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Effects of sowing methods (direct vs transplanting) on the growth and yield of Sanio pearl millet (*Pennisetum glaucum* L. R. Br.) in Lower Casamance (Southwestern Senegal)

Baboucar Bamba [1a*]; Assane Coundoul [2]; Rahimi Mballo [1b]; Cesar Bassene [2]

[1a] Senegalese Institute of Agricultural Research/Agricultural Research Center; of Djibelor, Cap-Skirring road BP 34, Ziguinchor, Senegal;
[1b] Senegalese Institute of Agricultural Research/Saint Louis Agricultural Research Center; Senegal, BP 240
[2] Crop Production and Agronomy Section, UFR of Agricultural Sciences, Aquaculture and Technologies Food, Gaston Berger University of Saint Louis, BP 234 Saint Louis.
Corresponding author : Baboucar BAMBA Email : *baboucar.bamba@isra.sn;*
tel : 00221 77 584 42 62

Abstract

Late-maturing millet or Sanio millet (*Pennisetum glaucum* (L.) R. Br.) is a cereal crop mainly cultivated in the southern and southeastern regions of Senegal. It is highly appreciated by rural populations due to its organoleptic and fodder qualities. The objective of this experiment was to evaluate the effects of two sowing methods on the productivity of Sanio millet. The trial was conducted at the Djibélor Agricultural Research Center during the 2021 rainy season. The sowing method was the studied factor, with four treatments: SD = direct sowing on July 14; R1= transplanting 15 days after direct sowing ; R2 = transplanting 35 days after direct sowing ; and R3 = transplanting 45 days after direct sowing. The experiment was arranged in a randomized complete block design with four replications. The results showed that plant height was more affected by direct sowing (168.45 ± 30.11 cm at 60 DAS; 225.20 ± 30.96 cm at 70 DAS; 289.10 ± 30.65 cm at 100 DAS) and transplanting at 15 DAS (153.45 ± 13.70 cm; 181.50 ± 38.02 cm; 292.15 ± 35.61 cm). The same trend was observed for stem collar diameter. Grain yield (P = 0.3739), straw yield (P = 0.0554), and thousand-grain weight (P = 0.3878) did not vary significantly regardless of the sowing method. However, transplanting at 30 DAS recorded an 11% increase in grain yield compared with direct sowing.

Keywords: Sanio millet, productivity, sowing method, Casamance, Senegal.

Introduction

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is the fourth most widely cultivated cereal crop worldwide after wheat, rice, and maize (FAO, 2018). In 2019, global production reached 28.37 million tonnes harvested from 31.65 million hectares, with an average grain yield of 896 kg/ha (FAO, 2021). More than 80% of the global production is concentrated in Africa and India, highlighting the crop's importance for food security in arid and semi-arid regions (FAO, 2015). In West Africa, Senegal ranks fifth among pearl millet-producing countries, following Niger, Nigeria, Mali, and Burkina Faso (Kanfany, 2017).

In Senegal, pearl millet is the most extensively cultivated cereal crop and constitutes a major staple food, particularly in rural areas (Agency Ecofin, 2020). In 2019, the crop covered 880.408 ha and produced 807.044 tonnes, with an average yield of 916 kg ha^{-1}, representing approximately 29% of the country's total cereal production (FAO, 2021).

The late-maturing pearl millet ecotype known as Sanio is mainly cultivated in the humid agroecological zones of southern and eastern Senegal, particularly in Lower Casamance and Eastern Senegal. Sanio occupies approximately 15% of the total area devoted to pearl millet cultivation in the country (Fofana and Mbaye, 1990). Despite its socioeconomic importance, limited scientific information is available on the agronomic management of this ecotype, particularly with regard to crop establishment practices (Muller, 2015; Bamba, 2020). Local Sanio cultivars are well adapted to the environmental conditions of Casamance and are highly appreciated by farming communities for their grain quality and forage value. However, agronomic recommendations to support producers remain scarce. Improving crop establishment through appropriate sowing methods could enhance the expression of the genetic potential of these locally adapted cultivars and ultimately increase productivity.

The present study was conducted to contribute to the sustainable improvement of Sanio pearl millet productivity in smallholder farming systems of Lower Casamance, Senegal. Specifically, the objectives were to: (i) assess the agronomic and morphological performance of Sanio pearl millet under two sowing methods, namely direct seeding and transplanting; and (ii) determine the best sowing method for maximizing grain production under the agroecological conditions of Lower Casamance.

Material and Method

Study Area

The field experiment was conducted at the Djibélor Agricultural Research Center (12°33′39″ N, 16°18′25″ W), located along the Cap Skirring road in the municipality of Niaguis, Ziguinchor Region, southwestern Senegal (Figure 1). The experimental site is characterized by tropical ferruginous soils with a predominantly sandy texture. According to Sagna (2005), the region experiences a southern coastal Sudanian climate. The climate is characterized by two distinct seasons: A dry season lasting 7–8 months (November to May) and A rainy season extending over 4–6 months (June to November). During the 2021 growing season, the total annual rainfall reached 2,037 mm. The highest monthly rainfall was recorded in August (768 mm), followed by September (555 mm) (Figure 2).

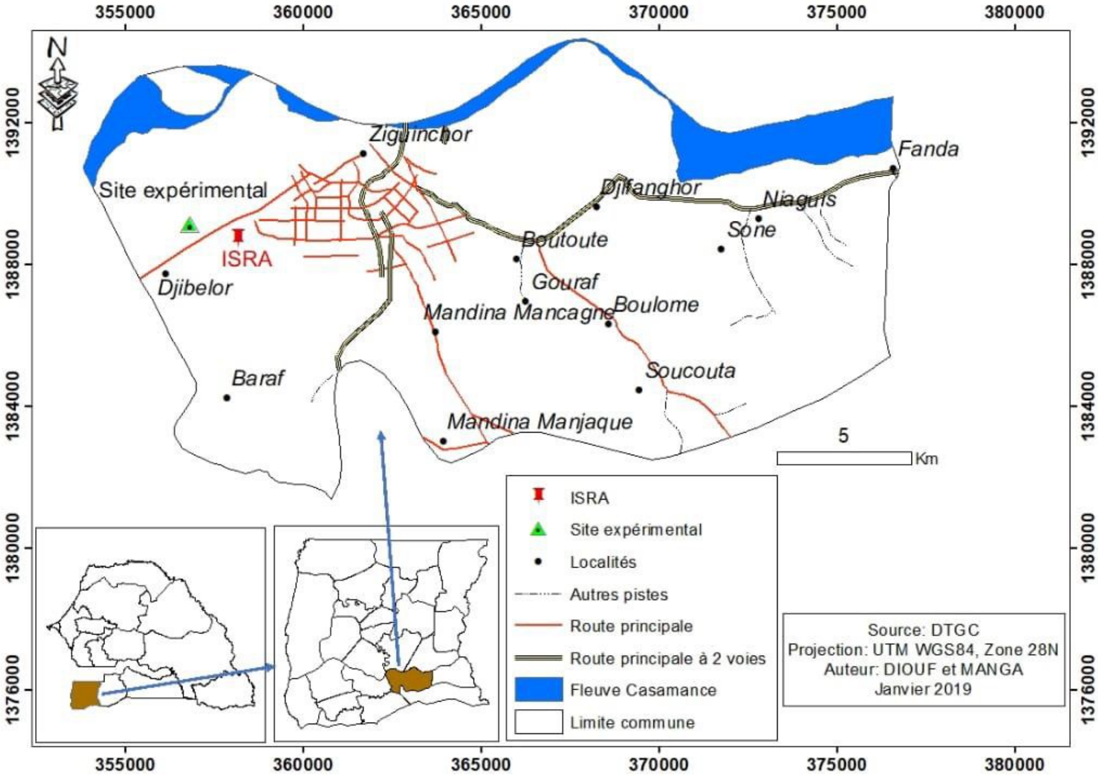

Figure 1 : Localization of the experimental site
Source: Manga and Diouf (2019)

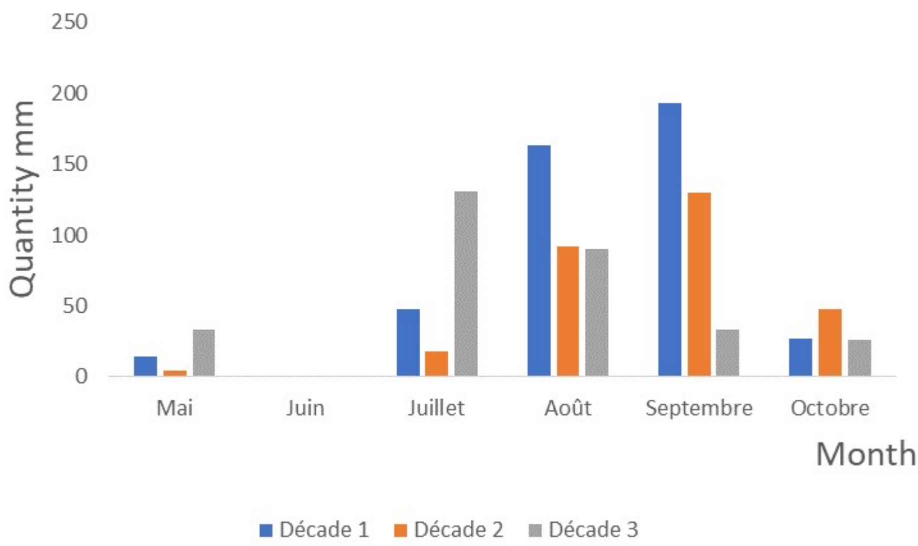

Figure 2 : decadal rainfall distribution at the Djibélor Agricultural Research Center during the 2021 rainy season

Plant Material

The plant material used in this study consisted of a Sanio pearl millet cultivar originating from Séfa (Middle Casamance, Senegal). This cultivar has a crop cycle ranging from **130 to 150 days**and is characterized by **awned panicles** It is a photoperiod-sensitive cultivar, flowering only when day length decreases below a critical threshold (Diouf, 2001).

Experimental factor and design

The factor investigated was the sowing method**(SM)** with four treatments: **DS1 = direct seeding; T1 (R1) = transplanting at 15 days after direct seeding; T2 (R2) = transplanting at 30 days after direct seeding; and T3 (R3) = transplanting at 45 days after direct seeding**. The treatments were arranged in a **randomized complete block design (RCBD)** with four replications. The experimental unit consisted of an elementary plot measuring **5 m × 4 m (20 m²).**The spacing between experimental plots was 1 m, while the distance between blocks was 1.5 m.

Trial Management

Pearl millet was directly sown on **14 July 2021**, and the nursery was established on the same date.Transplanting operations were carried to**15, 30, and 45 days after direct seeding** respectively. The sowing spacing was 90 cm between rows and 90 cm between hills. Thinning was performed in the direct seeding treatment to maintain a density of **three plants per hill.** Organic fertilizer **(cattle manure)** and mineral fertilizers (15**N-15P-15K and urea 46% N)** were applied at the recommended rates and dates according to agricultural research recommendations. A hand hoeing and weeding operation was carried out at **35 days after sowing (DAS)**. Pearl millet was harvested **110 days after direct seeding** from the yield sampling area **(12 m²).**

Data Collection

The following measurements were recorded:

- **Morphological parameters:** number of tillers, plant height, and stem collar diameter measured on four (4) randomly selected hills within each experimental plot at 60, 70, 80, 90, and 100 days after sowing (DAS).
- **Yield parameters and components :** number of ears, fresh and dry ear weight, fresh and dry aboveground biomass weight, grain yield, thousand-grain weight, and harvest index.

All production measurements were carried out within the 12 m² harvest area.

Statistical Analysis

The collected data were entered into Microsoft Excel and analyzed using **XLSTAT version 2014.5.03**. Analysis of variance (ANOVA) was performed at the 5% significance level, and treatment means were compared using Fisher's Least Significant Difference (LSD) test at the 5% significance level. Principal component analysis (PCA) was conducted to assess the relationships between the tested treatments and the measured parameters.

Results

Collar and Ear Diameter

Table 1 shows the variation in collar diameter and ear diameter as affected by the sowing method. The analysis revealed that plant diameter was significantly influenced by the sowing method during the vegetative phase (Pr = 0.0096; Pr = 0.0136) and the reproductive phase (Pr = 0.0017; Pr < 0.0001).At 60 days after sowing (DAS), direct sowing and transplanting at 15 DAS resulted in the highest collar diameters, with values of 1.50 ± 0.18 cm and 1.52 ± 0.13 cm, respectively, compared with intermediate (30 DAS) and late (45 DAS) transplanting.

The same trend was observed at 70 DAS, with collar diameters of 1.47 ± 0.07 cm and 1.52 ± 0.13 cm, respectively. At 90 DAS, direct sowing (1.45 ± 0.14 cm), transplanting at 15 DAS (1.37 ± 0.10 cm), and intermediate transplanting (30 DAS) (1.32 ± 0.09 cm) recorded statistically similar collar diameters. However, at 100 DAS, direct sowing (1.46 ± 0.10 cm) and transplanting at 15 DAS (1.34 ± 0.09 cm) resulted in the highest collar diameters.

Ear diameter was not significantly affected by the sowing method (Pr = 0.3979). The highest ear diameters were recorded under direct sowing (1.91 ± 0.06 cm) and transplanting at 30 DAS (1.82 ± 0.16 cm).

Table 1 : effect of sowing method on collar and ear diameter variation in Sanio millet

Treatment	Collar diameter (cm)					Ear diameter (cm)
	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS	
Transplanting at 15 DAS	1.52 ± 0.13 A	1.52 ± 0.13 A	1.38 ± 0.18 A	1.37 ± 0.10 A	1.34 ± 0.09 A	1.78 ± 0.16 A
Direct sowing	1.50 ± 0.18 A	1.47 ± 0.07 A	1.57 ± 0.33 A	1.45 ± 0.14 A	1.46 ± 0.10 A	1.91 ± 0.06 A
Transplanting at 30 DAS	1.02 ± 0.35 B	1.32 ± 0.09 AB	1.29 ± 0.14 A	1.32 ± 0.09 A	1.10 ± 0.07 B	1.82 ± 0.16 A
Transplanting at 45 DAS	0.82 ± 0.34 B	1.15 ± 0.15 B	1.22 ± 0.31 A	1.11 ± 0.08 B	0.97 ± 0.13 B	1.75 ± 0.09 A
General mean	**1.22 ± 0.39**	**1.37 ± 0.19**	**1.37 ± 0.27**	**1.31 ± 0.16**	**1.22 ± 0.22**	**1.82 ± 0.13**
Probability	**0.0096****	**0.0136***	**0.3877 ns**	**0.0017****	**<0.0001*****	**0.3979 ns**
LSD	**0.4193**	**0.2149**	**0.3877**	**0.1339**	**0.1353**	**0.3979**

*DAS: days after sowing. Means followed by the same letter are not significantly different according to Fisher's LSD test at the 5% probability level. ns: not significant; * significant at 5%; ** significant at 1%; *** significant at 0.1%.*

Millet Plant Growth

The variation in plant height as affected by sowing method is presented in Table 2 : variation in millet plant height as affected by sowing method. Highly significant differences were observed in plant height during the vegetative phase (Pr = 0.0024; Pr = 0.0008) and the maturation phase (Pr = 0.0008).

Direct sowing and transplanting at 15 days after sowing (DAS) resulted in the highest plant heights throughout the growth cycle of Sanio millet, with statistically similar values. Plant heights were statistically comparable at 60 DAS (168.45 ± 30.11 cm and 153.45 ± 13.70 cm) and at 100 DAS (289.10 ± 30.65 cm and 292.15 ± 35.61 cm). However, at 70 DAS, only direct sowing resulted in the highest plant growth (225.20 ± 30.96 cm).

Table 2 : variation in millet plant height as affected by sowing method

Treatment	Plant height (cm)				
	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS
Direct sowing	168.45 ± 30.11 A	225.20 ± 30.96 A	250.15 ± 72.25 A	282.05 ± 36.51 A	289.10 ± 30.65 A
Transplanting at 15 DAS	153.45 ± 13.70 A	181.50 ± 38.02 B	234.30 ± 46.12 A	266.15 ± 38.98 A	292.15 ± 35.61 A
Transplanting at 30 DAS	98.50 ± 21.20 B	159.10 ± 8.66 B	209.25 ± 49.31 A	227.15 ± 25.35 AB	242.30 ± 29.78 AB
Transplanting at 45 DAS	85.70 ± 18.72 B	106.10 ± 11.75 C	222.05 ± 51.23 A	205.65 ± 32.33 B	211.65 ± 34.17 B
General mean	**126.52 ± 41.17**	**167.97 ± 49.88**	**228.93 ± 52.20**	**245.25 ± 43.49**	**258.80 ± 45.38**
Probability	**0.0024****	**0.0008*****	**0.8275 ns**	**0.0609 ns**	**0.0008*****
LSD	**39.4551**	**41.21**	**102.6364**	**59.5312**	**57.9858**

*DAS: days after sowing. Values followed by the same letter within a column are not significantly different according to Fisher's LSD test at the 5% probability level. ns: not significant; ** significant at 1%; *** significant at 0.1%.*

Tillering and fertility rate

Table 3 presents tiller production and fertility rate. The results showed that neither tillering (Pr = 0.4064) nor tiller fertility percentage (Pr = 0.3401) varied significantly according to the sowing method. The average tillering and fertility rate were 18.63 ± 2.50 tillers/m² and 40.20 ± 9.32%, respectively. The highest tiller production and fertility rate were recorded with transplanting at 30 DAS (19.67 ± 0.81 tillers/m²) and direct sowing (46.54 ± 13.81%), respectively.

Table 3 : **Effect of sowing method on tillering and fertility rate**

Treatment	Number of tillers/m²	Fertility rate (%)
Transplanting at 30 DAS	19.67 ± 0.81 A	36.46 ± 8.94 A
Transplanting at 45 DAS	19.33 ± 1.23 A	34.68 ± 3.86 A
Direct sowing	19.00 ± 2.93 A	46.54 ± 13.81 A
Transplanting at 15 DAS	16.53 ± 2.58 A	43.13 ± 4.97 A
General mean	**18.63 ± 2.50**	**40.20 ± 9.32**
Probability	**0.4064 ns**	**0.3401 ns**
LSD	**4.3945**	**15.7931**

Within a column, means followed by the same superscript letter are statistically similar according to Fisher's test at the 5% significance level. ns: not significant at the 5% level.

Biomass Production

The effects of sowing method on biomass production are presented in Table 4. No significant difference was observed for straw yield (Pr = 0.0554). The highest straw yields were recorded under direct sowing (5940.62 ± 885.32 kg/ha), followed by transplanting at 15 DAS (5545.83 ± 1662.10 kg/ha).

Table 4 : **straw yield of Sanio millet as affected by sowing method**

Treatment	Straw yield (kg/ha)
Transplanting at 30 DAS	4630.21 ± 1508.56 A
Direct sowing	5940.62 ± 885.32 A
Transplanting at 15 DAS	5545.83 ± 1662.10 A
Transplanting at 45 DAS	2987.50 ± 826.27 A
General mean	**4776.04 ± 1636.80**
Probability	**0.0554 ns**
LSD	**2184**

Within a column, means followed by the same superscript letter are statistically similar according to Fisher's test at the 5% significance level. ns: not significant at the 5% level.

Yield and components

The number of ears, grain yield, thousand-grain weight, and harvest index are presented in Table 5. No significant differences were observed for ear production (Pr = 0.3434), grain yield (Pr = 0.3739), thousand-grain weight (Pr = 0.3878), or harvest index (Pr = 0.0572).The highest ear production and grain yields were recorded under direct sowing (85,000.00 ± 11,013.46 ears/ha; 1,067.71 ± 59.45 kg/ha) and transplanting at 30 DAS (71,458.33 ± 16,192.92 ears/ha; 1,185.42 ± 307.25 kg/ha). Transplanting at 15 DAS and 45 DAS resulted in the highest thousand-grain weights, with values of 6.02 ± 0.87 g and 5.56 ± 0.60 g, respectively. However, transplanting at 45 DAS and 30 DAS recorded the highest harvest index.

Table 5 : **effect of sowing method on ear number, grain yield, thousand-grain weight, and harvest index**

Treatment	**Number of ears/ha**	**Grain yield (kg/ha)**	**1000-grain weight (g)**	**Harvest index**
Direct sowing	85.000.00 ± 11.013.46 A	1.067.71 ± 59.45 A	5.06 ± 1.41 A	0.15 ± 0.03 A
Transplanting at 30 DAS	71.458.33 ± 16.192.92 A	1.185.42 ± 307.25 A	5.17 ± 0.40 A	0.21 ± 0.02 A
Transplanting at 15 DAS	71.250.00 ± 13.919.41 A	1.021.87 ± 329.04 A	6.02 ± 0.87 A	0.16 ± 0.03 A
Transplanting at 45 DAS	67.083.33 ± 9.267.13 A	850.00 ± 145.42 A	5.56 ± 0.60 A	0.23 ± 0.06 A
General mean	**1.82 ± 0.13**	**1.031.25 ± 246.87**	**5.4563 ± 0.8966**	**0.19 ± 0.49**
Probability	**0.3434 ns**	**0.3739 ns**	**0.3878 ns**	**0.0572 ns**
LSD	**22.181**	**411.305**	**1.3107**	**0.063**

Within a column, means followed by the same superscript letter are statistically similar according to Fisher's test at the 5% significance level. ns: not significant at the 5% level.

Relationships between treatments and measured variables

Principal Component Analysis (PCA) was performed based on the evaluated parameters and the different sowing methods (Figure 3). The results showed that axes F1 and F2 explained 66.77% of the total variability, providing a good graphical representation of the information contained in the data matrix. PCA revealed the existence of four groups correlated with one or more sowing methods.

On axis F2 (21.55%), sowing methods R1, R2, R3, and DS (group 1) were positively correlated with all variables. Furthermore, R1, R2, and DS (group 2) were negatively correlated with collar diameter, fertility rate, and thousand-grain weight.

On axis F1 (45.22%), all parameters were positively correlated with sowing methods R1, R2, and R3 (group 3), except for thousand-grain weight. However, the number of tillers was negatively correlated with sowing methods R1, R2, and R3. Moreover, collar diameter, plant height, ear yield, grain yield, straw yield, and harvest index were negatively correlated with sowing methods R3 and DS (group 4).

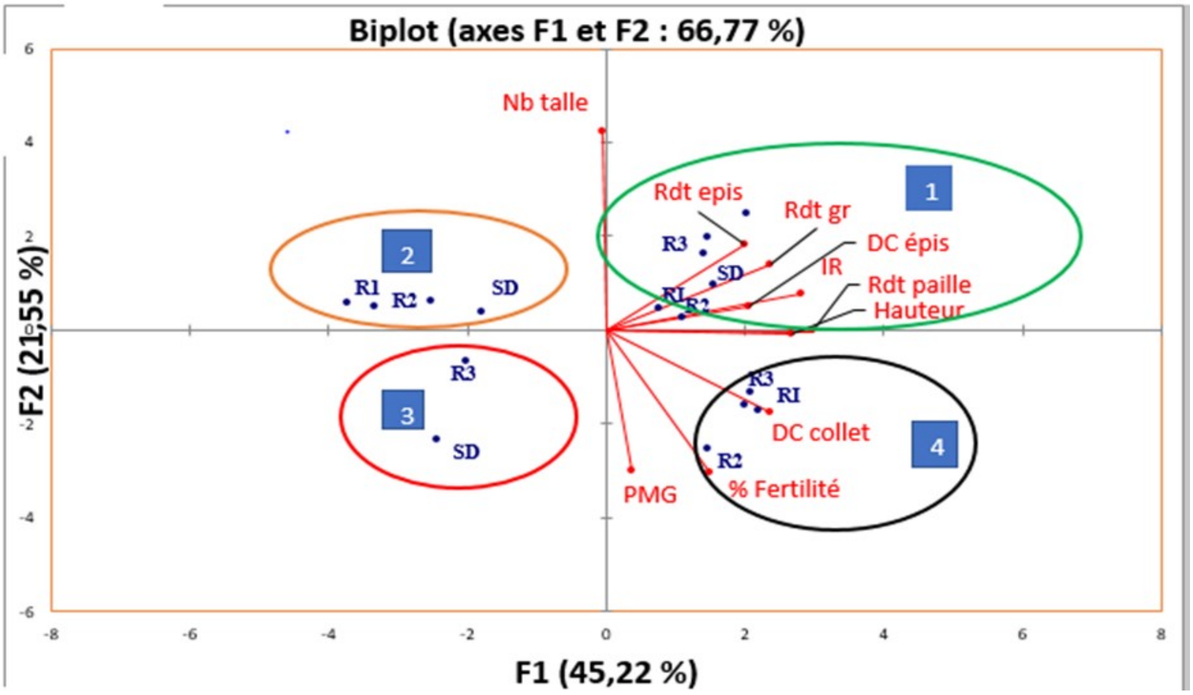

Figure 3 : **correlation between the sowing method and the tested parameters**

Discussion

The diameter increased more with direct sowing and early transplanting (15 DAS). Indeed, in the Sahelian zone, sowing date is undoubtedly one of the key factors determining yield potential. The advantages of early sowing (the first rains with cumulative rainfall greater than or equal to 20 mm) are numerous and mainly concern the beneficial effects related to the rapid decomposition of plant residues and nitrogen flux. Our results are consistent with the findings of Diallo (2021), who showed that the vigor of Sanio millet plants increases mainly during the vegetative phase.

Better plant height growth was promoted by transplanting at 15 DAS (292.15 ± 35.61 cm) and direct sowing (289.10 ± 30.65 cm). Early sowing also provides a favorable environment for plant vegetative development through the availability of nutrients. These results corroborate those of Tovignan et al. (2015), who found variations in sorghum plant height with early sowing. Similarly, the values obtained fall within the range reported by Pandey et al. (2001), who showed that in semi-arid regions, stem height ranges from 0.5 to 3.5 meters. These results are consistent with those reported by Sêkloka et al. (2015), who demonstrated that sowing period significantly affected cotton plant morphology under water-limited conditions, with shorter plants observed in plots where late sowing was carried out.

Tiller production did not vary regardless of the sowing method. This is due to the fact that tillering depends on soil and climatic conditions as well as the genetic characteristics of the cultivar used. Our results agree with the work of Bamba (2020) on Sanio millet in Casamance and Eastern Senegal, which showed that sowing date did not affect tillering regardless of the year and location. However, they contradict the findings of Amadou (1994), and Alhassane (2009), who showed that the total number of tillers produced by a millet plant increases with the length of the variety’s growth cycle, provided that water is not a limiting factor.

The highest biomass production was recorded with direct sowing. Direct sowing promotes better nutrient utilization by influencing the mineralization coefficient, resulting in higher biomass production. This result is similar to that of Reddy and Visser (1993), who observed a reduction in biomass yield with late sowing in a local short-day photoperiod-sensitive millet variety. Furthermore, studies conducted by ICRISAT (1993) in Niger showed that a delay of 5–7 weeks in sowing strongly reduced millet biomass production (late-maturing local Sommo variety), from 3.7 to 0.9 tons per hectare.

Grain yield was higher with early transplanting (1185.42 ± 307.25 kg/ha) and direct sowing (1067.71 ± 59.45 kg/ha). This can be explained by the fact that early sowing promotes good grain filling and reduces pest attacks (insects, molds, birds) during flowering and grain maturation stages. These results are consistent with those of Ahn (1993), who showed that grain yield in photoperiod-sensitive millet and sorghum varieties is almost always higher under early sowing conditions. The studies of Dokuyucu et al. (2004), Yang and Zhang (2006), and Aslani and Mehrvar (2012) showed that late sowing of cereals under water deficit conditions and high temperatures during the grain-filling stage increases the proportion of small and immature grains. However, Sêkloka et al. (2015) reported yield reductions of 12% for early exotic varieties and 30% for late varieties due to late sowing in northern and southern Benin. Indeed, late sowing is often exposed to unfavorable environmental conditions (excessive temperatures, excessive or insufficient rainfall) that negatively affect the development and maintenance of reproductive organs. This ultimately reduces final yield (Ali et al., 2004; Bilal et al., 2015). A 34.13% reduction in seed cotton yield due to a two-week delay in cotton sowing compared with the recommended sowing date was reported in Pakistan (Bozbek et al., 2006).

The 1000-grain weight was not affected by the sowing method. On average, thousand-grain weight ranged from 5.4563 ± 0.8966 grams. These results are consistent with those reported by Bamba (2020) on Sanio millet in Casamance.

Conclusion

The assessment of the effects of two sowing methods on the morphological and production parameters of Sanio millet in Lower Casamance contributed to improving scientific knowledge on Sanio millet. The results showed that the sowing method mainly influenced morphological parameters. Indeed, direct sowing and transplanting at 15 DAS had a greater effect on growth parameters (plant height and collar diameter). In terms of production, transplanting at 15. 30 ; DAS and direct seedling had a greater impact on yield parameters and their components.

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