Scientific Paper

Yield and nutritional value of ten varieties of *Saccharum officinarum* L. grown in Argentina

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Abstract

Objective: To evaluate the yield and nutritional value of *Saccharum officinarum* L. varieties in Corrientes, Argentina.

Materials and Methods: Ten varieties of *S. officinarum* were evaluated at the Experimental Teaching Field of the School of Agricultural Sciences of the Northeast National University, in Corrientes. Several variables were analyzed: number of tillers and mature stems per linear meter, height and average individual weight of mature stems, radiation intercepted by the crop, ripening coefficient and nutrient content in the varieties. A complete randomized design was applied and analysis of variance and multiple comparison of means test (Tukey) were performed when there were significant differences among varieties. The statistical package InfoStat® was used.

Results: No differences in yield were observed among the evaluated varieties. The average green biomass yield was 52 370 kg ha^{-1} and reached exceptional values up to 130 000 kg ha^{-1}. The average dry biomass yield was 17 700 kg ha^{-1} and showed no differences between varieties. It reached average values of 32 000 kg ha^{-1} associated with the varieties FAM 05-662 and FAM 05-691. Nutritionally, there were no differences among varieties, except for crude protein and phosphorus contents. *In vitro* digestibility indices averaged 70,6 %, with total digestible nutrients of 78,0 % and digestible energy of 3,45 Mcal/kg dry matter.

Conclusions: The varieties that showed promise for yields were FAM 05-662 and FAM 05-691. In addition, the latter had a high CP content (2,9 %). On average, digestibility was 70,6 %, total digestible nutrients 78,0 % and digestible energy 3,45 Mcal/kg dry matter. *S. officinarum* can be a viable option to improve animal production in the region, provided that the appropriate varieties are used.

Keywords: biomass, forage, yield

Introduction

Saccharum officinarum L. is a perennial species, which belongs to the Poaceae family. Most of its production, approximately 54 %, comes from the American continent (FAO, 2022). The average yield of *S. officinarum* in the world is around 60 t ha^{-1}, with Argentina being one of the major producers, with annual production close to 16 583 044 t (Yara, 2020). This crop is mainly distributed in three provinces: Tucumán, Salta and Jujuy, where 345 679 ha are cultivated with an average annual yield of 48 t ha^{-1} (FAOSTAT, 2024). These hectares are mainly dedicated to obtaining white sugar and bioethanol.

In the Corrientes province, located outside the core zone, land evaluation studies have identified 300,000 ha as potentially suitable for cultivation. They are classified into 110 000 ha, as very suitable and 190 000 ha as moderate (Perucca and Kurtz, 2016). Corrientes is the fourth province in animal husbandry on a national scale, with 4,7 million heads, where 60,0 % of the total number of farmers have less than 100 heads. Cattle ranching occupies approximately 6,3 million hectares (Ministerio de Hacienda, 2019).

In this context, forage production of *S. officinarum* is of vital importance. Therefore, it is pertinent to carry out adaptive experimental trials and select suitable genetic materials that ensure high yields and a chemical and nutritional composition known to formulate adequate rations. According to Fernández-Gálvez *et al*. (2024), in order to achieve efficiency and profitability in agricultural systems through the use of *Saccharum* spp. it is essential to use forage varieties that not only have a good nutritional value, but are also capable of producing biomass in soils characteristic of animal husbandry.

Studies conducted in Corrientes by Perucca and Kurtz (2016) have proven the agroecological suitability of this province for the cultivation of *S. officinarum*. For decades, the use of *S. officinarum*

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in ruminant feeding has been investigated due to its high productivity and superior energy value during winter, when forage is scarce in northeastern Argentina (Castelán *et al*., 2021).

This species is suitable for intensive and semi-intensive animal husbandry systems (Salazar-Ortiz *et al*., 2017). However, for its massive implementation in ruminant feeding it is crucial to have detailed knowledge about key aspects, such as the type of variety, cutting age and certain growth indicators. In addition, biometric variables and chemical compositions should be considered, which serve as a reference for the selection and evaluation of genotypes with forage characteristics suitable for the region (Lagos-Burbano and Castro-Rincón, 2019). The objective of this work was to evaluate the forage potential of ten varieties of *S. officinarum*, grown in Corrientes for forage purposes by determining biomass production and their chemical and nutritional composition.

Materials and Methods

Experimental site. Didactic and experimental field of the School of Agricultural Sciences-National Northeast University (FCA-UNNE), located in the Capital Department, Corrientes province.

Soil. It is classified as arganic Udipsament, mixed family, hyperthermic, belonging to the Ensenada Grande Series. It shows coarse granulometry on the surface, from moderate to weakly acid in the sandy A. horizon. They are soils of low fertility, low cation exchange capacity, but with good physical conditions associated with its sandy texture (table 1).

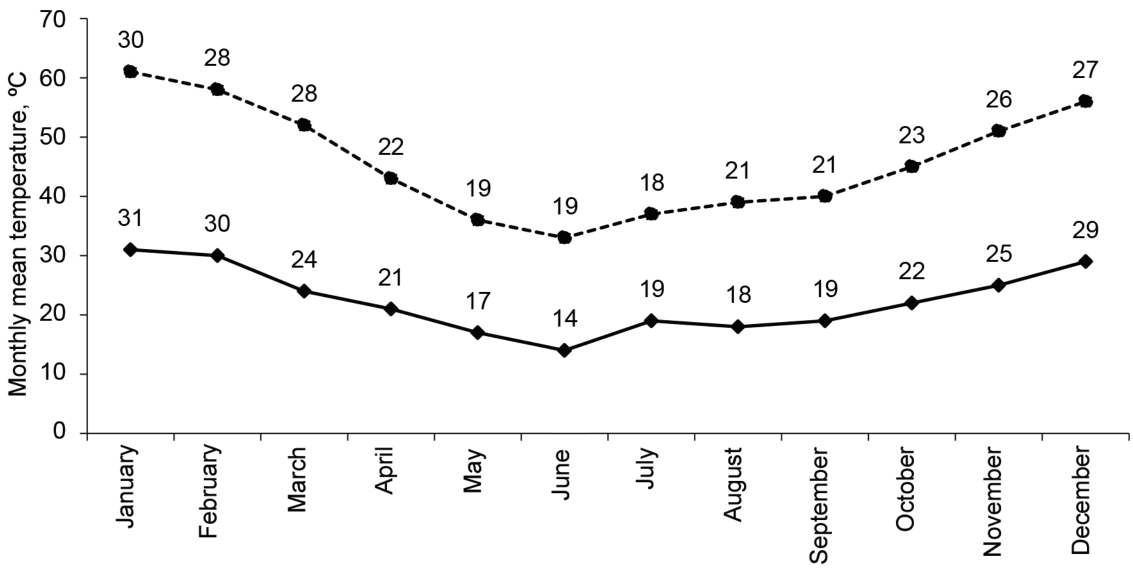
Climate. It is characterized by average annual rainfall of 1 300 mm, average annual temperatures of 21,6 °C. The frost-free period is 340 to 365 days per year and its frequency of occurrence is 0,5. According to the modified Köppen classification, the climate in the region is classified as humid mesothermal, Cf w'a (h). Throughout the experiment, temperatures and rainfall were recorded at the experimental site (figures 1 and 2).

Biological materials: 10 varieties of *S. officinarum*, planted in June, 2022, were used. The varieties under study were provided by the Experimental Operational Center Tacuarendí, under the Ministry of Production of the Santa Fe Province

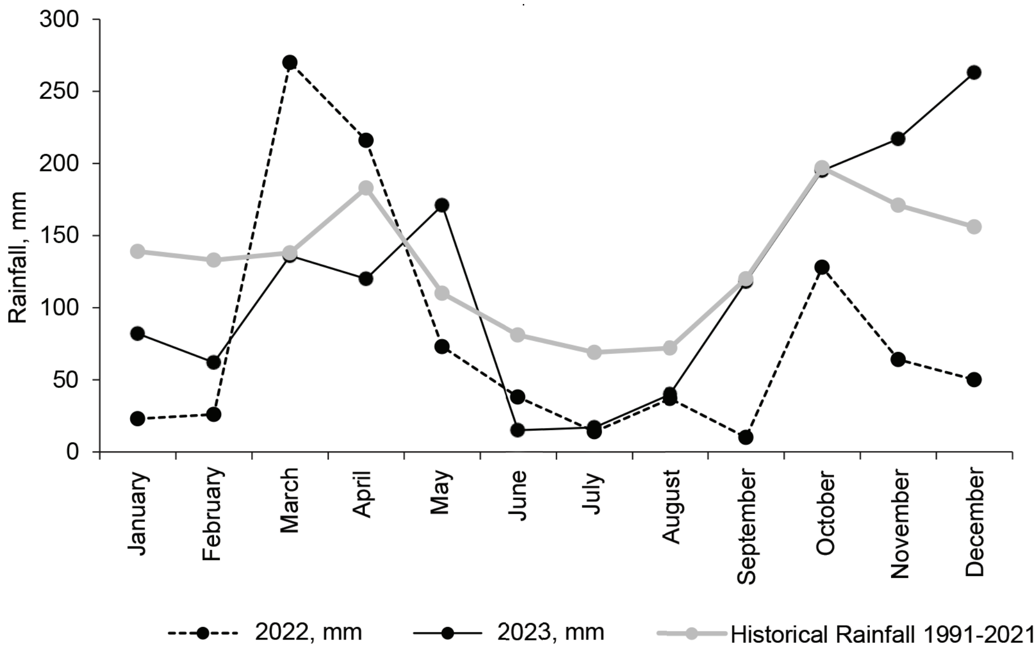
Table 1. Soil chemical analysis of the *S. officinarum* experimental site.

pH	EC	TN	OC	P	K	Ca	Mg
Act.	ds/m	%	%	ppm	Cmolc/kg	Cmolc/kg	Cmolc/kg
5,7	0,04	0,07	0,47	64,1	0,24	2,8	1,6

pH: hydrogen potential; EC: electrical conductivity; TN: total nitrogen; OC: organic carbon; P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium



Source: Automatic weather station-ICAA.
Figure 1. Monthly temperatures in Corrientes during 2022-2023.



Source: Automatic weather station-ICAA.

Figure 2. Rainfall recorded during the years 2022-2023 and historical record of the 1991-2021 series of Corrientes capital.

to the Department of Crops III (FCA - UNNE) in 2022.

Varieties of *S. officinarum* under study:

- FAM 01-1505
- FAM 05-469
- FAM 05-662
- FAM 05-691
- FAM 06-162
- FAM 08-241
- FAM 08-550
- FAM 08-1016
- LCP 85-384
- NA 85-1602

Treatment and experimental design. Each of the *S. officinarum* varieties constituted a treatment. The experimental design responded to a complete randomized model. Each variety was planted along 2 furrows, each 10 m long. Of the 10 m length of each furrow, the first initial and final meter were considered the edge effect, so the central 16 m were used for sampling. In each furrow, three sampling stations of one linear meter each were randomly established and considered as replicas, for which there were six replicas per treatment (variety). The rows were spaced 1,6 m apart. Planting density was 30 buds per linear meter for all varieties. Planting was done manually, in June, 2022, between 15 and 20 cm by ridging.

Experimental procedure. The 180 m^2 lot, where the 10 varieties of *S. officinarum* were planted, received supplementary irrigation at two different times. The first irrigation was carried out on December 20, 2022, and the second on January 15, 2023, due to drought conditions.

A first weed control was carried out chemically on December 1, 2022, with 600 cc. of glyphosate (3 %) + atrazine 400 cc in 10 L of water applied with a hand backpack. During the sprouting and tillering phases, the controls were carried out manually with the use of a hoe. Fertilization of the *S. officinarum* crop was carried out, taking into account soil analysis and extraction of crop macronutrients (nitrogen, phosphorus and potassium).

Measured variables. All variables were measured between planting and the first harvest of the cane field ("cane plant"), from October, 2022, to August, 2023.

Stem height (cm). In August, three stalks per sampling station of each variety were measured with a tape measure at harvest, nine were representative of each variety.

Number of tillers per linear meter. Counting was carried out from the sprouting and tillering stage until the period of high growth, at the six sampling stations of 1 linear meter each for each variety. Counting was carried out from October to December, 2022. The established dates were: 10/17/2022- 11/04/2022- 11/8/2022- 12/02/2022 and 12/14/2022.

Number of mature stems per linear meter. The number of mature stems per linear meter is the first of the numerical components of yield. The above-mentioned methodology was followed for the variable number of tillers, taking into account the same sampling stations. The number of mature stems per linear meter was determined on 08/02/2023.

Average individual weight of mature stems (kg). Average individual stem weight is the second numerical component of *S. officinarum* crop yield, defined at the high growth stage. Nine stem samples were taken from each variety at each of the six sampling stations. Stems were cut from each linear meter at each station and weighed using a digital scale. Once the weight of the stems was obtained, the average individual weight of the mature stems was determined by dividing the number of mature stems per linear meter and the weight of the stems obtained from the samples.

Dry matter percentage of mature stems (%). Three canes were taken from each variety, from which 20-cm long portions of the basal, middle and apical part were selected and placed in paper bags, duly labeled. Each sample was weighed to obtain the fresh weight (g). The samples were placed in an oven at 60 °C until they reached constant weight and were weighed. Once the fresh and dry weights were obtained, the percentage of dry matter of the samples of each variety was determined: % DM = fresh weight / dry weight *100.

Cultural yield of green biomass (kg ha^{-1}). Linear meters of furrow per hectare (ha) were calculated, dividing in 100 linear m by 1,6 m (distance between furrows). This was taken to hectare multiplied by 100, to obtain the number of stems ha^{-1}, the product of the multiplication between the linear meters of furrow per hectare and the number of stems to be milled per meter. The average weight of stems per linear meter of each treatment multiplied by the number of stems ha^{-1} allowed estimating the cultural yield of each variety (kg ha^{-1}).

Dry biomass cultural yield (kg ha^{-1}). It was obtained by determining the DM (%) by the gravimetric method (AOAC, 2019) of fresh samples. It was calculated by dry biomass cultural yield (kg ha^{-1}) and green biomass cultural yield * DM (%)/100.

Radiation intercepted by the crop (% Ric). The percentages of photosynthetically active radiation (PAR) intercepted by the crop (RIc) were measured by a ceptometer, with PAR radiation sensors, with spectral response in the band between 400 and 700 nm wavelength. Measurements were taken every 45 days, at three sampling moments throughout each crop cycle (initial, intermediate and final). For this purpose, the interception bar was placed in the lower layer of the canopy, between the soil and the first green leaf. Measurements of RIc (%) were made at CENIT (between 11:00 and 13:00 h) at three stations in each furrow, placing the ceptometer bar perpendicular to the furrow, located from the center of one inter-row to the center of the adjoining inter-row. The percentage of PAR, intercepted by the crop was calculated as [1 - (It /I0)] x 100. Where It is the PAR, measured at the stratum level, I0 is the PAR incident above the crop.

Thermal requirement. Throughout the experiment, the temperature record was counted and the cumulative thermal time (TT) from sprouting to harvest was calculated for the 10 varieties. The residual method was used based on the concept of thermal time (TT), defined as the sum of the difference between the average daily air temperature (T) and the corresponding base temperature (Tb). The calculation of thermal time, taken from sprouting (September 2022) to harvest (August 2023) for the plant cane crop, calculated with Tb of 16 °C, is presented, since below this value the plant stops growing (Duarte-Álvarez and González-Villalba, 2019).

Content of Total Soluble Solids (TSS %) and Maturity Coefficient (MC). A handheld refractometer was used to measure TSS %. Three untipped canes were randomly sampled for each variety per sampling station to show genotypic variability and TSS % accumulation strategies in sugarcane stalks. The maturation coefficient for canes used for forage purposes was calculated from the ratio of the upper part of the cane to the value obtained at the base. It is worth mentioning that the maturity index for sugarcane is defined as follows: immature, less than 0,95; mature, between 0,95 and 1; and finally, overripe, higher than 1.

Nutritional quality. Three plants of each variety were taken with leaves and without blunting. Samples of 20 cm of stems were taken from the basal and middle portion, labeled and sent to the laboratory. Nitric-perchloric digestion was carried out to determine phosphorus (P %) by the Murphy-

Riely colorimetric method, nitrogen (N %) by micro-Kjeldahl; exchangeable potassium (K %) by flame photometry, calcium (Ca, %) and magnesium (Mg, %) by complexometry. Crude protein (CP) was calculated by formula from the N content, when multiplied by the conversion factor 6,25. Acid detergent fiber content (ADF %) was determined by the method of Van Soest and Wine (1967). Digestibility (DIG %), total digestible nutrients (TDN %) and digestible energy (DE, Mcal/kg DM) indicators were calculated using the formulas proposed by Undersander *et al*. (1993), where:

DIG = 88,9 - (% ADF x 0,779)

TDN = 96,35 - (% ADF x 1,15)

DE = 0,04409 x TDN

In this way it was possible to obtain a biomass, chemical and nutritional composition profile for each variety.

Statistical analysis. For the statistical analysis of the data, the values of the different variables were analyzed using Tukey's multiple comparisons test, considering the Minimum Significant Difference (m.s.d.) for α=0,05. Prior to data analysis, the normal distribution of the data was confirmed and, if this was not met, the data were transformed so that the variable was normally distributed by applying the Log 10. Statistical analyses were performed with the Infostat program (Di Rienzo *et al*., 2020).

Results and Discussion

One of the most important phenological phases is tillering, since it is important in the definition and yield, given that the potential number of harvestable organs (mature stems) is established between this phase and the large growth phase.

Table 2 shows the results of the number of tillers and stems achieved per linear meter of furrow during the phenological phase of tillering and large growth of *S. officinarum*. The varieties with the highest number of tillers were four (FAM 06-162, FAM 05-691, FAM 05-662 and FAM 08-1016) and these were increased to six in the large growth phase (FAM 06-162, FAM 05-691, FAM 05-662, FAM 08-1016, LCP 85-348 and NA 85-1602). In all these cases they were able to reach no less than 15 tillers per linear meter.

Stem height, measured at harvest, showed a mean of 2,0 m and differences were found between varieties under the same growing conditions (table 3). The varieties FAM 08-241, FAM 05-469 and FAM 06-162 reached the highest values above 2,30 m and differed statistically from FAM 05-662, which did not exceed 1,40 m. All other varieties showed statistically similar heights.

According to Poudyal *et al*. (2023), this variable can serve as a basis for the characterization and

Table 2. Number of tillers and stems per linear meter of furrow during the phenological phase of tillering and high growth of each variety of *S. officinarum*.

Variety	Phenological phase: tillering	Phenological phase: large growth
	Number of stems	
FAM 06-162	23,8[a]	21,0[ab]
FAM 05-691	20,3[abc]	22,4[a]
FAM 05-662	20,6[ab]	19,3[abc]
FAM 08-1016	14,6[abc]	20,0[abc]
LCP 85-348	11,7[cd]	18,6[abc]
FAM 08-241	12,1[bcd]	13,13[c]
NA 85-1602	11,4[d]	15,5[abc]
FAM 08-550	9,8[d]	13,4[c]
FAM 01-1505	11,6[d]	14,5[bc]
FAM 05-469	10,3[d]	14,0[bc]
VC, %	35,4	25,9
SE ±	1,83	1,57
P - value	< 0,0001	< 0,0001

Means with common letters in the column are not significantly different (Tukey p<0,05).

Table 3. Stem height, number of stems, individual stem weight, green and dry biomass yield, radiation intercepted by the crop and stem dry matter of *S. officinarum* varieties.

Variety	Stem height, m	Number stems/m, (Log 10)	Stem weight, kg	Biomass yield		Dry matter, stems, %	RIC %, (October-April)
				Green, kg ha^{-1} (Log 10)	Dry, kg ha^{-1} (Log 10)		
FAM 08-241	2,3[a]	10	1,33	54 114,6	22 817,3	25,3	59,0[ab]
FAM 05-662	1,4[b]	16	1,28	130 416,7	34 461,3	25,7	74,7[a]
FAM 05-691	2,0[ab]	14	1,04	103 050,9	29 977,0	27,7	61,2[ab]
FAM 05-469	2,4[a]	6	0,93	40 449,8	11 510,9	25,7	65,0[ab]
NA 85-1602	1,9[ab]	8	0,92	53 460,7	15 259,5	28,7	64,8[ab]
FAM 01-1505	1,8[ab]	9	0,86	52 754,6	16 055,2	28,7	68,0[ab]
FAM 06-162	2,5[a]	9	0,85	50 694,4	13 980,5	28,7	67,9[ab]
FAM 08-1016	2,1[ab]	9	0,79	54 114,6	15 868,2	27,3	73,5[a]
FAM 08-550	2,0[ab]	6	0,69	23 449,1	6 007,0	27,0	55,7[b]
LCP 85-348	1,7[ab]	10	0,64	41 122,7	11 280,6	26,3	54,9[b]
P - value	0,0044	0,0657	0,4361	0,3023	0,4706	0,9933	0,0009
VC %	15,12	16,7	41,34	7,24	9,21	19,49	28,73
SE ±	0,18	0,09	0,22	0,2	0,22	3,05	3,78

Means with common letter in the column are not significantly different (Tukey p < 0,05).
RIC: radiation intercepted by the crop, VC: variation coefficient, SE: standard error.

selection of promising varieties. However, in this work, the tallest varieties were not the ones that achieved the highest cultural yields (table 3). The mean stem height of the population in this trial (2 m) was below the mean values of 2,5 m reported by Fernández-Gálvez *et al*. (2024).

The number of mature stems per linear meter is the first numerical component of yield. On average, the varieties were able to establish 9 mature stems per linear meter, the varieties FAM 01-1505 and FAM 08-1016 had stem production equal to the average; while FAM 05-469, NA 85-1602, FAM 06-162 and FAM 08-550 were below the average. The varieties that exceeded this value were FAM 08-241, FAM 05-662, FAM 05-691 and LCP 85-348 (table 3). Stem production per hectare is one of the most relevant indicators in the breeding programs of *Saccharum* spp. This variable represents an important function in crop productivity (Cervantes-Preciado, 2022).

In this study, the two varieties that reached high biomass yield potentials were those that showed a minimum of 14 mature stems per linear meter (table 3). The difference between the means of the number of mature stems per linear meter (tables 2 and 3) is explained by the process of self-thinning undergone by the sugarcane plantation.

Individual stem weight is the second numerical component of yield. In August, the average individual stalk weight was 0,93 kg. Only four sugarcane varieties equaled or exceeded the mean value, including FAM 08-241, FAM 05-469, FAM 05-662 and FAM 05-691. The last two showed a minimum of 1,28 kg per stem and reached high biomass yield potentials (table 3).

Cultural green biomass yield showed the diversity of responses among the 10 varieties. Although the statistical analyses did not show statistical significance, in terms of cultural yields three groups can be established: the varieties that did not reach 50 000 kg ha^{-1} (FAM 05-469, LCP 85-348 and FAM 08-550), the five varieties that were within this average of 50 000 kg ha^{-1} and the two that doubled this yield (FAM 05-662 and FAM 05-691). In this regard, it is worth mentioning that according to the latest production data published by FAOSTAT (2024), the average yield of the crop in Argentina is 48 000 kg ha^{-1}. Therefore, only three of the 10 evaluated varieties were found to be below this average yield (FAM 05-469, FAM 08-1016, FAM 08-550 and LCP 85-348). The varieties FAM 05-662 and FAM 05-691 reached extraordinary yields of 130 400 and 103 000 kg ha^{-1}, which allow their recommendation for the agroecological conditions under which they were evaluated: sandy soils and water deficit.

The Ensenada Grande soil series, where the experiment was conducted, has been specifically classified for the cultivation of *S. officinarum* as moderately suitable with basic management and very suitable for more technified management, which includes genetic material of known origin, annual fertilization, weed management and furrow spacing of 1,4 to 1,6 m between the main management actions (Perucca and Kurtz, 2016).

The results for the varieties FAM 05-662 and FAM 05-691 are close to the mean of 104 000 kg ha^{-1} reported by Fernández-Gálvez *et al.* (2024) for *S. officinarum* plant grown in Cuba. The maximum yields expressed in dry biomass correspond to the aforementioned varieties FAM 05-662 and FAM 05-691, which reached extraordinary yields of 130 400 and 103 000 kg ha^{-1} in fresh biomass and 34 400 and 30 000 kg ha^{-1} in dry biomass, respectively. These values are lower than the 42 000 kg ha^{-1} cited by Fernández-Gálvez *et al.* (2024) for *S. officinarum* plant.

The average DM content of the varieties at harvest was 27,0 %, in contrast to that reported by Fernández-Gálvez *et al.* (2021), who found average DM values of 11 cultivars, at the cane plant stage, to be around 18,8 %. According to Lagos-Burbano and Castro-Rincón (2019), dry biomass production of *S. officinarum* depends on the genetic characteristics of the variety, growth period, prevailing season of the year, timely input and application of crop inputs and products, and planting method.

In the absence of limiting factors, the total biomass production of a crop is directly related to the solar radiation intercepted by the crop. In *S. officinarum* crop foliage, the first six upper leaves intercept 70 % of the radiation and the photosynthetic rate of the lower leaves decreases due to mutual shading (Duarte-Alvarez and González-Villalba, 2019). Two varieties differed from the others, but not from each other (p = 0,0009), FAM 05-662 and FAM 08-1016 which, over the course of the crop cycle, intercepted on average 74,7 and 73,5 % Ric, respectively. The former showed the highest biomass yields (table 3). The varieties that showed the lowest RIc during the cycle were LCP and FAM 08-550 (average 55 %) and differed from FAM 08-1016 and FAM 05-662 (p = 0,0009).

FAM 05-662, which had more than 15 mature stalks per linear meter of furrow and individual stalk weight above 1,20 kg, was able to intercept 75 % of incident radiation and achieved DM yields of 34 400 kg ha^{-1}, which was twice the average of the sugarcane varieties under study.

During the course of the crop cycle, each variety was able to intercept a certain percentage of radiation (table 4). Measurements of RIc over time for each of the varieties showed that, starting in October, it increased significantly over time. It remains stable from November to January and increases again in February and April. As can be seen in table 4, only six varieties managed to intercept more than 90,0 % of the incident radiation in April. The six varieties that managed to intercept

Table 4. Evolution of radiation intercepted by each variety of *S. officinarum* throughout the crop cycle.

Variety	October	November	December	January	February	April	P - value	VC, %	SE ±
FAM 01-1505	39,5^{c}	62,3^{bc}	61,5^{bc}	69,0^{ab}	83,0^{ab}	92,5^{a}	< 0,0001	15,8	5,37
FAM 05-469	44,3^{c}	45,5^{c}	52,5^{c}	74,0^{ab}	79,3^{ab}	94,3^{a}	< 0,0001	10,3	3,36
FAM 05-662	57,8^{c}	65,3^{bc}	71,8^{bc}	78,0^{abc}	80,3^{ab}	95,0^{a}	0,0006	12,8	4,77
FAM 05-691	55,3^{ab}	45,5^{b}	40,5^{b}	59,3^{ab}	74,5^{ab}	92,0^{a}	0,0038	27,4	8,37
FAM 06-162	59,3^{c}	56,5^{c}	63,8^{bc}	53,3^{c}	83,3^{ab}	91,5^{a}	< 0,0001	12,8	4,36
FAM 08-1016	55,8^{d}	62,8^{cd}	74,8^{bc}	68,3^{c}	84,8^{ab}	95,0^{a}	< 0,0001	7,3	2,69
FAM 08-241	43,0^{b}	49,5^{b}	50,0^{b}	55,5^{b}	59,3^{b}	88,3^{a}	0,0001	16,7	4,91
FAM 08-550	36,0^{c}	49,5^{bc}	52,8^{bc}	50,0^{bc}	61,5^{b}	84,5^{a}	< 0,0001	15,6	4,35
LCP 85-348	27,5^{d}	44,8^{cd}	51,5^{bc}	50,5^{bc}	66,8^{b}	88,3^{a}	< 0,0001	14,0	3,85
NA 85-1602	35,5^{d}	51,8^{cd}	65,00^{bc}	68,0^{abc}	78,8^{ab}	89,50^{a}	< 0,0001	16,7	5,39
Average	45,43	53,32	58,4	62,575	75,12	91,0	0,0009	28,73	

Means with common letters horizontally are not significantly different (Tukey p < 0,05).
SE: standard error

more than 90,0 % in April (table 4) are those that on all measurement dates showed the highest %RIc values (FAM 01-1505, FAM 05-469, FAM 05-662, FAM 05-691, FAM 06-162 and FAM 08-1016). FAM 05-662, which had a high dry matter yield (table 3), was one of the varieties that intercepted 95 % of the incident radiation in April (table 4).

The recorded temperatures were favorable to the crop (figure 1). Monthly degree day measurements were positive (figure 3). The accumulated thermal time was 2 9671 degree days from sprouting to harvest of the sugarcane field under study. This accumulation of degree days is higher than that of other sugarcane growing areas in Argentina, even in the north of the province Santa Fe, which is close to Corrientes (Lovisa, 2010).

Crop ripening can be estimated by determining the total soluble solids measured in the apical and basal part of *S. officinarum*, the quotient of which determines its ripening coefficient (table 5).

According to the analysis of the ripening coefficient (table 5), the Brix of the basal part ranged between 19,33 and 21,57. Meanwhile, in the apical part, they varied between 18,1 and 21,1. Similar values for the basal part were obtained in an 11-month-old crop, with values between 20 and 18, but not in the apical part, where values were lower and ranged between 17,4 and 14 Brix (Rincón-Castillo and Becerra-Campiño, 2020).

Differences in the ripening coefficient could be observed among the different varieties (p = 0,0062). Five varieties (FAM 01-1505- FAM 06-162 - FAM 05-469 - FAM 05-691- FAM 05-662) were significantly more mature than the others (RC > 0,95) and did not differ among them (p = 0,0062). The other five were still immature (FAM 08-241- FAM 08-1016- FAM 08-550- NA 85-1602- LCP 85-348) and did not differ from each other (p = 0,0062).

In addition to the estimation of fresh and dry biomass yield, explained through various biometric and ecophysiological variables, the nutritional contribution of the harvested raw material must be determined and quantified, in order to be able to program a balanced diet that satisfies the requirements of a given animal category. The chemical analysis of the raw material and the estimations of the nutritional value are summarized in table 6.

Table 6 shows significant differences in the percentage of CP among varieties (p = 0,0010). The statistically superior materials were FAM 05-469, FAM 05-691 and FAM 01-1505, which did not differ from each other, but did differ from the others (p = 0,0010) and showed a mean of 3,1 %.

The varieties FAM 05-662, FAM 06-162, FAM 08-550, NA 85-1602, LCP 85-384, FAM 08-1016 are not statistically different (p = 0,0010) and showed mean CP percentages of 2,1 %. FAM 08-241 showed a CP content of 1,7 %, statistically lower than the other varieties (p = 0,0010). The results are in agreement with the publication by Lagos-Burbano and Castro-Rincón (2019), who evaluated *S. officinarum* harvested at 16 months and cited CP contents between 3,6 and 1,9 %. Likewise, Suarez-Benítez *et al.* (2023) studied five cultivars for forage purposes and obtained results between 2,7 and 3,8 % CP.

Significant differences were observed in P content (p = 0,018). The varieties NA 85-1602, FAM 05-662, LCP 85-384, FAM 08-241 showed

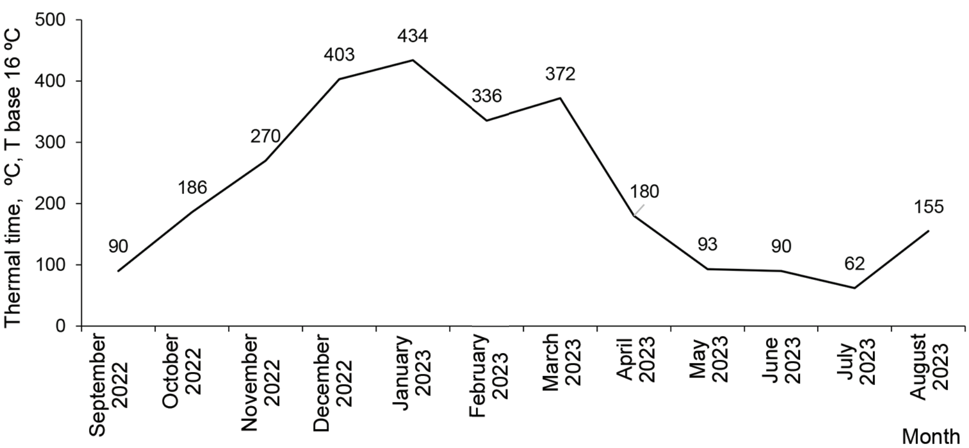


Figure 3. Accumulated monthly degree days during the productive cycle from sprouting to harvest of *S. officinarum* plant.

Table 5. Determination of total soluble solids and ripening coefficient for the different varieties of *S. officinarum*.

Variety	Basal Brix	Apical Brix	Ripening coefficient
FAM 01-1505	19,3	21,1	1,10[a]
FAM 06-162	19,4	19,7	1,02[a]
FAM 05-469	20,9	20,8	0,99[a]
FAM 05-691	20,7	20,3	0,98[a]
FAM 05-662	19,7	19,2	0,98[a]
FAM 08-241	20,4	19,0	0,93[b]
FAM 08-1016	21,6	20,1	0,93[b]
FAM 08-550	20,7	18,8	0,91[b]
NA 85-1602	21,0	19,1	0,91[b]
LCP 85-348	20,3	18,1	0,89[b]
VC, %	5,6	7,3	5,78
P - value	0,3140	0,3121	0,0062
SE ±	0,66	0,84	0,03

Means with a common letter are not significantly different (Tukey p < 0,05).
SE: standard error

Table 6. Components determining the forage nutritional quality of stem samples of *S. officinarum* varieties.

Variety	CP, %	P, %	K, %	Ca, %	Mg, %	NDF, %	ADF, %	DIG, %	TDN, %	AE Mcal/ kg DM
FAM 05-469	3,7[a]	0,08[b]	0,55	0,61	0,12	41,9	24,5	69,8	77,3	3,4
FAM 05-691	2,9[a]	0,08[b]	0,78	0,55	0,14	42,2	24,0	70,2	77,7	3,4
FAM 01-1505	2,8[a]	0,08[b]	0,43	0,57	0,14	38,5	25,4	69,1	76,6	3,4
FAM 05-662	2,3[b]	0,11[a]	0,62	0,57	0,13	38,3	22,8	71,1	78,6	3,5
FAM 06-162	2,3[b]	0,07[b]	0,40	0,53	0,14	39,6	23,1	70,9	78,4	3,5
FAM 08-550	2,1[b]	0,09[b]	0,68	0,53	0,15	41,5	27,3	67,6	75,1	3,3
NA 85-1602	2,1[b]	0,13[a]	0,64	0,57	0,15	33,6	19,6	73,6	81,1	3,6
LCP 85-384	2,0[b]	0,10[a]	0,53	0,55	0,13	32,7	18,8	74,3	81,7	3,6
FAM 08-1016	1,9[b]	0,09[b]	0,30	0,55	0,15	37,7	23,6	70,6	78,0	3,4
FAM 08-241	1,7[c]	0,10[a]	0,36	0,57	0,14	35,5	23,6	70,5	78,0	3,4
VC %	12,05	9,83	39,14	8,89	16,79	8,4	13,52	3,46	3,13	3,1
P - value	0,0010	0,0018	0,4343	0,8788	0,8079	0,1169	0,3514	0,3514	0,3515	0,3510
SE ±	0,20	0,01	0,15	0,04	0,02	2,26	2,22	1,73	1,73	0,08

Means with a common letter are not significantly different Tukey (p<0,05).
N: nitrogen, CP: crude protein, P: phosphorus, K: potassium, Ca: calcium, Mg: magnesium, ADF: acid detergent fiber, NDF: neutral detergent fiber, DIG: digestibility, TDN: total digestible nutrients and AE: available energy.

higher contents and a mean of 0,11 %. Meanwhile, FAM 08-550, FAM 08-1016, FAM 05-469, FAM 05-691, FAM 01-1505, FAM 06-162 showed mean P contents of 0,08 % (table 6), statistically lower than the previous ones (p value 0,0010). The elements K, Ca and Mg showed mean values of 0,52; 0,55 and 0,13 %, respectively (table 6).

FAM 05-662, which had a high dry matter yield (table 3), intercepted 95,0 % of the incident radiation in April (table 4) and had an intermediate CP content of 2,3 %.

In the analysis of NDF and ADF percentages, the means were not statistically different among varieties (p = 0,1169 and p = 0,3514, respectively).

The average NDF content was 38,1 % and ADF was 23,3 %. The values cited by Suarez-Benítez *et al.* (2023) for ADF (46,0 to 53,0 %) were higher than those obtained in this trial.

Compared with the work conducted by Lagos-Burbano and Castro-Rincón (2019), the obtained average NDF content was similar, since when evaluating *S. officinarum* harvested between 8 and 12 months, they cited values of 35,2 %. In fact, these authors agree that the chemical composition of *S. officinarum* depends on the interaction between cultivar, regrowth age and plant fraction (whole plant, top and stem), with the NDF being higher for the top (74 %), intermediate for whole *S. officinarum* (54,1 %) and lower for the stems (35,2 %), due to the amount of soluble sugars in the cellular content. This last value coincides with those found in this work, where the average NDF concentration was close to 37,0 % (table 6).

According to Lagos-Burbano and Castro-Rincón (2019), when harvesting *S. officinarum* between 8 and 12 months of age, there is lower NDF content, good content of non-reducing and reducing sugars and adequate moisture, which facilitates the feedstuff degradation process, a fact that adds to the high biomass supply.

For the percentage results of DIG (p = 0,3514) and TDN (p = 0,3515), there were no significant differences and a mean of 70,8 and 78,2 % was obtained for each of these variables, respectively (table 6).

According to Salazar-Ortiz *et al.* (2017), the high sugar content and reduced starch content of *S. officinarum* limit fiber digestibility (50,0 to 68,0 %) with lower values, but close to the average of 70,87 % reported in this work. For AE results, there were no differences among varieties (p = 0,3515) and the mean was 3,45 Mcal/kg DM.

When studying the chemical composition between basal and middle sections of stems, independently of varieties, differences in percentage concentrations were found only in K (p = 0,0060) and Mg (p = 0,0073). Both minerals were found in greater proportion in the middle section of the canes compared with the basal section (table 7).

Dry matter digestibility is of great importance when recommending *S. officinarum* cultivars for animal feeding (Suarez-Benítez *et al.*, 2023). Interestingly, the percentage composition of NDF and ADF and, consequently, digestibility, did not differ among the sections, so they would be equally useful for the diet (table 6).

Conclusions

The results of the study indicate the high productive and nutritional potential of *Saccharum officinarum* in the region, especially when selecting varieties that are adapted to the local edaphoclimatic conditions. The average yield observed was 52 370 kg ha^{-1}, reaching up to 130 000 kg ha^{-1} in some exceptional varieties. The varieties FAM 05-662 and FAM 05-691 stood out for their high dry biomass yields.

In terms of nutritional composition, FAM 05-662 showed intermediate crude protein content; while FAM 05-691 had a higher content of 2,9 %. digestibility indices averaged 70,6 %, with TDN of 78,0 % and digestible energy of 3,45 Mcal/kg DM. These results suggest that *S. officinarum* can be a viable option for improving animal production in the region, provided that appropriate varieties are used and growing conditions are optimized.

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Conflict of interests

The authors declare that there is no conflict of interests among them.

Table 7. Components of the forage nutritional quality of stem samples of *S. officinarum* varieties from the apical sections.

Section	CP, %	P, %	K, %	Ca, %	Mg, %	NDF, %	ADF, %	DIG, %
Middle	2,4	0,1	0,7[a]	0,6	0,2[a]	38,9	22,8	70,4
Basal	2,4	0,1	0,4[b]	0,6	0,1[b]	37,4	23,7	71,1
VC, %	27,1	20,7	33,2	7,8	12,5	10,6	14,6	3,75
P - value	0,9044	0,8146	0,0060	0,5452	0,0073	0,4077	0,5671	0,5666
SE ±	0,20	0,01	0,06	0,01	0,01	1,28	1,08	0,84

Means with a common letter are not significantly different Tukey ($p<0,05$).
N: nitrogen, CP: crude protein, P: phosphorus, K: potassium, Ca: calcium, Mg: magnesium, ADF: acid detergent fiber, NDF: neutral detergent fiber, DIG: digestibility.

Authors' contribution

- Angela María Burgos. Research design and planning, revision of the manuscript.
- Francisco Méndez. Field test, measurement of variables and drafting of the original manuscript.
- Miriam Porta. Laboratory chemical analysis, critical revision of the manuscript.

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