InvPicGau: 90% GMX Invernia white oats + 5% GMX Picasso black oats + 5% UPF Gaudéria white oats; TamGau: 30% GMX Tambo white oats + 70% UPF Gaudéria white oats; and Pic: 100% GMX Picasso black oats. All materials were subjected to three successive cuts, at the vegetative, full vegetative, and pre-flowering and/or dough grain stages. With cuts made at the vegetative and full vegetative stages, the TamPic intercropping had the lowest whole plant dry matter content and the lowest dry biomass production (11.71% and 979 kg ha^{-1}). With cuts made at the pre-flowering and dough stages, the black oat cv. Picasso monocrop had lower proportions of leaves (43.5% and 15.4% respectively) and higher proportions of stems (53.1% and 60.3% respectively) compared to the other cropping systems. On average, the ruminal degradation of the forages after 168 hours of incubation was higher: 75.84% at

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the pre-flowering stage and 74.18% at the dough grain stage. In general, oats allow up to three cuts without significantly compromising quality and productivity, whether in monocropping or intercropping systems.
Key words: Dry biomass production. Oat intercropping. Ruminal degradation. Winter cereals.

Resumo

O estudo teve como objetivo avaliar as características produtivas e bromatológicas de aveias forrageiras (branca e preta) cultivadas solteira ou em consórcio, colhidas conforme designação dos tratamentos: TamPic: 90% de aveia branca GMX Tambo + 10% de aveia preta GMX Picasso; InvPicGau: 90% de aveia branca GMX Invernia + 5% de aveia preta GMX Picasso + 5% de aveia branca UPF Gaudéria; TamGau: 30% de aveia branca GMX Tambo + 70% de aveia branca UPF Gaudéria e Pic: 100% de aveia preta GMX Picasso. Todos os materiais foram submetidos a três cortes sucessivos, em estádio vegetativo, pleno vegetativo e de pré-florescimento e/ou grão farináceo. Com os cortes realizados em estádio vegetativo e pleno vegetativo o consórcio TamPic teve o menor teor de matéria seca da planta inteira e a menor produção de biomassa seca (11,71% e 979 kg ha^{-1}). Com os cortes realizados em Pré-florescimento e Grão farináceo a aveia preta cv. Picasso cultivada solteira teve menor participação de folhas (43,5% e 15,4% respectivamente) e maiores participações de colmo (53,1% e 60,3% respectivamente) comparativamente aos demais cultivos. Na média geral, a degradação ruminal das forrageiras após 168 horas de incubação foram maiores, com 75,84% quando colhidas em estádio de Pré-florescimento e 74,18% quando colhidas em estádio de Grão farináceo. De maneira geral, as aveias sejam cultivadas em consórcio ou solteira permitem até três cortes, sem que haja elevado comprometimento de qualidade e produtividade.
Palavras-chave: Cereais de inverno. Consórcio de aveias. Degradação ruminal. Produção de biomassa seca.

Introduction

White and black oats are cool-season forage crops with a high biomass production capacity per hectare. They can be used for soil cover, grazing, grain production, and preserved foods. These species can be cultivated in monoculture or intercropping systems (Guzatti et al., 2015).

Intercropping cultivars or even different species of cool-season cereals for preserved foods production reduces the risk of losses and improves the cost-benefit ratio for rural producers (Dall'Agnol et al., 2022). The success of this system depends on factors impacting production levels, nutritional value, and the distribution of forage accumulation during the growing period, such as climate, genotype, and especially the phenological stage at harvest (Zeni et al., 2022). Additionally, preventing piracy in seed production ensures the sale and/or purchase of higher-quality seeds under current inspection.

Intercropping combines the peaks of dry matter (DM) production, which occur at different times according to genotype, resulting in increased production and a longer forage utilization period. Thus, it allows for the appropriate scheduling of grazing time and/or the timing of hay, haylage, or silage production (Tavares et al., 2015).

Variations in the bromatological quality of each intercropping cultivar should be closely observed since changes in quality are due to phenological stages and the rate at which these stages change reflects climate, management, and the cultivars' intrinsic characteristics. Advancement in the phenological stage allows for greater accumulation of DM, but reduces crude protein and mineral matter content due to the plant's increased nutrient requirements (Bueno et al., 2020). Along with advancing stages (i.e., plant aging), the leaf-to-stem ratio decreases, the cell wall thickens, cytoplasmic content is lost, and the content of fiber carbohydrates increases, reducing the nutritional quality of the forage (i.e., higher fiber content) (Dochwat et al., 2020).

The response to different harvesting strategies is not the same for all winter cereals, as shown in studies developed by Leão et al. (2019) and Pathan et al. (2020); thus, there is a need for research to determine the appropriate number of cuts to obtain quality forage.

The objective of this study was to evaluate the biomass production, morphological and bromatological composition, and ruminal degradation of dry matter in white and black forage oats grown in monocropping or intercropping systems and harvested at the vegetative, full vegetative, pre-flowering, and dough grain stages, aiming to obtain qualitative viability, with standards to be directed to one of the forms of forage preservation.

Material and Methods

The experiment was conducted at the Animal Production Center (NUPRAN) within the Master's Program in Plant Production at the Agricultural and Environmental Sciences Sector of the State University of the Midwest (UNICENTRO), located in the municipality of Guarapuava, state of Paraná.

According to the Köppen classification, the Guarapuava region has a Cfb climate, characterized by humid subtropical mesothermal conditions, including cool summers, a moderate winter, and no dry season. The region is located at an altitude of approximately 1,100 m, with an average annual rainfall of 1,944 mm, average annual minimum and maximum temperatures of 12.7°C and 23.5°C, respectively, and a relative air humidity of 77.9%. The soil of the experimental area is classified as Typical Brown Latosol (Michalovicz et al., 2018).

Before sowing, the area was managed using preventive weed control with the chemical method and the herbicides Glyphosate (Roundup WG®: 1.5 kg ha^{-1}) and Clethodim (Select One Park®: 3 L ha^{-1}), according to the manufacturer's recommendations. After sowing, the chemical properties of the soil presented (profile from 0 to 20 cm): pH $CaCl_2$ 0.01M: 5.98; phosphorus: 15.30 mg dm^{-3}; K^+: 0.43 cmolc dm^{-3}; OM: 23.73%; Al^{3+}: 0.21 cmolc dm^{-3}; $H+Al^{3+}$: 6.42 cmolc dm^{-3}; Ca^{2+}: 6.33 cmolc dm^{-3}; Mg^{2+}: 1.67 cmolc dm^{-3}, and base saturation: 56.75%.

The climatic data for maximum and minimum temperatures, in ºC, and rainfall (mm) for the experimental period are illustrated in Figure 1.

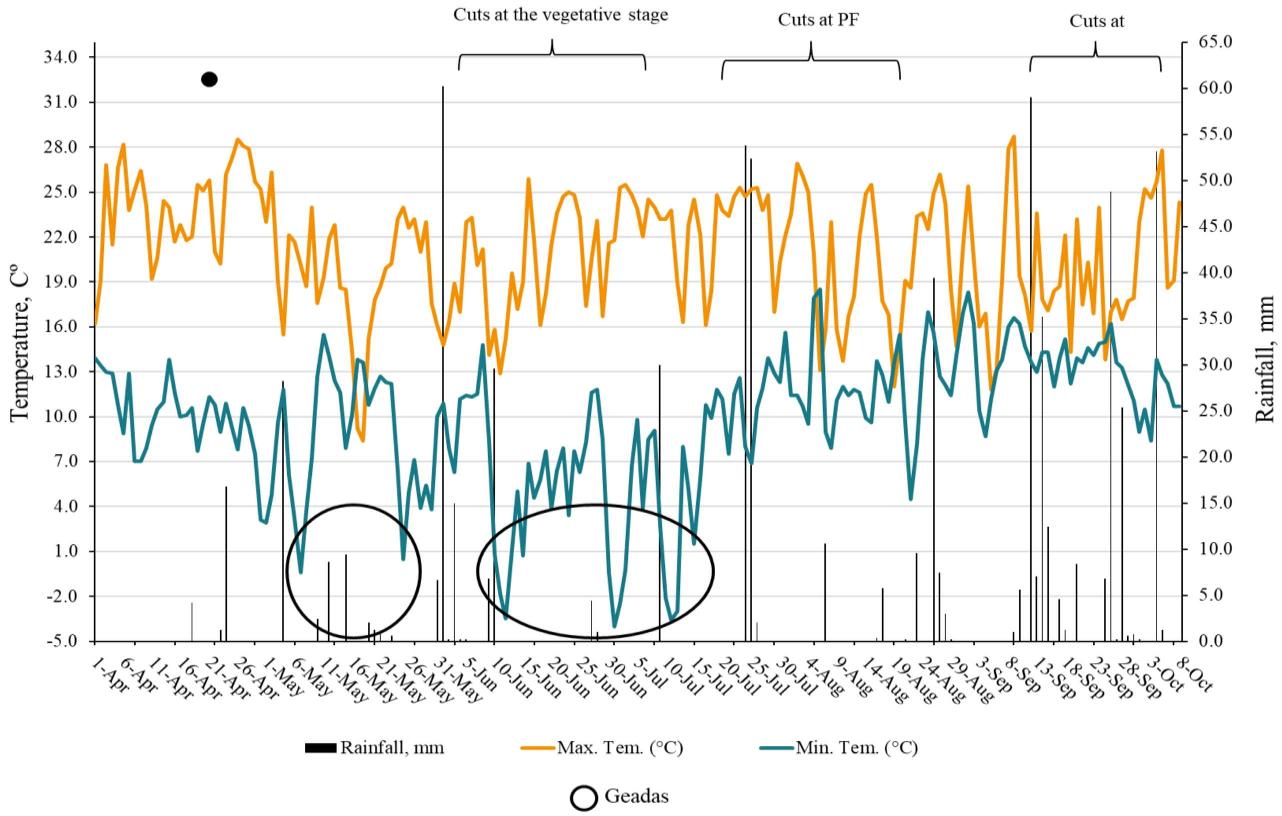

Figure 1. Rainfall, maximum and minimum temperatures during the experimental period.
● Sowing date: April 21, 2022; Harvests: Vegetative stage: June 5, 2022 to July 6, 2022; Pre-flowering (PF): July 21, 2022 to August 19, 2022; Dough grain (DG): September 13, 2022 to October 4, 2022.
Source: SIMEPAR/UNICENTRO experimental station, Guarapuava, state of Paraná, 2022.

The experiment used different combinations of forage oat cultivars, designated as follows: TamPic: 90% GMX Tambo white oat + 10% GMX Picasso black oat; InvPicGau: 90% GMX Invernia white oat + 5% GMX Picasso black oat + 5% UPF Gaudéria white oat; TamGau: 30% GMX Tambo white oat + 70% UPF Gaudéria black oat; and Pic: 100% GMX Picasso black oat, as a monocropping system.

These oat cultivar combinations follow the recommendations of GMAX Genética Gaúcha®, the company that owns the evaluated genotypes, which are commercially available. To prevent genetic material piracy, oat combinations require experimental validation of the resulting forage's productive and qualitative aspects.

The experimental design was a 4×2 factorial randomized block design, with 5 repetitions each, in which forage oats grown in monocropping or intercropping were subjected to two successive cuts. The experimental area consisted of five blocks with 8 plots of 15.47 m² (2.21 m × 7.0 m), totaling 40 plots and a useful evaluation area of 6.8 m² each (1.36 m × 5.0 m).

The forage crops were sown on April 21, 2022, in a no-till system, with a row spacing of 17 cm, a sowing depth of 2 cm, and sowing densities of 343, 332, 315, and 360 plants/m^{2-1} for the TamPic, InvPicGau, TamGau intercropping systems, and Pic monocropping system, respectively.

Basal fertilization was carried out with 300 kg ha^{-1} of 04-20-20 (N-P_2O_5-K_2O) fertilizer, according to the Fertilization and Liming Recommendations for the State of Paraná (Sociedade Brasileira de Ciências do Solo [SBCS], 2017). Topdressing fertilization was carried out in two stages: the first at 45 days after sowing (DAS) and at the full tillering stage, with 300 kg ha^{-1} of urea (46% N), and the second at 85 days DAS and at the booting stage, with 150 kg ha^{-1} of urea (46% N).

All materials (40 plots) were subjected to two successive cuts at the vegetative and full vegetative stages, respectively, when they reached a plant height of 32 cm and were reduced to 12 cm using a scythe. The treatments were then evaluated with a third cut, at the pre-flowering and dough grain stages, which were cut to a height of 12 cm from the ground, aiming to assess the potential of these materials for possible hay, haylage, and/or silage production. Plots evaluated at the pre-flowering stage (20 plots) were cut at the vegetative, full vegetative, and pre-flowering stages, as well as the plots evaluated at the dough grain stage (20 plots) had their cuts carried out at the vegetative, full vegetative, and dough grain stages, as listed in Table 1.

These harvested materials were not used to make haylage and/or silage; however, the data simulate the timing of cutting for producing these feeds. Based on the obtained nutritional values, the most appropriate decision can be made for each situation. All material cut in the useful area of the plot was weighed at each evaluation to determine green biomass production (kg ha^{-1}).

Homogeneous samples of each material were sent to the laboratory at the time of each harvest for analysis of the plant's morphological composition. This involved separating the stem, leaves, and reproductive structure components, as well as determining the dry matter content of the whole plant and its morphological components, in a forced-air oven at 55ºC for 72 hours (Association of Official Analytical Chemists [AOAC], 1995). The relationship between the fresh weight of the plant in the evaluated useful area and the dry matter content allowed for the estimation of dry biomass production (kg ha^{-1}). Then, the whole plant samples were ground in a Wiley mill with a 1 mm mesh sieve.

The pre-dried, ground samples were then subjected to the following analyses: total dry matter content, in an oven at 105°C for 4 hours, crude protein (CP) by the micro-Kjeldahl method (Silva & Queiroz, 2009), and mineral matter (MM) by incineration at 550°C for 4 hours, according to AOAC (1995). The neutral detergent fiber (NDF) content was obtained using α-amylase (Van Soest et al., 1991). Acid detergent fiber (ADF) and acid detergent lignin (ADL) contents were determined non-sequentially using the method of Goering and Van Soest (1970).

Table 1
Days to harvest after emergence and interval (days) between harvests of forage oats in monocropping or intercropping systems, harvested at different developmental stages

Harvest time	Forages*			
	TamPic	InvPicGau	TamGau	Pic
	Harvest, days after emergence			
Vegetative	44	44	42	44
Full vegetative	62	62	62	69
Pre-flowering	106	113	106	106
Dough grain	159	159	159	159
Harvest time	Forages*			
	TamPic	InvPicGau	TamGau	Pic
	Interval between harvests, days			
Vegetative	44	44	42	44
Full vegetative	18	18	20	25
Pre-flowering	44	51	44	37
Dough grain	53	46	53	53

*TamPic: 90% GMX Tambo white oats + 10% GMX Picasso black oats; InvPicGau: 90% GMX Invernia white oats + 5% GMX Picasso black oats + 5% UPF Gaudéria white oats; TamGau: 30% GMX Tambo white oats + 70% UPF Gaudéria white oats; and Pic: 100% GMX Picasso black oats.

Ruminal degradation of forages was measured using the in situ technique (Nocek, 1988), which involved placing 5 g of pre-dried, ground material (1 mm) in 12 cm × 8 cm nylon bags with 50 μm pores for incubation in the rumen. For this purpose, a 72-month-old male bovine with an average body weight of 800 kg, with a permanent ruminal cannula, previously approved by the Animal Research Ethics Committee (CEUA/UNICENTRO), under official letter 010/2023, was used. The incubation times used were 48, 72, and 168 hours.

The data were initially subjected to the Shapiro-Wilk and Bartlett tests to check the assumptions of normality and homogeneity of variance, respectively.

Once these assumptions were met, for the evaluated parameters related to biomass production, plant morphological composition, bromatological composition, and dry matter digestibility, an F-test was applied at a 5% probability through analysis of variance (ANOVA). Then, the Tukey test for comparison of multiple means was applied at a 5% significance level using the SAS statistical program (Statistical Analysis System Institute [SAS Institute], 1993).

The analysis of the parameters related to biomass production, dry matter of the whole plant and leaves, of forage oats, grown in monocropping or intercropping systems, harvested at the vegetative and full vegetative stages, followed the mathematical model Yijkl = μ + Mi + ECj + Bk + (MiERj)l + Eijkl, where: μ = treatment mean; Mi = effect of the forage intercropping of order i, where 1 = TamPic, 2 = InvPicGau, 3 = TamGau and 4 =

Pic; ECj = effect of the harvest stage of order j, where 1 = vegetative and 2 = full vegetative; Bk = effect of the block of order k, where 1 = first, 2 = second, 3 = third, 4 = fourth and 5 = fifth; (MiERj)l = interaction effect of different forage and harvest stage combinations; and Eijkl = random error associated with each observation Yijkl.

Parameters related to biomass production, plant morphological composition, bromatological analysis, and ruminal degradation of dry matter were evaluated independently for the pre-flowering and dough grain stages, using the mathematical model: $Y_{ijkl} = \mu + F_i + B_j + E_{ijk}$, where: μ = treatment mean; F_i = effect of the intercropping of winter forage crops grown in monocropping or intercropping systems of order i, where 1 = TamPic, 2 = InvPicGau, 3 = TamGau and 4 = Pic; B_j = effect of the block of order k, where 1 = first; 2 = second, 3 = third, 4 = fourth and 5 = fifth; and E_{ijkl} = random error associated with each Y_{ijk} observation.

Results and Discussion

Table 1 shows the number of days required for harvest after emergence. The first cut (vegetative) occurred 42 to 44 days after emergence (DAE). The second cut (full vegetative stage) occurred 18 days after the first cut for TamPic and InvPicGau, 20 days after the first cut for TamGau, and 25 days after the first cut for Pic. The third cut, when made at pre-flowering, was performed 44 days after the full vegetative stage for TamPic and TamGau, 37 days for Pic, and 51 days for InvPicGau. When the third cut was performed at the dough grain stage, the interval between the full vegetative stage and the cut was 53 days for TamPic, TamGau, and Pic and 46 days for InvPicGau.

These cuts can simulate different situations and assist in decision-making. The first two cuts, carried out at the vegetative and full vegetative stages, aimed to evaluate the production and quality of forage that could be used for grazing and/or hay production, and to demonstrate resilience to a third cut for haylage or silage production.

The variation in the number of days required for harvest is directly related to the production cycle. Forages harvested at shorter intervals after emergence are earlier-maturing, regardless of whether they are grown in monocropping or intercropping. However, once the reproductive phase is reached, all materials exhibit the same behavior until they reach the dough grain stage.

Table 2 presents the dry matter content of the whole plant, leaves, and dry biomass production (kg ha^{-1}) of forages harvested at the vegetative and full vegetative stages. An interaction was found between the forage species and the harvest time for the dry matter content of the leaves.

The mean value for the dry matter content of leaves at the vegetative stage was higher for TamGau (12.19%) than for InvPicGau (11.62%) and Pic (10.64%), but not different from TamPic (11.98%), which had intermediate values. At the full vegetative stage, Pic had the highest dry matter content (16.70%), followed by InvPicGau (13.78%) and TamPic (13.79%). On average, the dry matter content of the leaves of forages at the full vegetative stage was higher than at the vegetative stage (15.29% and 11.87%, respectively).

When evaluating the dry matter content of the whole plant of forage crops grown in monocropping or intercropping, the highest mean values were observed in the TamGau intercropping system (13.26%), and in the black oat monocrop (Pic; 12.84%), followed by the InvPicGau (12.62%) and TamPic (11.71%) intercropping systems. The dry biomass production of the different forage crops showed the highest mean value for Pic (1,168 kg DM ha^{-1}), followed by InvPicGau (1,072 kg DM ha^{-1}), TamGau (988 kg DM ha^{-1}), and TamPic (979 kg DM ha^{-1}) intercropping systems, which had lower mean biomass productions.

Table 2

Dry matter content of the whole plant and leaves, and dry biomass production of forage oats in monocropping or intercropping systems, harvested at vegetative and full vegetative stages

Harvest time	Forages*				
	TamPic	InvPicGau	TamGau	Pic	Média
	Dry matter of the whole plant, %				
Vegetative	11.93	11.57	12.09	10.76	11.58B
Full vegetative	11.48	13.67	14.42	14.91	13.62A
Mean	11.71b	12.62b	13.26a	12.84ab	
	Dry matter of the leaves, %				
Vegetative	11.98ab	11.62b	12.19a	10.64b	11.87B
Full vegetative	13.99b	13.78b	14.39ab	16.70a	15.29A
Mean	12.99	12.70	13.29	13.67	
	Dry biomass production, kg ha^{-1}				
Vegetative	1003	1076	1045	1288	1109A
Full vegetative	955	1068	930	1048	957B
Mean	979b	1072ab	988b	1168a	

*TamPic: 90% GMX Tambo white oats + 10% GMX Picasso black oats; InvPicGau: 90% GMX Invernia white oats + 5% GMX Picasso black oats + 5% UPF Gaudéria white oats; TamGau: 30% GMX Tambo white oats + 70% UPF Gaudéria white oats; and Pic: 100% GMX Picasso black oats.
Means in the same row, followed by different lowercase letters, differ from each other by Tukey's test at 5%, when comparing forage crops grown in monocropping or intercropping systems, for each harvest time.
Means in the same column, followed by different uppercase letters, differ from each other by Tukey's test at 5%, when comparing forage crops grown in intercropping systems, for each harvest time.

These differences in dry matter content of the whole plant and leaves, and dry biomass production reflect the intrinsic characteristics of each cultivar and its ability to regrow after defoliation, as the plant produces new tillers, thereby increasing biomass production (Bortolini et al., 2004).

The higher mean biomass production of the Pic cultivar, grown in monocropping, may be due to the absence of other cultivars with distinct growth patterns. When species or cultivars with different growth vigor are present in the same space, competition for nutrients and light increases, creating disparities in the stand (Dias, 2006).

When the cut was made at the pre-flowering stage (Table 3), the Pic cultivar had the highest mean dry matter content for the whole plant, leaves, and stems (15.12%, 17.88%, and 12.85%, respectively); its reproductive structure did not differ from the others'. With the cut made at the dough grain stage(Table 3), the dry matter content of the leaves did not differ between intercropping systems. However, for the whole plant, stems, and reproductive structure, there was a significant difference ($P < 0.05$). The Pic cultivar monocrop showed a higher mean (30.18%, 24.32%, and 39.26%, respectively) than other forages grown in intercropping.

The increase in forage dry matter content accompanies the advancement of the plant's phenological cycle. This characteristic is intrinsic to each cultivar (Pereira & Reis, 2001). Since each cultivar has its own cycle, it is natural for there to be differences in dry matter content between intercropping and monocropping systems.

Table 3

Dry matter content of the whole plant and structural components of forage oats grown in monocropping or intercropping systems and harvested at pre-flowering and dough grain stages

Forages*	Forages*			
	Whole plant	Leaves	Stems	Reproductive structure
		Pre-Flowering		
TamPic	12.62b	15.44b	10.31ab	27.04a
InvPicGau	12.83b	16.51ab	10.22b	19.58b
TamGau	13.38b	15.35b	10.64ab	25.15a
Pic	15.12a	17.88a	12.85a	28.32a
Mean	13.48	16.29	11.00	25.02
SEM	0.1872	0.2200	0.3082	0.5695
Probability	0.0020	0.0051	0.0325	0.0008
		Dough grain		
TamPic	26.25ab	47.25a	20.79b	37.69ab
InvPicGau	23.62b	43.03a	19.20b	34.85b
TamGau	25.54ab	43.15a	19.49b	36.78ab
Pic	30.18a	45.45a	24.32a	39.26a
Mean	26.39	44.72	20.95	37.14
SEM	0.5594	1.0540	0.4202	0.4294
Probability	0.0094	0.5963	0.0037	0.0235

* TamPic: 90% GMX Tambo white oats + 10% GMX Picasso black oats; InvPicGau: 90% GMX Invernia white oats + 5% GMX Picasso black oats + 5% UPF Gaudéria white oats; TamGau: 30% GMX Tambo white oats + 70% UPF Gaudéria white oats; and Pic: 100% GMX Picasso black oats
SEM: Standard error of the mean.
Means in the same row, followed by different lowercase letters, differ from each other by Tukey's test at 5%, when comparing forage crops grown in monocropping or intercropping systems, for each harvest time.

During the pre-flowering stage (Table 4), the monocropping system (Pic) exhibited lower ($P < 0.05$) leaf proportions and higher stem proportions in the plant structure (43.5% and 53.1%, respectively) than the intercropping systems. Higher proportions were found for the reproductive structure in the InvPicGau (4.1%) and TamGau (3.7%) intercropping systems compared to the TamPic (1.5%) system and the Pic monocrop (3.4%).

In the dough grain, the proportion of leaves and stems followed the same pattern (Table 4): the Pic monocrop showed a lower leaf proportion (15.4%) and a higher stem proportion (60.3%) than the intercropping systems. Changes in the leaf-to-stem ratio of forage are related to its productive cycle. It is suggested that the black oat monocrop advanced its cycle more quickly than the intercropping systems, which led to a more pronounced characteristic. According to Oral (2024), this leads to a decrease in the leaf-to-stem ratio as the forage matures.

At the pre-flowering stage, there was no difference in biomass production between the forage crops, regardless of whether they were cultivated in intercropping or monocropping. However, at the dough grain stage, the highest yields were observed in TamGau intercropping (4,575 kg ha^{-1}) and black oat monocrop (4,098 kg ha^{-1}), compared to other intercropping systems. These higher yields may be related to the plants' cycle and the absence of competition since they involve a single forage crop and an intercropping system with two cultivars of the same species with similar growth patterns. When different species are used in intercropping systems and there is intense competition for resources such as water, light, space, and nutrients due to differences in productive cycles, productive losses are likely to occur (Dall'Agnol et al., 2021).

Table 4

Morphological composition of the plant and dry biomass production of forage oats grown in monocropping or intercropping systems, harvested at pre-flowering and dough grain stages

Forages*	Structural composition of the plant, % DM			Dry biomass, kg ha^{-1}
	Stems	Leaves	Reproductive structure	
		Pre-Flowering		
TamPic	31.1b	67.4a	1.5b	2.721a
InvPicGau	35.8b	60.1a	4.1a	2.290a
TamGau	31.4b	64.8a	3.7a	2.478a
Pic	53.1a	43.5b	3.4ab	2.331a
Mean	37.8	58.9	3.1	2.455
SEM	1.2002	1.1774	0.1525	0.0909
Probability	0.0001	0.0001	0.0084	0.3748
		Dough grain		
TamPic	57.3ab	21.0a	21.7a	3.031b
InvPicGau	54.8b	21.7a	23.5a	3.301b
TamGau	53.8b	20.6a	25.6a	4.575a
Pic	60.3a	15.4b	24.3a	4.098a
Mean	56.5	19.6	23.7	3.752
SEM	0.6292	0.8218	0.9422	0.1934
Probability	0.0144	0.0490	0.5460	0.0441

*TamPic: 90% GMX Tambo white oats + 10% GMX Picasso black oats; InvPicGau: 90% GMX Invernia white oats + 5% GMX Picasso black oats + 5% UPF Gaudéria white oats; TamGau: 30% GMX Tambo white oats + 70% UPF Gaudéria white oats; and Pic: 100% GMX Picasso black oats
SEM: Standard error of the mean.
Means in the same row, followed by different lowercase letters, differ from each other by Tukey's test at 5%, when comparing forage crops grown in monocropping or intercropping systems, for each harvest time.

Dry biomass production increases as the forage cycle progresses due to dry matter accumulation. In the present study, the cycle change from pre-flowering to dough grain promoted a mean increase of 1,297 kg ha^{-1}, which is significant because dry biomass production dictates the volume of feed available for animal nutrition and relates to production costs (Bueno et al., 2020).

Regarding the chemical composition of the studied forages (Table 5), there was no difference in crude protein and mineral matter regardless of harvest time. However, the highest mean values for NDF, ADF, and ADL occurred when black oats were cultivated alone or in intercropping at the pre-flowering stage and at the dough grain stage for ADF and ADL. Leão et al. (2019) also reported higher NDF and ADF contents in black oats when evaluating the cultivation of different winter forages, which suggests that this characteristic may be peculiar to the species.

A high content of fiber compounds that constitute the structural portion of the forage can be harmful because it reduces dry matter intake and rumen degradation of food. This restricts the action of digestible enzymes produced by ruminal microorganisms (Oral, 2024; Hoppen et al., 2021; Kir, 2020).

Table 5
Mean content of crude protein, mineral matter, neutral detergent fiber, acid detergent fiber, and lignin in forage oats, grown in monocropping or intercropping systems, harvested at pre-flowering and dough grain stages

Forages*	Chemical composition of the plant, % DM				
	CP	MM	NDF	ADF	ADL
			Pre-Flowering		
TamPic	18.39a	11.12a	54.42ab	37.39a	7.56b
InvPicGau	18.17a	10.89a	55.77a	35.56ab	9.59a
TamGau	17.40a	10.11a	51.82b	33.42b	8.85ab
Pic	16.81a	9.73a	56.20a	36.46ab	8.68ab
Mean	17.69	10.46	54.55	35.70	8.67
SEM	0.6934	0.2566	0.4599	0.2770	0.2119
Probability	0.8425	0.2368	0.0228	0.0017	0.0359
			Dough grain		
TamPic	8.54a	5.31a	68.88a	44.32c	11.14a
InvPicGau	8.10a	6.91a	70.64a	48.86ab	12.19ab
TamGau	8.53a	5.60a	69.66a	47.09b	10.87b
Pic	9.05a	5.82a	71.96a	50.99a	11.94ab
Mean	8.55	5.91	70.28	47.81	11.53
SEM	0.3025	0.1956	0.5186	0.2972	0.2093
Probability	0.7452	0.0636	0.2345	0.0001	0.0376

*TamPic: 90% GMX Tambo white oats + 10% GMX Picasso black oats; InvPicGau: 90% GMX Invernia white oats + 5% GMX Picasso black oats + 5% UPF Gaudéria white oats; TamGau: 30% GMX Tambo white oats + 70% UPF Gaudéria white oats; and Pic: 100% GMX Picasso black oats.
CP: Crude protein; MM: Mineral matter; NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin; SEM: Standard error of the mean.
Means in the same row, followed by different lowercase letters, differ from each other by Tukey's test at 5%, when comparing forage crops grown in monocropping or intercropping systems, for each harvest time.

Regardless of the forage evaluated (Table 5), fiber compound levels were lower at the pre-flowering stage than at the dough grain stage. However, the increase in fiber components is directly related to the developmental stage of the forage. As this stage progresses, cell wall thickening occurs due to the deposition of structural compounds. Additionally, the content of soluble carbohydrates inside the cells decreases. These actions cause compounds such as NDF, ADF, and ADL to become more concentrated (Zhang et al., 2023; Bausch-Fluck et al., 2018; Hoppen et al., 2021).

When evaluating the ruminal degradation of forages at the pre-flowering stage (Table 6) with 48- and 72-hour incubations, there was no difference between treatments (P > 0.05). For 168-hour incubations, the highest mean degradation was found in the TamGau intercropping system (78.33%), and the lowest was found in the Pic black oat monocrop (73.84%). After 168 hours of degradation, only the fiber fraction of the forage is affected. When the quality is better (lower ADF and ADL contents), the degradation is greater.

The lower degradation observed in the Pic black oat monocropping system is related to its higher proportion of stems and lower proportion of leaves (Table 4), in addition to higher ADF and ADL mean values (Table 5). As the phenological stage progresses, ADF and ADL concentrations increase and intracellular content decreases, leading to reduced forage degradation (Akbağ, 2022; Zhang et al., 2023). Furthermore, since stems have cells with thicker walls and less photosynthetic tissue than leaves, they contain a higher proportion of cell walls. With an increase in forage content during maturation, cell wall components such as NDF, ADF, and ADL also increase (Villalba et al., 2021). Increased lignin restricts enzymatic hydrolysis of cellulose and hemicellulose, reducing fiber degradation (Horst et al., 2018).

Table 6
Ruminal degradation of dry matter in forage oats grown in monocropping or intercropping systems harvested at pre-flowering and dough grain stages

Forages*	Ruminal degradation of dry matter, %		
	48 hours	72 hours	168 hours
		Pre-Flowering	
TamPic	65.4a	72.72a	75.00ab
InvPicGau	66.78a	75.13a	76.22ab
TamGau	70.84a	73.81a	78.33a
Pic	63.38a	73.60a	73.84b
Mean	66.60	73.81	75.84
SEM	1.6322	1.9330	0.4952
Probability	0.2299	0.8990	0.0083
		Dough grain	
TamPic	48.90ab	55.63a	68.25a
InvPicGau	44.24b	49.85b	76.71a
TamGau	46.12ab	51.80ab	74.21a
Pic	50.22a	54.23a	77.56a
Mean	47.13	52.87	74.18
SEM	0.7651	1.1905	3.3722
Probability	0.0100	0.0215	0.9456

*TamPic: 90% GMX Tambo white oats + 10% GMX Picasso black oats; InvPicGau: 90% GMX Invernia white oats + 5% GMX Picasso black oats + 5% UPF Gaudéria white oats; TamGau: 30% GMX Tambo white oats + 70% UPF Gaudéria white oats; and Pic: 100% GMX Picasso black oats.
SEM: Standard error of the mean.
Means in the same row, followed by different lowercase letters, differ from each other by Tukey's test at 5%, when comparing forage crops grown in monocropping or intercropping systems, for each harvest time.

For ruminal degradation in the dough grain stage (Table 6), only the 48- and 72-hour rumen incubations differed. After 48 hours, the greatest ruminal degradation occurred with the Pic monocrop (50.22%), followed by the TamPic (48.90%), Tamgau (46.12%), and InvPicGau (44.24%) intercropping systems. After 72 hours, the greatest degradation occurred with the TamPic intercropping and the Pic monocrop (55.63% and 54.23% respectively), followed by the TamGau (51.80%) and InvPicGau (49.85%) intercropping systems.

The behaviors described above suggest a relationship with the composition of the compounds that make up the fiber. In other words, forages with greater degradation may have higher-quality fiber. For example, fibers with higher cellulose and hemicellulose content are more digestible because these are potentially digestible fiber carbohydrates (Sniffen et al., 1992; Gayer et al., 2019).

Conclusions

Forage crops grown in monocropping or intercropping systems adapt to successive cuts during the vegetative and reproductive stages in terms of the productive and qualitative aspects of the forage.

In the TamGau intercropping system, when harvested at the pre-flowering and dough grain stages, there was a lower proportion of stems in the plant structure, resulting in greater ruminal degradation of dry matter.

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References

Akbağ, H. I. (2022). Effects of growth stage on nutritional value of barley and triticale forages for goats. *Tropical Grasslands-Forrajes Tropicales, 10*(2), 116–123. doi: 10.17138/tgft(10)116-123.

Association of Official Analytical Chemists (1995). *Official methods of analysis* (16nd ed.). AOAC.

Bausch-Fluck, D., Goldmann, U., Muller, S., Oostrum, M. V., Muller, M., Schubert, O. T., & Wollscheid, B. (2018). The in silico human surfaceome. *Proceedings of the National Academy of Sciences, 115*(46), e10988-E10997. doi: 10.1073/pnas.1808790115

Bortolini, P. C., Sandini, I., Carvalho, P. C. F., & Moraes, A. D. (2004). Cereais de inverno submetidos ao corte no sistema de duplo propósito. *Revista Brasileira de Zootecnia, 3*(1), 45-50. doi: 10.1590/S1516-35982004000100007

Bueno, A. V. I., Ribeiro, M. G., Jacovaci, F. A., Três, T. T., Leão, G. F. M., Gomes, A. L. M., & Jobim, C. C. (2020). Nutritional value and digestible dry matter production of oat genotypes for ensiling. *Ciência Animal Brasileira, 21*(1), e-58129. doi: 10.1590/1809-6891v21e-58129

Dall'Agnol, E., Zeni, M., Fontaneli, R. S., & Bondan, C. (2022). Misturas de cereais de inverno de duplo propósito para silagem de planta inteira. *Research, Society and Development, 11*(8), e45511830938. doi: 10.33448/rsd-v11i8.30938

Dall'Agnol, E., Zeni, M., Silveira, D. C., Fontaneli, R. S., Rebesquini, R., Panisson, F. T., Ceolin, M. E. T., Escobar, F. M., & Webber, M. P. C. (2021). Consorciações de forrageiras anuais de inverno. *Revista Plantio Direto e Tecnologia Agricola, 180*(12), 1-11.

Dias, M. B., Fº. (2006). Competição e sucessão vegetal em pastagens. EMBRAPA Amazônia Oriental-Documentos (INFOTECA-E).

Dochwat, A., Neumann, M., Bumbieris Junior, V. H., Heker Junior, J. C., Cristo, F. B., Zdepski, B. F., Souza, A. M., & Matchula, A. F. (2020). Production and nutritional quality of black oat forage grown in different population stands under a successive cutting regime. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 72*(5), 1936-1946. doi: 10.1590/1678-4162-11313

Gayer, T. O., Kasper, N. F., Tadielo, L. E., Krolow, R. H., Azevedo, E. B. de, Oaigen, R. P., & Castagnara, D. D. (2019). Different dry matter contents used for the conservation of annual ryegrass (*Lolium multiflorum* Lam.) in anaerobic environment. *African Journal of Agricultural Research, 14*(6), 369-378. doi: 10.5897/AJAR2018.13675

Goering, H. K., & Van Soest, P. J. (1970). *Forage fiber analysis: apparatus reagents, procedures and some applications.* Agriculture Handbook.

Guzatti, G. C., Duchini, P. G., Sbrissia, A. F., & Ribeiro, H. M. N., F°. (2015). Aspectos qualitativos e produção de biomassa em pastos de aveia e azevém cultivados puros ou consorciados e submetidos a pastejo leniente. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 67*(5), 1399-1407. doi: 10.1590/1678-4162-8103

Hoppen, S. M., Neres, M. A., Oliveira, P. S. R. de, Oliveira, E. de, & Nath, C. D. (2021). Effects of intercropping on temperate grasses canopy architecture and nutritive profile. *Research, Society and Development, 10*(11), e401101119831. doi: 10.33448/rsd-v10i11.19831

Horst, E. H., Neumann, M., Mareze, J., Leão, G. F. M., Bumbieris, V. H., Jr., & Mendes, M. C. (2018). Nutritional composition of pre-dried silage of different winter cereals. *Acta Scientiarum. Animal Sciences, 40*(1), e42500. doi: 10.4025/actascianimsci.v40i1.42500

Kir, H. (2020). Características de rendimento e qualidade de algumas cultivares de milho para silagem. *Fresenius Environmental Bulletin, 29*(4), 2843-2849.

Leão, G. F. M., Jobim, C. C., Neumann, M., Santos, S. K., Horst, E. H., & Santos, L. C. (2019). Aspectos produtivos e nutricionais de cereais de inverno em regimes de corte para ensilagem. *Archivos de Zootecnia, 68*(262), 128-136. doi: 10.21071/az.v68i262.4132

Michalovicz, L., Müller, M. M. L., Tormena, C. A., Warren, A., Dick, M. V., & Meert, L. (2018). Soil chemical attributes, nutrient uptake and yield of no-till crops as affected by phosphogypsum doses and parceling in southern Brazil. *Archives of Agronomy and Soil Science, 65*(3), 385-399. doi: 10.1080/03650340.2018.1505041

Nocek, J. E. (1988). In situ and other methods to estimate ruminal protein and energy digestibility: a review. *Journal of Dairy Science, 71*(8), 2051-2069. doi: 10.3168/jds.s0022-0302(88)79781-7

Oral, H. H. (2024). Forage yields and nutritive values of oat and triticale pastures for grazing sheep in early spring. *PeerJ, 22*(12), e17840. doi: 10.7717/peerj.17840

Pathan, S. H., Damame, S. V., & Sinare, B. T. (2020). Effect of different cutting management on growth, yield, quality and economics of dual-purpose oat, barley and wheat. *Forage Research, 46*(2), 182-186. doi: 10.5958/0974-1136.2020.00017.8

Pereira, J. R., & Reis, R. A. (2001). Produção de silagem pré-secada com forrageiras temperadas e tropicais. *Anais do Simpósio sobre Produção e Utilização de Forragens Conservadas,* Maringá, PR, Brasil, 1.

Silva, D. J., & Queiroz, A. C. (2009). *Food analysis, chemical and biological methods.* Federal University of Viçosa.

Sniffen, C. J., O'Connor, J. D., Van Soest, P. J., Fox, D. G., & Russell, J. B. (1992). A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. *Journal of Animal Science, 70*(11), 3562-3577. doi: 10.2527/1992.70113562x

Sociedade Brasileira de Ciências do Solo (2017). *Manual de adubação e calagem do estado do Paraná.* Núcleo Estadual Paraná - SBCS.

Statistical Analysis System Institute (1993). *SAS language reference.* Version 6. (4nd ed.). SAS Institute.

Tavares, A. R., Fontaneli, R. S., Santos, H. P., Favero, D., Biazus, V., & Rebechi, I. A. (2015). Rendimento de forragem em consorciações de gramíneas anuais de inverno. *Anais da Mostra de Iniciação Científica, 9. Mostra de Pós-Graduação da Embrapa Trigo.* Passo Fundo, RS, Brasil.

Van Soest, P. J., Robertson, J. B., & Lewis, B. A. (1991). Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science, 74*(10), 3583-3597. doi: 10.3168/jds.s0022-0302(91)78551-2

Villalba, J. J., Ates, S., & MacAdam, J. W. (2021). Non-fiber carbohydrates in forages and their influence on beef production systems. *Frontiers in Sustainable Food Systems, 5*(1) e566338. doi: 10.3389/fsufs.2021.566338

Zeni, M., Bondam, C., Fontaneli, R. S., Mafron, A. C. A., & Dall'agnol, E. (2022). Mixtures of rye cultivars to improve forage yield, distribution and nutritive value. *Research, Society and Development, 11*(10), e52111032216. doi: 10.33448/rsd-v11i10.32216

Zhang, Y. J., Yu, K. Q., Yan, H., Ma, L., Zhou, P., & Peng, Y. (2023). Effect of harvesting time on forage yield and quality of whole-crop oat in autumn-sown regions of China. *Journal of Plant Biology and Crop Research, 6*(2), 1082. doi: 10.1111/gfs.12648