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# Biometric evaluation and nutrients of the corn, pearl millet, and sorghum crops

**Abstract** – The objective of this work was to evaluate the biometric measurements and nutrient contents of the corn, sorghum, and pearl millet crops from 30 days after sowing up to ensiling time. The experiment was conducted in a randomized complete block design, in which the three crops were evaluated with eight replicates. Stem height and diameter and leaf length and width were measured to determine plant growth. In addition, samples were collected to evaluate plant chemical composition. For the characterization of nutrient accumulation and biometric evaluation, linear and nonlinear models were used. Dry matter accumulation did not differ between corn and sorghum, but decreased in pearl millet from the fiftieth day up to ensiling. Crude protein, ashes, and neutral detergent fiber tend to reduce over time. The biometric variables do not differ between corn, pearl millet, and sorghum from 30 days after sowing until ensiling time.

**Index terms**: *Pennisetum glaucum*, *Sorghum bicolor*, *Zea mays*, linear model, nonlinear model.

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## Avaliação biométrica e nutrientes das culturas de milho, milheto e sorgo

**Resumo** – O objetivo deste trabalho foi avaliar as medidas biométricas e o conteúdo de nutrientes das culturas de milho, sorgo e milheto desde 30 dias após a semeadura até o momento da ensilagem. O experimento foi conduzido em delineamento de blocos ao acaso, tendo-se avaliado as três culturas, com oito repetições. A altura e o diâmetro do caule e a largura e o comprimento das folhas foram medidos para determinar o crescimento das plantas. Além disso, foram coletadas amostras para avaliar a composição química das plantas. Para a caracterização do acúmulo de nutrientes e a avaliação biométrica, foram utilizados modelos lineares e não lineares. O acúmulo de matéria seca não diferiu entre o milho e o sorgo, mas diminuiu no milheto do quinquagésimo dia até a ensilagem. Proteína bruta, cinzas e fibras em detergente neutro tendem a diminuir com o tempo. As variáveis biométricas não diferem entre o milho, o milheto e o sorgo desde 30 dias após a semeadura até o momento da ensilagem.

**Termos para indexação**: *Pennisetum glaucum*, *Sorghum bicolor*, *Zea mays*, modelo linear, modelo não linear.

## Introduction

Brazil is the second largest meat producer in the world, producing about 10.32 million tons in 2020 and exporting 2.7 million with revenues of US$ 7.7 billion (Abiec, 2021). About 90% of this meat comes from

cattle finished on pasture, which can significantly impact animal production in countries with a tropical climate, such as Brazil, where the dry season, from May to September, affects the growth capacity and vigor of grasses, i.e., the nutritive value of the pasture (Gomes et al., 2016). For this reason, supplementary practices, such as silage use, are adopted to keep the herd fed, healthy, and productive, regardless of drought duration and intensity (Henriksson et al., 2014). In tropical and subtropical regions, $C_4$ plants, as corn (*Zea mays* L.) and sorghum [(*Sorghum bicolor* (L.) Moench], are the most used in ruminant nutrition and also for silage production due to their yield potential, with sorghum standing out in regions with water stress (Getachew et al., 2016). In Brazil, pearl millet [(*Pennisetum glaucum* (L.) R.Br.] is widely used as mulch for direct sowing in soybean [*Glycine max* (L.) Merr.] crops because of its good resistance to drought (Torres et al., 2015), but it is still poorly explored for ruminant feeding.

The yield of $C_4$ crops may be negatively or positively affected by climate changes, which impact terrestrial ecosystems and, consequently, agricultural production (Arora, 2019). According to these authors, there may be yield losses in several crops due to the expected intensification of irregular rainfall and increases in temperature, which, inevitably, will result in cultivation sites with environmental constraints. Changes in the hydrological cycle are already being observed in Brazil, where the tendency is for more extreme and lasting droughts to occur, interspersed with short and very rainy periods (Arora, 2019).

Although corn has been improved for drought-prone regions, it is continuously challenged by water shortage, and pearl millet and sorghum are already considered more resilient in the few studies comparing these species (Chivenge et al., 2015).

In this scenario, it is important to understand the growth of $C_4$ crops, which is challenging due to the strong effect of the environment, modulating differently several components of the plant growth process. According to Pedó et al. (2015), the quantitative analysis of growth and nutrient accumulation is the most accessible and accurate way to evaluate the performance of plants and the contribution of each physiological process to their development. Considering those differences, it was hypothesized that the growth and nutrient accumulation of pearl millet can occur at a different time than those of corn and sorghum.

The objective of this work was to evaluate the biometric measurements and nutrient contents of the corn, sorghum, and pearl millet crops from 30 days after sowing up to ensiling time.

## Materials and Methods

The experiment was carried out in the municipality of Campos dos Goytacazes, in the Norte Fluminense region of the state of Rio de Janeiro, Brazil (21°48'34"S, 41°18'06"W, at 6 m of altitude), in 2019 and 2020, from January to April. Rainfall and temperature during the experimental period are shown in Figure 1. The climate of the region is classified as Aw, i.e., humid tropical, with a rainy summer and a dry winter, according to Köppen-Geiger's classification (Alvares et al., 2013). The soil in the experimental area is classified as a Cambissolo (Santos et al., 2018), corresponding to a Cambisol.

The pearl millet, sorghum, and corn cultivars used for crop planting were: BRS 1501, BRS 810, and PR 1150, respectively. All of them have an early phenological cycle with flowering around 50 to 70 days, i.e., 60–65 days for corn, 49–56 days for pearl millet, and 55–70 days for sorghum.

In the area used to sow all crops, conventional soil tillage was carried out, followed by the opening of furrows with a depth of 0.5 m, spaced at 0.7 m. Before sowing, soil samples were collected and sent to the testing center of Universidade Federal Rural do Rio de Janeiro for analysis. The soil presented the following chemical composition: pH ($H_2O$) 5.5, 23 mg $dm^{-3}$ P, 1.0 mg $dm^{-3}$ K, 0.02 mg $dm^{-3}$ Na, 0.47 $cmol_c$ $dm^{-3}$ Ca, 0.1 $cmol_c$ $dm^{-3}$ Mg, 0.0 $cmol_c$ $dm^{-3}$ Al, 0.77 $cmol_c$ $dm^{-3}$ H+Al, effective cation exchange capacity of 0.7 $cmol_c$ $dm^{-3}$, total cation exchange capacity of 1.4 $cmol_c$ $dm^{-3}$, sum of bases of 0.7 $cmol_c$ $dm^{-3}$, base saturation of 46.5%, 1.7% organic matter, 82.8 mg $dm^{-3}$ Fe, 0.2 mg $dm^{-3}$ Cu, 2.4 mg $dm^{-3}$ Zn, and 24 mg $dm^{-3}$ Mn.

Fertilizations were carried out on the basis of the soil analysis results. A total of 200 kg $ha^{-1}$ of 08-28-16 N-$P_2O_5$-$K_2O$ were applied to pearl millet and of 250 kg $ha^{-1}$ to corn and sorghum as recommended by Manual de calagem e adubação do Estado do Rio de Janeiro (Freire, 2013). There was no need to correct soil acidity. Sowing was done manually, using 60, 13,

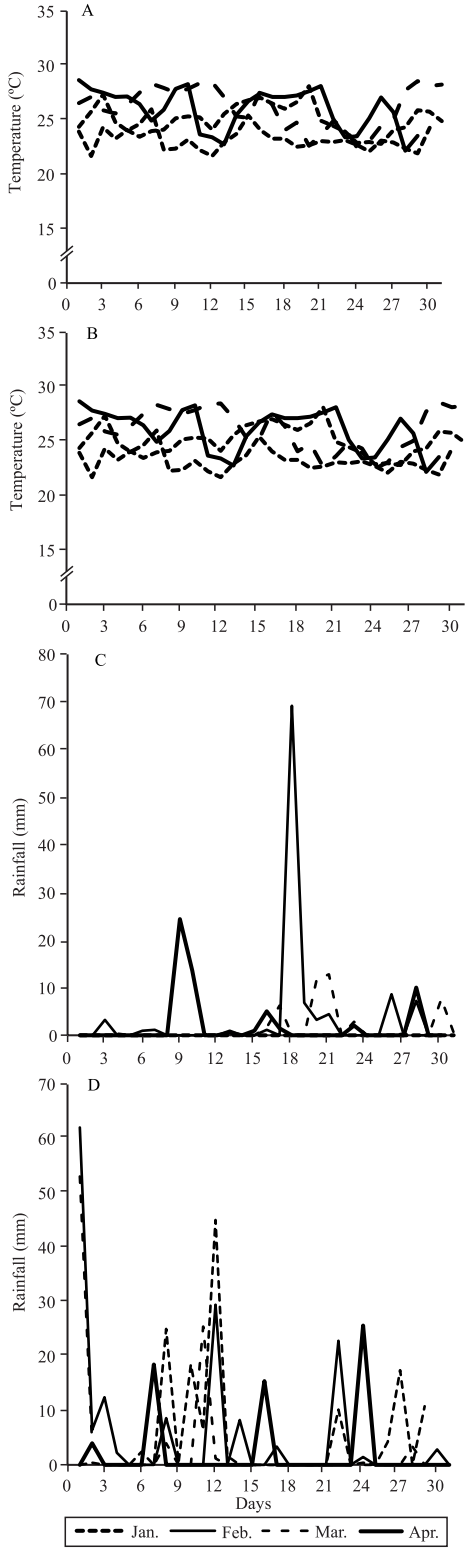


**Figure 1.** Average monthly temperature in 2019 (A) and 2020 (B) and monthly rainfall in 2019 (C) and 2020 (D) during the experimental period in the municipality of Campos dos Goytacazes, in the state of Rio de Janeiro, Brazil.

and 6 pure and viable seeds of pearl millet, sorghum, and corn per meter of furrow, respectively.

When there was drought during the rainy season, characterized by very sunny and hot days, irrigation was used only to allow the germination and emergence of seedlings, being interrupted right after plant emergence and rooting. Weeds were controlled by hand weeding during the crop cycle.

The experimental trial was conducted in a randomized complete block design, in which the corn, sorghum, and pearl millet crops were evaluated with eight replicates, totaling 24 experimental units. Each plot consisted of 12 lines of 5.0 m, spaced at 0.7 m (12x5.0x0.7 m), totaling 42 $m^2$ in each experimental unit and a total functional area of 1,008 $m^2$.

At 30 days after sowing (DAS), to determine leaf growth, the length of the central vein of the youngest leaf (with blade opening and located at the shoot apex) of each crop was measured using a 1.0 mm scale ruler. Measurements were performed every two days until crop growth was completed. Simultaneously, the length and width of the last fully expanded leaf, also located at the shoot apex, were measured using the same ruler.

To determine plant growth, stem height and diameter were measured, as follows: from the base of the stem to the tip of the most erect and central leaf (last emerging leaf) using a millimeter ruler; and at 0.3 m from the base of the stem using a digital caliper, respectively. These measurements were carried out at 5-day intervals for pearl millet and at 15-day intervals for corn and sorghum.

The interval between harvests – 5 days for pearl millet and 15 days for corn and sorghum – was determined according to the phenological cycle of each crop, aiming to evaluate plant chemical composition. The cycle of pearl millet is close to 60 DAS, and that of corn and sorghum to 90 DAS. For all crops, the first evaluation was performed at 30 DAS and the last at ensiling time.

In each experimental plot, the area to be harvested in a specific row was delimited with the aid of a metric ruler, leaving a 1.0 m border to avoid the effect of light. Within each plot, the initial evaluation was carried out on the first row and the following ones on randomly selected rows.

The samples collected at harvest were sent to the Animal Nutrition Laboratory of Universidade

Estadual do Norte Fluminense, where they were dried at 55°C, for 72 hours, in a forced-air oven and, then, processed in a knife mill fitted with a 1.0 mm sieve to yield the partially dried samples. The contents of dry matter (DM), mineral matter (MM), and crude protein (CP) were analyzed by methods 967.03, 942.05, 2001.11, respectively, of AOAC International (Latimer Jr., 2019). In addition, neutral detergent fiber (NDF) was determined using the TE-149 fiber analyzer (Tecnal, Piracicaba, SP, Brazil). Sodium sulfite and two additions of a standardized heat-stable amylase solution were used, as described by Detmann et al. (2012).

For the characterization of the chemical composition and for the biometric evaluation of pearl millet, corn, and sorghum at 30 DAS up to the harvest point for ensiling, linear and nonlinear models were used. The variables without repeated measures were: DM (g $kg^{-1}$), CP (g $kg^{-1}$), MM (g $kg^{-1}$), and NDF (g $kg^{-1}$). The biometric variables recorded as longitudinal data were: stem height (cm) and diameter (mm), and leaf length (cm) and width (cm). The following models were used:

$$y_i = \theta_0 + \theta_1 t_i,$$

$$y_i = \theta_0 + \theta_1 t_i + \theta_2 t_i^2,$$

$$y_i = A\exp(-\lambda t_i), \text{ and}$$

$$y_i = A t_i^{N-1}\exp(-\lambda t_i).$$

The linear and quadratic models correspond to the first two equations, where parameters $\theta_0$, $\theta_1$, and $\theta_2$, are the intercept, linear, and quadratic components, respectively. The exponential model, corresponding to the third equation, is the particular case for N = 1 of the rearranged Wood model (Wood, 1967), represented by the fourth equation, where A is a scale parameter, λ (1/day) is a fractional rate, and N is the parameter of the gamma distribution that shapes the function to mimic the time profile; A, N, and λ are assumed to be higher than zero.

The other used equations were:

$$\sigma_t^2 = \sigma^2,$$

$$\sigma_t^2 = \sigma^2 \exp(2\delta t_i), \text{ and}$$

$$\sigma_t^2 = \sigma^2 |f(\Theta, t_i)|^{2\Psi}.$$

In the fifth equation, the homogeneous variance ($\sigma^2$) represents the traditional assumption. In the sixth equation, the depicted variance function corresponds to an exponential increase or decrease in the residual variance over time, depending on the estimate of parameter δ (1/day), a fractional ratio whose parameter space is defined by interval (–∞,∞). Since variance may be a scaling function of $f(\Theta, t_i)$, the function of the power of the mean shown in the seventh equation can be used, where Ψ (dimensionless) is a scaling power contained in interval (–∞,∞).

To characterize leaf growth up to the harvest point for ensiling, the following growth models were used.

$$y_i = A \times (1 - \exp^{(-kt)}),$$

$$y_i = A \times (1 - \exp^{(-ct)})/(1 + b \times \exp^{(-ct)}),$$

$$y_i = A \times (b - b\exp^{(-ct)})/b - 1), \text{ and}$$

$$y_i = A \times t^c/(t^c + b^c).$$

These equations represent the fit of the monomolecular (Brody, 1945), logistic (López et al., 1999), Gompertz (López et al., 1999), and generalized Michaelis-Menten (López et al., 2000) models, respectively, where: $y_i$ is the i-th observation of the dependent variable; t are record days; A is the asymptotic value; b is a location parameter, important for maintaining the sigmoidal shape of the model; and c is associated with growth, indicating the precocity index. The higher the value of c, the less time will be required for the plant to reach the asymptotic value.

All models were fit by the gnls and nlme functions of R (R Core Team, 2019), and the models that converged were evaluated by Akaike's information criterion corrected for small samples ($AICc_h$) (Sugiura, 1978) and by derived likelihood criteria, i.e., the difference between the h-th different models ($\Delta_h$), Akaike's weights or likelihood probabilities ($w_h$), and evidence ratios ($ER_h$). Means were followed by the confidence interval of 95%, presented as: y ± (Ur – Lr)/2, where: y is the predicted answer; and Ur and Lr represent the upper and lower limits, respectively, predicted at a 95% confidence interval.

For the statistical analysis, the following model was used: $y_{ijk} = \mu + \alpha_i + \tau_j + \alpha\tau_{ij} + b_k + \varepsilon_{ijk}$, where: $y_{ijk}$ is the observation concerning crop i, in year j, in block k; μ is the overall mean; $\alpha_i$ is the crop, i = 1, 2, 3; $\tau_j$ is the effect of the year, j = 1,2; $\alpha\tau_{ij}$ is the interaction between

crop and year; $b_k$ is the effect of the block, k = 1, 2, 3, ..., 8; and $\varepsilon_{ijk}$ is the random error.

## Results and Discussion

There was no year effect (p = 0.2587) on any of the evaluated variables. The best-fit model for chemical composition was the linear model, specifically the first equation for DM and the second for CP and MM. However, the fiber portion represented by NDF showed a better fit to the nonlinear Wood model, corresponding to the fourth equation (Table 1). Regarding DM accumulation, there was no difference (p = 0.1265) between corn and sorghum, whereas pearl millet showed a different behavior, with a decreasing DM content from the fiftieth day onwards (Table 2 and Figure 2 A).

For CP contents, no difference (p = 0.3205) was found between corn, pearl millet, and sorghum (Table 1 and Figure 2 B). This measure is important since nitrogen is not only an essential plant nutrient but is also a signaling molecule that controls several aspects of plant metabolism and development (Bang et al., 2021). Plants can absorb $NH_4^+$ and $NO_3^-$, although the assimilation of the latter is more critical

**Table 1.** Parameter estimates of the models chosen to evaluate the chemical composition of pearl millet (*Pennisetum glaucum*), corn (*Zea mays*), and sorghum (*Sorghum bicolor*) from 30 days after sowing up to the harvest point for ensiling[(1)].

| Variable | Model | A or $\theta_0$ | $\theta_1$ | $\theta_2$ |
|---|---|---|---|---|
| DM | | | | |
| Pearl millet | Linear | 225.29±60.29 | -0.45±1.29 | - |
| Corn | Linear | 137.82±47.65 | 1.83±0.73 | - |
| Sorghum | Linear | 169.8±47.38 | 1.13±0.72 | - |
| CP | | | | |
| Pearl millet | Q | 587.44±173.61 | -19.02±7.13 | 0.17±0.07 |
| Corn | Q | 211.10±62.51 | -3.21±1.86 | 0.016±0.013 |
| Sorghum | Q | 308.52±91.90 | -5.77±2.56 | 0.034±0.018 |
| MM | | | | |
| Pearl millet | Q | 25.2±8.52 | -0.48±0.39 | 0.004±0.004 |
| Corn | Q | 19.02±3.98 | -0.27±0.14 | 0.002±0.001 |
| Sorghum | Q | 19.78±4.16 | -0.17±0.14 | 0.0006±0.0001 |
| | Model | A or $\theta_0$ | N | λ |
| NDF | | | | |
| Pearl millet | Wood | 43.98±66.01 | 0.91±0.54 | 0.017±0.012 |
| Corn | Wood | 111.86±73.58 | 0.60±0.22 | 0.011±0.004 |
| Sorghum | Wood | 77.83±64.97 | 0.69±0.28 | 0.012±0.005 |

[(1)]A, scale parameter; N, parameter of the gamma distribution that shapes the function to mimic the time profile; λ, fractional rate (1/day); $\theta_0$, $\theta_1$, and $\theta_2$, intercept and first and second slopes, respectively; DM, dry matter; CP, crude protein; NDF, neutral detergent fiber; MM, mineral matter; and Q, quadratic.

**Table 2.** Chemical composition of pearl millet (*Pennisetum glaucum*), corn (*Zea mays*), and sorghum (*Sorghum bicolor*) from 30 days after sowing up to the harvest point for ensiling.

| Variable[(1)] | Days | | | | | | | | | SEM[(2)] |
|---|---|---|---|---|---|---|---|---|---|---|
| | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 75 | 90 | |
| DM | | | | | | | | | | |
| Pearl millet | 198.56 | 220.61 | 230.22 | 213.89 | 201.18 | 181.19 | 182.21 | - | - | 5.623 |
| Corn | 197.66 | - | - | 262.64 | - | - | 230.78 | 297.28 | 312.03 | 7.168 |
| Sorghum | 182.23 | - | - | 248.57 | - | - | 245.20 | 279.79 | 289.65 | 6.713 |
| CP | | | | | | | | | | |
| Pearl millet | 167.14 | 143.65 | 98.54 | 84.66 | 65.96 | 64.83 | 66.06 | - | - | 3.801 |
| Corn | 146.39 | - | - | 73.96 | - | - | 82.91 | 63.00 | 54.95 | 3.755 |
| Sorghum | 188.50 | - | - | 87.32 | - | - | 90.98 | 66.85 | 65.66 | 4.855 |
| NDF | | | | | | | | | | |
| Pearl millet | 588.38 | 631.61 | 674.12 | 693.63 | 669.26 | 693.31 | 692.26 | - | - | 4.096 |
| Corn | 632.56 | - | - | 662.92 | - | - | 702.44 | 678.14 | 625.12 | 4.664 |
| Sorghum | 581.59 | - | - | 639.18 | - | - | 654.89 | 619.99 | 601.56 | 4.968 |
| MM | | | | | | | | | | |
| Pearl millet | 14.31 | 13.18 | 11.81 | 12.41 | 10.23 | 10.73 | 10.38 | - | - | 0.188 |
| Corn | 12.55 | - | - | 9.46 | - | - | 8.79 | 7.84 | 7.56 | 0.250 |
| Sorghum | 15.68 | - | - | 12.43 | - | - | 12.55 | 10.68 | 9.31 | 0.258 |

[(1)]DM, dry matter, expressed as g $kg^{-1}$ on a feed basis; CP, crude protein, expressed as g $kg^{-1}$ DM; NDF, neutral detergent fiber, expressed as g $kg^{-1}$ DM; and MM, mineral matter, expressed as g $kg^{-1}$ DM. [(2)]Standard error of the mean.

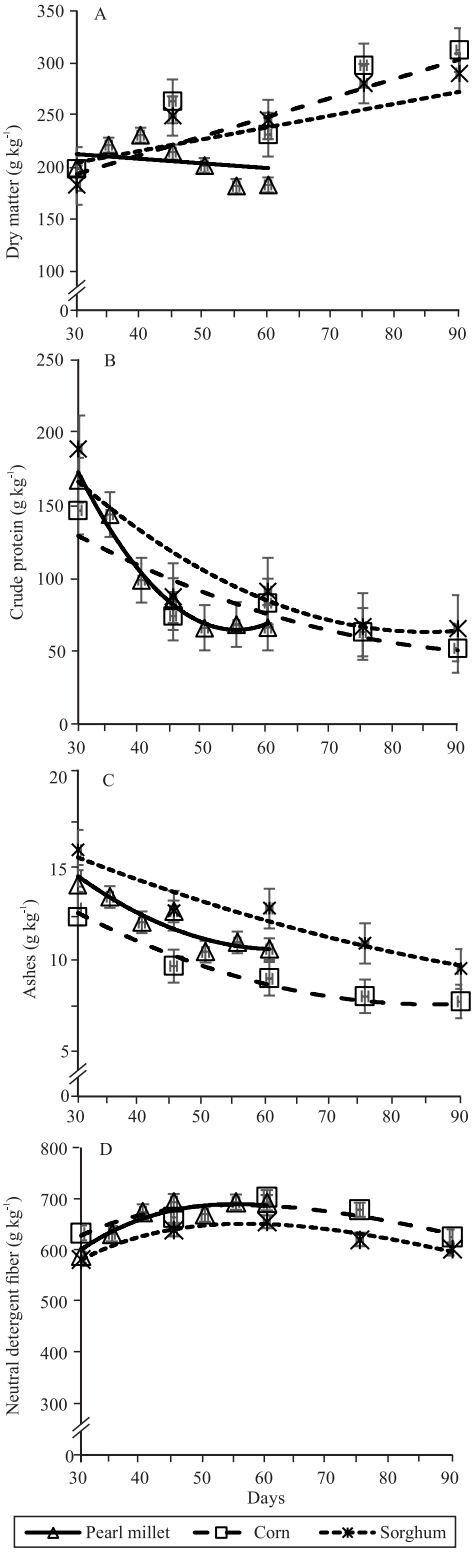


**Figure 2.** Nutrient deposition in pearl millet (*Pennisetum glaucum*), corn (*Zea mays*), and sorghum (*Sorghum bicolor*) from 30 days after sowing up to the harvest point for ensiling. Symbols, least squares means; and lines, predicted values.

for processes related to nitrogen metabolism, and their photosynthetic capacity is associated with foliar nitrogen, leaf area, and net photosynthetic assimilation rate (Zhu et al., 2021). In the present study, a decrease in protein levels (nitrogen x 6.25) was verified at the end of the growth cycle, which is probably related to the decrease in nitrogen absorption rate and to the loss of dead leaves (Masclaux-Daubresse et al., 2010). Mariem et al. (2021) highlighted that the decrease in leaf and stem protein contents are indicative of nutrient translocation to the grains, characterizing the start of the grain-filling stage, as observed here.

MM contents (Table 2 and Figure 2 C) presented a similar behavior to those of CP (Table 2 and Figure 2 B) when the crops were ready to be ensiled. From 30 DAS, the plant moves from the initial vegetative phase to the active (reproductive) vegetative phase. In general, during initial growth, there is a low plant biomass but a high concentration of nutrients from the soil. However, as plants grow, their accumulation of mass is more expressive than their absorption capacity (Xu et al., 2020). In the active vegetative phase, there is nutrient translocation to the reproductive organs for panicle development and grain formation, which is why ash (residue of MM) content showed a behavior similar to that of protein. For Xu et al. (2020), the observed decrease in ash levels over the days can also be attributed to the dilution effect caused by plant growth due to the more significant amount of structures, such as the stem, found in total dry matter. In the present study, MM contents reduced about 0.06 g (14.31–10.38/60) for pearl millet, 0.05 g for corn, and 0.07 g for sorghum over time (Table 2).

Sorieul et al. (2016) defines NDF as the cell wall of vegetables formed mainly by cellulose, hemicellulose, pectin, lignin, protein, and other minor compounds. For corn and sorghum from 60 DAS onwards, there was a tendency of a decreasing NDF content, explained by nutrient translocation for grain formation after 50 DAS (Table 2). However, the NDF curves overlapped for corn and pearl millet, highlighting the lower values of fiber content in sorghum (Figure 2 D). This result could be explained by the fact that sorghum produces tannin, a secondary metabolite that protects the plant against pathogens or herbivores, by attracting pollinators or plant-plant competition agents, but also acts as a plant carbon drain during its formation (Sosenski & Parra-Tabla, 2019). In addition, the used sorghum cultivar,

BRS 810, has a brown midrib (BMr) gene related to a lower lignin deposition in the cell wall according to the same authors.

The biometric variables plant height and leaf width had a better fit to the linear model in the second equation, whereas leaf diameter and length showed a better fit to the nonlinear Wood model represented by the fourth equation (Table 3). The biometric variables did not differ (p = 0.1863) between corn, pearl millet, and sorghum (Table 4 and Figure 3), and, in the case of corn and sorghum, the model curves overlapped for all variables.

The best-fit model for leaf growth was that of Gompertz, represented by the tenth equation. The rate of growth was estimated by the first derivative of this model, as described in the following equation:

$$y_i = A \times (\exp^{(-b)} \times \exp^{(-c \times t)}) \times (b \times (\exp^{(-c \times t)}) \times c).$$

The parameter estimates for the growth curve of the chosen models were: A = 37.34±9.85, b = 3.79±1.23, and c = 0.086±0.026 for pearl millet; A = 49.80±4.60, b = 3.66±0.52, and c = 0.073±0.008 for corn; and A = 49.14±5.03, b = 3.24±0.45, and c = 0.069±0.009 for sorghum. The values estimated by the models behaved slightly differently from the trends of the observed means.

Moreover, for pearl millet and for corn and sorghum, from the twenty-sixth and thirty-fourth day onwards, respectively, the values predicted using the tenth equation were systematically lower than the trend of the means (Figure 4).

Growth is a quantitative term related to changes in plant and animal size and/or mass (Balduzzi et al., 2017). In the present study, in the first 50 DAS, corn, pearl millet, and sorghum showed the same behavior regarding plant height (Figure 3 A). However, from 60 DAS onwards, pearl millet grew 3.8 cm per day (146.71–32.01/30), i.e., 14.47 and 11.32% more than corn and sorghum, respectively (Table 4). This difference can be attributed to the more efficient development of the pearl millet root system, whose growth is essential for nutrient and water absorption in the soil. Furthermore, the shorter phenological cycle of pearl millet may also have had a significant effect, since the phase of growth

**Table 3.** Parameter estimates of the models chosen for the agronomic evaluation of pearl millet (*Pennisetum glaucum*), corn (*Zea mays*), and sorghum (*Sorghum bicolor*) from 30 days after sowing up to the harvest point for ensiling[1].

| Variable[2] | Model[3] | A or $\theta_0$ | $\theta_1$ | $\theta_2$ |
|---|---|---|---|---|
| Height | | | | |
| Pearl millet | Q | 165.10±23.35 | -8.55±1.18 | 0.14±0.01 |
| Corn | Q | 62.10±14.63 | -3.0±0.68 | 0.07±0.007 |
| Sorghum | Q | 58.57±14.62 | -2.86±0.68 | 0.07±0.007 |
| Width | | | | |
| Pearl millet | Q | 2.67±1.85 | -0.03±0.09 | 0.001±0.0009 |
| Corn | Q | 6.20±1.07 | -0.21±0.04 | 0.003±0.0004 |
| Sorghum | Q | 5.43±1.07 | -0.18±0.04 | 0.003±0.0004 |
| | Model | A or $\theta_0$ | N | λ |
| Diameter | | | | |
| Pearl millet | W | 0.0002±0.0001 | 3.40±1.20 | 0.036±0.027 |
| Corn | W | 0.0001±0.0001 | 3.51±0.61 | 0.038±0.011 |
| Sorghum | W | 0.0001±0.0001 | 3.62±0.60 | 0.040±0.011 |
| Length | | | | |
| Pearl millet | W | 0.0003±0.0001 | 3.78±0.87 | 0.049±0.020 |
| Corn | W | 0.0016±0.0021 | 3.09±0.45 | 0.032±0.009 |
| Sorghum | W | 0.0010±0.0013 | 3.25±0.45 | 0.034±0.009 |

[1]A, scale parameter; N, parameter of the gamma distribution that shapes the function to mimic the time profile; λ, fractional rate (1/day); and $\theta_0$, $\theta_1$, and $\theta_2$, intercept and first and second slopes, respectively. [2]Height and diameter were measured on the stem, and length and width, on the leaf. [3]Q, quadratic; W, wood.

**Table 4.** Biometric evaluation of pearl millet (*Pennisetum glaucum*), corn (*Zea mays*), and sorghum (*Sorghum bicolor*) from 30 days after sowing up to the harvest point for ensiling.

| Variable (cm)[1] | Days | | | | SEM[2] |
|---|---|---|---|---|---|
| | 30 | 45 | 60 | 75 | |
| Height | | | | | |
| Pearl millet | 32.01 | 58.13 | 146.71 | - | 3.778 |
| Corn | 32.97 | 61.71 | 130.75 | 213.08 | 4.511 |
| Sorghum | 32.64 | 61.04 | 133.81 | 210.98 | 4.548 |
| Diameter | | | | | |
| Pearl millet | 5.09 | 11.73 | 18.45 | - | 0.401 |
| Corn | 5.48 | 12.83 | 20.14 | 25.02 | 0.487 |
| Sorghum | 5.50 | 13.07 | 20.49 | 25.01 | 0.489 |
| Length | | | | | |
| Pearl millet | 22.89 | 50.98 | 73.04 | - | 1.503 |
| Corn | 23.51 | 51.98 | 76.59 | 96.44 | 1.786 |
| Sorghum | 23.21 | 50.89 | 80.14 | 96.90 | 1.878 |
| Width | | | | | |
| Pearl millet | 2.67 | 3.46 | 4.69 | - | 0.071 |
| Corn | 2.93 | 3.54 | 5.71 | 9.35 | 0.159 |
| Sorghum | 2.77 | 3.55 | 5.81 | 9.42 | 0.167 |

[1]Height and diameter were measured on the stem, and length and width, on the leaf. [2]Standard error of the mean.

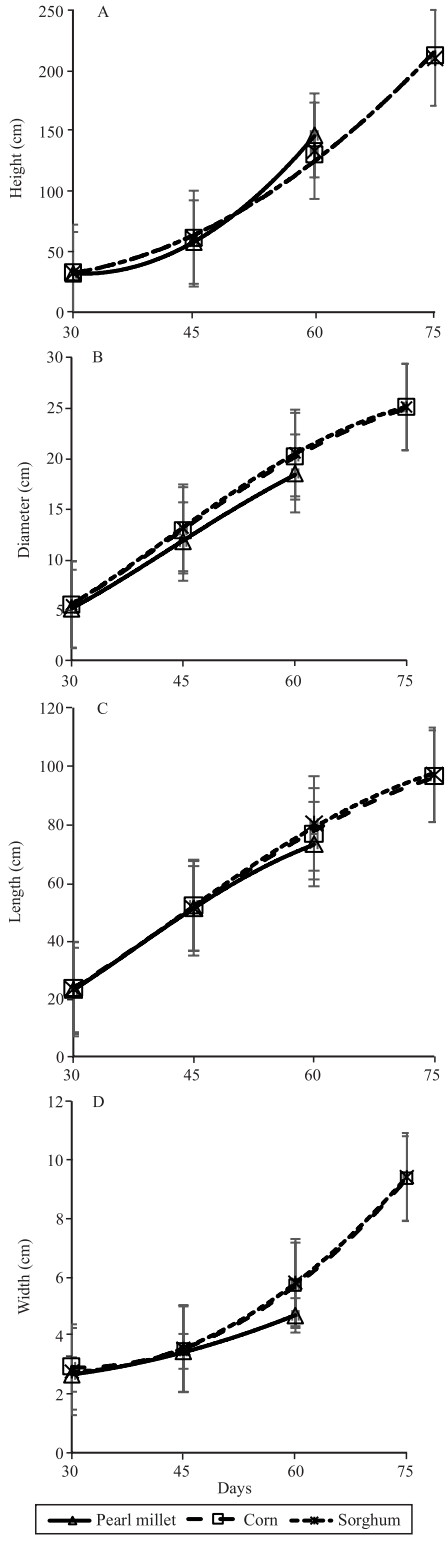


**Figure 3.** Biometric evaluation of pearl millet (*Pennisetum glaucum*), corn (*Zea mays*), and sorghum (*Sorghum bicolor*) from 30 days after sowing up to the harvest point for ensiling. Height and diameter were measured on the stem, and length and width, on the leaf.

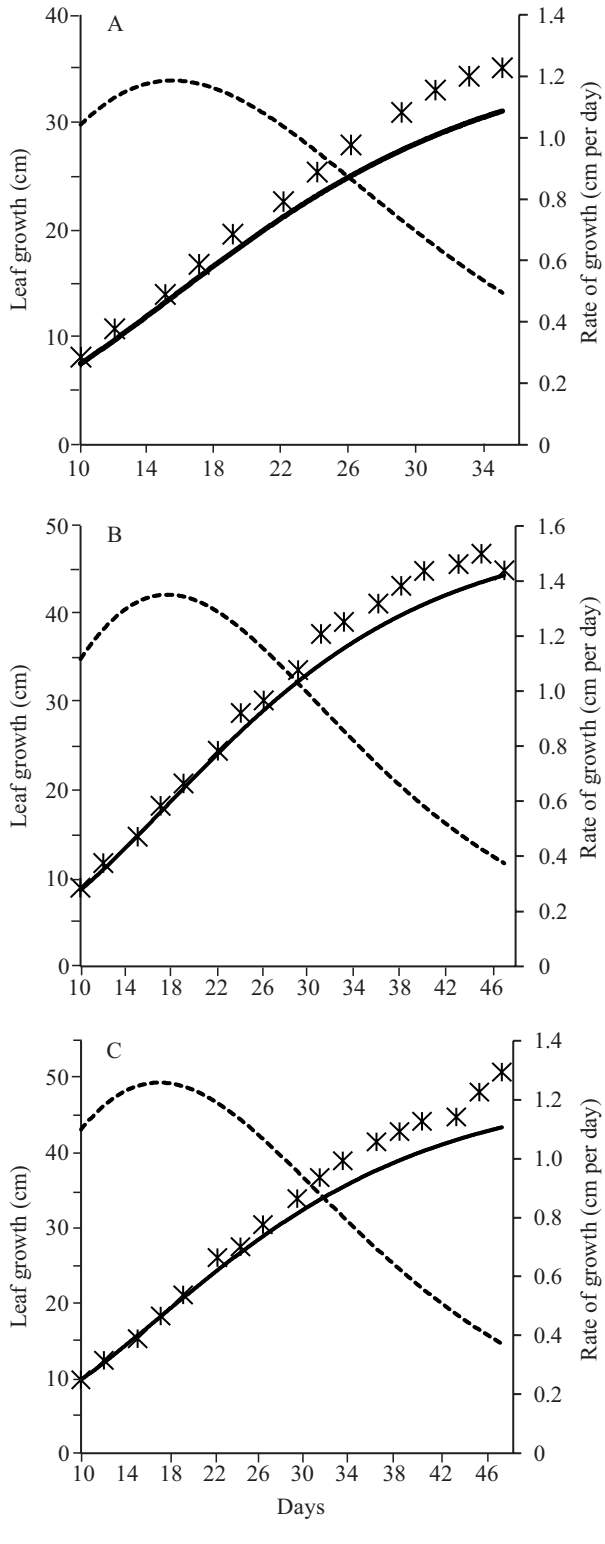


**Figure 4.** Growth curve from 30 days after sowing to the harvest point for ensiling of: A, pearl millet (*Pennisetum glaucum*); B, corn (*Zea mays*); and C, sorghum (*Sorghum bicolor*). *, least squares means; solid lines, predicted values; and dashed lines, rate of growth.

acceleration started earlier than that of the corn and sorghum crops.

## Conclusions

1. Dry matter accumulation does not differ between corn (*Zea mays*) and sorghum (*Sorghum bicolor*), but decreases in pearl millet (*Pennisetum glaucum*) from the fiftieth day after sowing until ensiling.

2. Crude protein, ashes, and neutral detergent fiber tend to reduce over time in the evaluated crops.

3. The evaluated biometric variables do not differ between corn, pearl millet, and sorghum from 30 days after sowing until ensiling.

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