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# Sustainable Intensification of Cassava Production towards Food Security in the Lomami Province (DR Congo): Role of Planting Method and Landrace

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**Abstract:** Cassava is a mainstay crop for food security in Africa, its tubers being a large source of carbohydrates for the human diet. In some regions (e.g., the Democratic Republic of the Congo; DRC), leaves are also consumed as a source of proteins, vitamins, and minerals. Cassava adapts well to a range of soil-climate conditions and requires low inputs, yet yields are often unsatisfactory because of failures in disseminating improved genotypes and agricultural practices. The aim of this study was to test the effect of (i) seedbed preparation for planting cassava (i.e., flat, mounds, and ridges) and (ii) local landraces (i.e., Kakuanga, Kasongoy, Kasonie, Ndunda, and Ngoymuamba) on yield components and their nutritional quality in the Lomami province (DRC). In-depth measurements of yield components were performed, including the number of tubers and stems per plant, leaf biomass, stem biomass, root yield, and peeling yield. Tubers and leaves were also analyzed for chemical composition. Our results demonstrated that mound and ridge seedbed preparations may highly increase tuber yield (+32–68%) compared with flat. This is not the case for leaves and stems, which were not affected. The Ngoymuamba landrace showed a tuber yield about three times larger than Ndunda, which represented the common productivity values (5–8 Mg ha$^{-1}$). No effect of seedbed preparation was observed and only minor differences between landraces were observed for the chemical composition of roots and leaves. We concluded that selecting the best-performing seedbed preparations × landraces could have a significant potential for achieving in a relatively short time the goal of "Zero Hunger" and improving the diet in the DRC.

**Keywords:** cassava landraces; planting method; yield; Democratic Republic of the Congo; sustainable developing goals; zero hunger

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## 1. Introduction

Cassava (*Manihot esculenta* Crantz)—a plant species belonging to the family of Euphorbiaceae—is one of the three major staple crops in Africa [1,2], being at the same time the third largest (after rice and maize) source of carbohydrates for the human diet in the tropics [3]. The annual consumption of cassava tubers is estimated to be around 17 kg per capita, but this amount rises to 80 kg per capita if only Africa is considered [4,5]. In addition, several reports [6–8] highlighted its major role for industrial uses, including the production of starch, animal feed, ethanol, pharmaceuticals, and biofuels. Such a broad range of uses derives from the fact that all parts of the cassava plant can be utilized according to their specific physical features and chemical composition.

Cassava is the most widespread crop in many African countries due to its favorable agronomic characteristics, which include high adaptability to a wider range of pedo-climatic conditions, tolerance to low soil fertility, resistance to drought, relative ease of cultivation, very high starch yielding potential, simple root storability in soil, and ease of placement on local markets [6,9,10]. Indeed, cassava can yield up to 10 Mg ha$^{-1}$ of fresh tubers without agronomic inputs other than family work, although the yield potential is much higher. For instance, the Asian average yield is estimated to be about 22 Mg ha$^{-1}$ [11]. As results of their experiments in East Africa, Legg et al. [12], Ntawuruhunga et al. [13], and Obiero [14] recorded cassava fresh root yields around 60 Mg ha$^{-1}$ under experimental conditions, while Fermont et al. [15] observed 6–17 Mg ha$^{-1}$ of cassava fresh root yields in Kenyan and Ugandan farmer fields. Overall, a potential yield of between 75 and 90 Mg ha$^{-1}$ has been suggested [15,16]. In fact, several researchers reported that cassava yields at research sites are often greater than those in smallholder farmer fields [17]. A recent review confirms this potential productivity of cassava from on-station and on-farm trials [18], reporting a yield of 40 Mg ha$^{-1}$ of fresh tubers in Nigeria, 54 in Togo, 59 in Uganda and Kenya, 90 in Colombia, and 66 in Australia.

In the Democratic Republic of the Congo (DRC), Munyahali et al. [19] observed yields varying between 20.2 Mg ha$^{-1}$ and 29.4 Mg ha$^{-1}$ in the Kalehe district of the South Kivu Province, confirming the results of Kintché et al. [20], who found that the yields of cassava genotypes in research-managed systems are at least twice as high as those in farmer-managed systems. However, current yield performances are still low because of failures in disseminating improved genotypes and proper agricultural practices. However, care must be taken not to lose genetic biodiversity, especially in subsistence agricultural contexts where genotype choice through a participatory approach of local populations is very helpful [21].

The common cultivation of cassava is based on vegetative propagation by cuttings. The main methods for planting are flats, mounds, and ridges. Planting cassava cuttings on the flat (simply soil tillage without raising the land) is the most common method in the DRC as it requires less labor and energy. However, it has been reported that flat is also the method with the lowest yield, also due to improper soil drainage management [22]. On the other hand, mounds and ridges have been previously suggested as improving methods. In their review study, Fasinmirin and Reichert [23] concluded that ridge and mound techniques ensure good development of plants, especially roots and tubers, and facilitate the management of water and soils by gathering fertile soil around cultivated plants. In detail, mounding is the practice of crop cultivation consisting of building up the surface of the land in a heap of soil measuring between 20–40 cm in height. Ridging is the process of modeling land as a long, narrow raised formation about 15–30 cm high with sloping sides; this technique has many advantages such as soil conservation by reducing erosion, better control of weeds, good drainage of the soil, and increased root development. Nevertheless, the choice of one cultivating technique over another should depend on soil type, topography, and available labor and energy.

However, cassava is not grown only for tubers. Indeed, cassava is also called in the Democratic Republic of the Congo (RDC) an "all-sufficient" crop because "roots constitute the bread, while leaves are the meat" [24]. Despite the fact that cassava leaves are not commonly consumed in all African countries, this is especially the case in the DRC [19,25–27], where cassava leaves account for more than 60% of the entire vegetable consumption every year [26]. Indeed, being an extra-source of protein, vitamins, and minerals, cassava leaves may be considered a functional food to be introduced into traditional cassava root-based diets [5,28–33], which are excessively rich in carbohydrates [34]. However, the appearance and taste of different cassava varieties play a crucial role in the food's acceptance because there are some local preferences between cultivars with green or pink petiole. Some people consider that the green petiole cassava leaves are toxic, while others prefer mildly mosaic-infected cassava leaves, considering them sweeter [26].

Then, cassava stems are widely used as propagation material for transplanting for the next cropping season, while peelings are used for animal nutrition. However, due to their high content in hydrocyanide, phytates, and mycotoxins, as well as the difficulties in drying and conservation, peels are often not utilized and left to rot in heaps or set on fire, polluting the environment and wasting a potential feed [35,36]. A good production of peelings and the development of effective detoxification and conservation treatments could promote the use of this by-product as feed, improving livestock production in rural areas.

In the current context of climate change and food insecurity, the importance of cassava should be further underlined since it may contribute to the achievement of several sustainable development goals (SDGs 1, 2, and 3, as described in the United Nations [37]). To do that, a program of sustainable intensification of cassava production must be implemented, starting with the selection of more productive available varieties, especially in very rural areas of Africa [21,38], and avoiding agro-environmental risks [39]. This should be based on the recognition that the softer the innovation, the more easily it will be adopted by smallholder farmers.

The present study aimed to assess the best technique of seedbed preparation for planting cassava and the most performant cultivars among local landraces in the Kabinda district of the Lomami province in the Democratic Republic of the Congo. Specifically, the experiment was targeted to: (1) run a field study to compare three seedbed preparation techniques (i.e., flat, mounds, and ridges) for planting cassava cuttings; (2) identify the more productive local cassava landrace among Kakuanga, Kasongoy, Kasonie, Ndunda, and Ngoymuamba, both for tubers and leaves; and (3) nutrient composition analyses of tubers and leaves.

## 2. Materials and Methods

### *2.1. Site Description*

The study was carried out at the experimental farm of the University Notre-Dame de Lomami, located in Kimulo, near Kabinda, in the Lomami Province of the Democratic Republic of the Congo (Lat. 6°06′34.5″ S; Long. 24°33′37.3″ E, 787 m a.s.l.). The climate of the area belongs to Aw3 according to the Köppen classification system. It has a humid tropical climate with rainy seasons from mid-August to mid-January and from mid-February to mid-May and dry seasons from mid-January to mid-February and mid-May to mid-August. The average annual rainfall is around 1600 mm, and the average annual temperature is around 25 °C [40] (Figure 1).

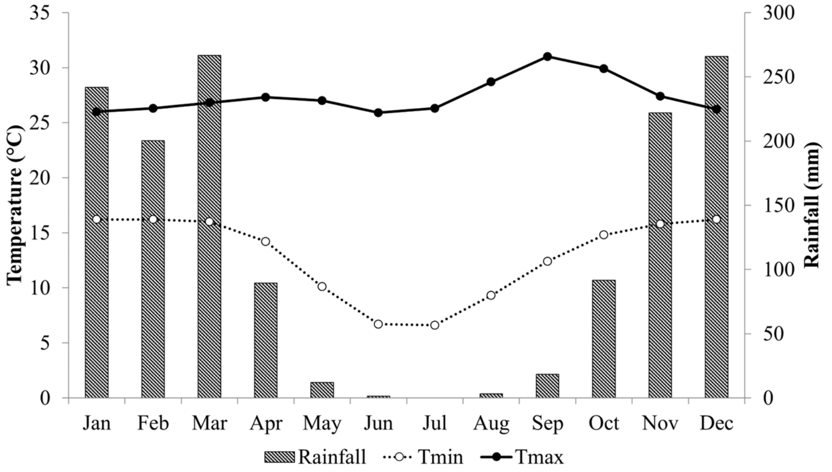

**Figure 1.** Monthly rainfall (columns) and air temperatures (lines) in Kabinda district (mean years 1990–2015).

Main soil properties at the beginning of the experiment are reported in Table 1.

**Table 1.** Soil physico-chemical properties (0–20 cm depth) of the experimental field (sd, standard deviation).

| Soil Property | Unit | Value ± sd |
|---|---|---|
| Sand (2–0.05 mm) | g kg$^{-1}$ | 907 ± 22 |
| Silt (0.05–0.002 mm) | g kg$^{-1}$ | 19 ± 12 |
| Clay (<0.002 mm) | g kg$^{-1}$ | 74 ± 12 |
| Texture class (USDA) | | Sand |
| pH ($H_20$, 2.5:1 suspension ratio) | | 5.4 ± 0.2 |
| pH (KCl 1M) | | 4.5 ± 0.1 |
| Organic Matter (Walkley and Black) | g kg$^{-1}$ | 10.2 ± 2.0 |
| Total N (Kjeldahl) | g kg$^{-1}$ | 0.396 ± 0.020 |
| C:N ratio | | 14.9 ± 2.2 |
| Available P (Na bicarbonate, 0.5 M, pH 8.5) | mg kg$^{-1}$ | 9.3 ± 3.3 |
| Exchangeable K ($NH_4$ acetate, pH 7.0) | mg kg$^{-1}$ | 72.4 ± 5.6 |
| C.E.C. (Ba chloride, pH 8.2) | cmol$^+$ kg$^{-1}$ | 5.6 ± 0.9 |

### 2.2. Experimental Design, Treatments, and Crop Management

The experimental design was a factorial split-plot with five replications. The main factor had three levels and consisted of three land preparation methods for planting cassava: flat (F), mound (M), and ridge (R), as illustrated in Figure 2. The secondary factor, with five levels, consisted of five bitter-type cassava landraces (Kakuanga, Kasongoy, Kasonie, Ndunda, and Ngoymuamba), as obtained from local farmers in Kabinda district. These landraces are easy to recognize and are sold separately on local markets.

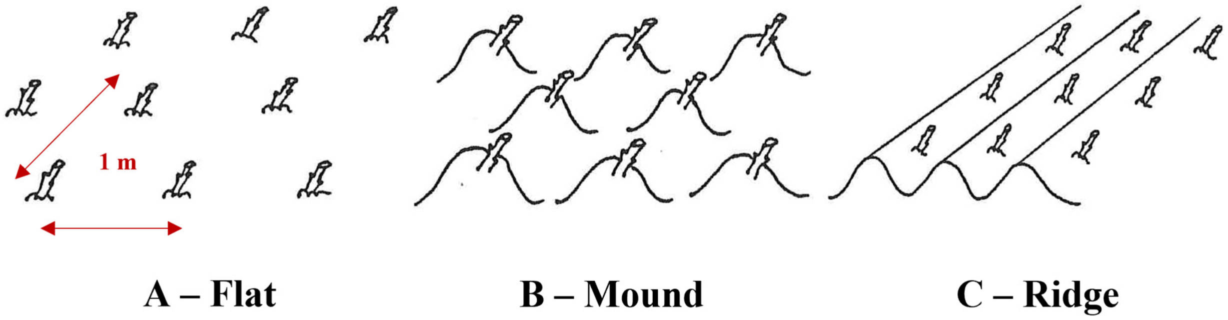

**Figure 2.** The three planting methods compared in this study: flat (**A**), mound (**B**), ridge (**C**). (Drawn by Davide Pochintesta).

Main characteristics about the five landraces are listed in Table 2.

The main plot size was 125 m$^2$ (25 m long and 5 m wide); within each plot, five subplots were established, each of 25 m$^2$, corresponding to the five cassava landraces. Before starting the experiment, weeds in the field were manually rooted out and subsequently burned, according to local practices. Then, the soil was tilled in September 2013 by hoe and prepared for planting on the flat soil or on the crest of mounds or ridges, according to the different land preparation methods. Cassava cuttings of 30-cm length with 5–7 nodes were prepared from healthy stems of each landrace and buried for two-thirds into the soil with an angle of about 45°, at a spacing of 1 × 1 m apart, resulting in a plant population of 10,000 stands ha-1. Two manual weedings were done during the cropping season, 3 and 8 weeks after planting, respectively. During the whole trial, neither fertilizer nor irrigation were applied, according to the local management. Cassava was harvested on 28 April 2015, after a 17-month growing season. The incidence of cassava mosaic disease (CMD) was <10% for all the landraces (data not shown), demonstrating the good resistance of the local genotypes used in this trial.

**Table 2.** Main characteristics of the five landraces of cassava used in the trial.

| Landrace | Characteristics | Origin | Altitude (m asl) | Soil Type |
|---|---|---|---|---|
| Kakuanga | The name refers to a very bitter taste (in the local language) | Kananga village, 12 km E of Kabinda | 843 | sandy |
| Kasongoy | From the name of the farmer who introduced this landrace in Kabinda (Kasongo Ngoy) | Nyenka village, 16 km W of Kabinda | 812 | sandy clay loam |
| Kasoni | The name refers to very acute, pointed leaves | Kimonga village, 12 km NE of Kabinda | 843 | sandy |
| Ndunda | Acacia-like leaves (acacia is Ndunda in the local language) | Kabengiele village, 26 km N of Kabinda | 795 | sandy |
| Ngoymuamba | From the name of the farmer who introduced this landrace in Kabinda (Ngoy Muamba) | Kamana village (Lubao area), 70 km E of Kabinda | 741 | sandy clay loam |

### *2.3. Sampling and Chemical Analysis*

At harvest, five plants were taken into the center of each sub-plot for collecting agronomic data: number of tubers per plant, number of stems per plant, leaf biomass, stem biomass, total tuber yield, and peelings production. All these parameters are reported on both a fresh and dry matter basis. Representative samples of tubers and leaves were brought to the laboratory for analysis. Samples were peeled (only for tubers) and chopped into small pieces, weighed into pre-labelled, pre-weighed dishes, and dried at 105 °C to a constant weight. Dry matter (%) was calculated as "100–Moisture content (%)". The dried samples were subsequently powdered in a mill and used for the analytical determination.

Ground samples were analyzed for crude protein (CP) (AOAC 990.03) using the VARIO MAX CN elemental analyzer and for ash (AOAC 942.05). Ether extract (EE) (AOAC Official Method 920.39) and ash (AOAC Official Method 942.05). Neutral detergent fibre (NDF) levels were determined according to the ANKOM Technology Method 13, Neutral Detergent Fiber in Feeds, that refers to the methodology described by Van Soest, Robertson, and Lewis (1991), while omitting sodium sulphite. Starch analysis was performed only on tuber flour samples (AOAC Official Method 996.11), using the K-TSTA assay kit (Megazyme International, Bray, Ireland).

### *2.4. Statistical Analysis*

Analysis of variance (ANOVA) with a linear model was performed using the "agricolae" package of RStudio 3.3.3. All variables were examined for normality with the Shapiro-Wilk test and for homogeneity of variances with Levene's test before the analyses. When the tests did not confirm the assumptions of ANOVA, the data were log-transformed before the analysis. The means of each treatment were compared using Tukey's test ($p < 0.05$) ("multcomp" package).

## 3. Results

### *3.1. Number of Tubers and Stems per Plant*

The method of planting resulted in significant differences concerning the number of tubers per plant (Table 3; $p < 0.05$): mound (M) produced a 45% higher number of tubers than flat (F), while ridge (R) had intermediate values. Differences in number of tubers were detected also depending on landraces ($p < 0.01$): Ngoymuamba had the highest value with 4 tubers per plant, while Ndunda and Kasonie had the lowest, with only 2.1 and 2.3 tubers per plant, respectively. No interaction between "planting method × landrace" was observed.

The number of stems per plant was not affected by the planting method but was affected by landraces ($p < 0.01$). In particular, Ngoymuamba has a higher number of stems per plant (2.9) than all the other landraces, except for Ndunda. No interaction effect "planting method × landrace" was observed (Table 3).

**Table 3.** Number of cassava tubers per plant and number of stems per plant. *, **, and *** indicate significance at $p \leq 0.05$, 0.01, and 0.001, respectively. Within columns, different letters indicate differences among the means. Mean values ± standard deviations are reported. n.s.: no significance.

| | **Tubers per Plant (no.)** | **Stems per Plant (no.)** |
|---|---|---|
| **Planting method** | | |
| Flat | 2.2 ± 1.0 b | 2.0 ± 0.8 |
| Mound | 3.2 ± 2.2 a | 2.1 ± 1.0 |
| Ridge | 3.1 ± 1.3 ab | 1.8 ± 0.6 |
| **Significance** | * | **n.s.** |
| **Landrace** | | |
| Kakuanga | 2.9 ± 1.1 ab | 1.4 ± 0.6 b |
| Kasongoy | 2.8 ± 1.4 ab | 1.7 ± 0.7 b |
| Kasonie | 2.3 ± 1.3 b | 1.5 ± 0.6 b |
| Ndunda | 2.1 ± 1.2 b | 2.3 ± 1.0 ab |
| Ngoymuamba | 4.0 ± 2.4 a | 2.9 ± 1.8 a |
| **Significance** | ** | ** |
| **Planting method × Landrace** | | |
| **Significance** | **n.s.** | **n.s.** |
| **Field Mean** | **2.8 ± 1.6** | **1.9 ± 1.2** |

### 3.2. Fresh and Dry Tuber Yield

Cassava yields as fresh and dry tubers were affected by both planting methods and landraces (Table 4; $p < 0.01$). Ridge planting yielded 69% more fresh tubers than flat, while mound was between the former and the latter. The pattern of dry yield as affected by planting method was very similar to that of fresh yield: ridge produced 6.9 Mg ha$^{-1}$ of tubers, while flat showed the lowest yield (4.1 Mg ha$^{-1}$), and once again mound was intermediate.

As regard the landrace effect, the fresh tuber yield of Ngoymuamba was higher than that of Ndunda (+182%) and Kasonie (+64%); Kakuanga was similar to the top landrace, and Kasongoy did not differ significantly from all the other landraces (Table 4). Almost the same was observed for dry tuber yield: Ngoymuamba was the most productive landrace (8.6 Mg ha$^{-1}$), followed by Kakuanga, while Ndunda had the lowest dry yield (2.7 Mg ha$^{-1}$).

The interaction "planting method × landrace" was significant ($p < 0.05$) for both fresh and dried tuber yield (Table 4). The general pattern consists in a yield increase in the order ridge > mound > flat, but with two particularities: for Ngoymuamba, this increase is very rapid and reaches a maximum already with the mound; for Kakuanga, instead, there is a decrease from flat to mound and then a plateau.

### 3.3. Fresh and Dry Leaves, Stems, and Peelings

Both fresh and dry leaf yields were not affected by planting methods (Table 5). On the contrary, a significant effect was observed within landraces ($p < 0.01$). Ngoymuamba produced the highest yield in fresh and dry leaves (1.41 Mg ha$^{-1}$ and 0.45 Mg ha$^{-1}$, respectively) compared with all the other landraces. The yield increase ranged from +91% (compared with Kasonie) to +152% (compared with Kakuanga) on a fresh matter basis, and from +88% (Ndunda) to +137% (Kasongoy) on a dry matter basis. The interaction "planting method × landrace" was not significant in both cases.

The fresh stems yield was not affected by planting method but was by landrace ($p < 0.01$). Ngoymuamba had a higher fresh stem yield than Ndunda and Kakuanga, with a 92% and 60% increase, respectively. The other two landraces were in between. The interaction "planting method × landrace" was also significant (Table 6; $p < 0.05$). Three patterns were evident: two landraces had no response to the change in planting methods (Ndunda and Kakuanga), two other landraces (Ngoymuamba and Kasonie) sharply raised yield using the mound method and then decreased or plateaued, and finally *Kasongoy* responded positively only with the ridge method.

**Table 4.** Yield in fresh and dry tubers. *, **, and *** indicate significance at $p \leq 0.05$, 0.01, and 0.001, respectively. Within columns, different letters indicate differences among the means. Mean values ± standard deviations are reported.

| | **Fresh Tubers Yield ($\text{Mg ha}^{-1}$)** | **Dry Tubers Yield ($\text{Mg ha}^{-1}$)** |
|---|---|---|
| **Planting method** | | |
| Flat | 10.2 ± 7.0 b | 4.1 ± 2.8 b |
| Mound | 13.3 ± 7.5 ab | 5.4 ± 3.1 ab |
| Ridge | 17.2 ± 8.5 a | 6.9 ± 3.6 a |
| **Significance** | *** | *** |
| **Landrace** | | |
| Kakuanga | 17.2 ± 8.8 ab | 7.1 ± 3.6 ab |
| Kasongoy | 13.0 ± 7.7 abc | 4.5 ± 2.5 bc |
| Kasonie | 11.7 ± 7.0 bc | 4.6 ± 2.8 bc |
| Ndunda | 6.8 ± 5.1 c | 2.7 ± 2.0 c |
| Ngoymuamba | 19.2 ± 6.8 a | 8.6 ± 3.3 a |
| **Significance** | ** | *** |
| **Planting method × Landrace** | | |
| Flat × Kakuanga | 20.8 ± 8.8 | 8.3 ± 3.5 |
| Mound × Kakuanga | 14.9 ± 10.4 | 6.2 ± 4.3 |
| Ridge × Kakuanga | 15.9 ± 7.9 | 7.1 ± 3.5 |
| Flat × Kasongoy | 8.6 ± 2.2 b | 3.4 ± 0.9 b |
| Mound × Kasongoy | 10.3 ± 8.5 b | 3.2 ± 2.6 b |
| Ridge × Kasongoy | 20.1 ± 5.8 a | 6.8 ± 2.0 a |
| Flat × Kasonie | 6.9 ± 3.5 b | 2.7 ± 1.4 b |
| Mound × Kasonie | 11.0 ± 3.6 ab | 4.4 ± 2.5 ab |
| Ridge × Kasonie | 17.1 ± 7.3 a | 6.8 ± 2.9 a |
| Flat × Ndunda | 6.0 ± 4.0 | 2.4 ± 1.6 |
| Mound × Ndunda | 5.3 ± 3.0 | 2.1 ± 1.2 |
| Ridge × Ndunda | 9.0 ± 4.6 | 3.6 ± 3.0 |
| Flat × Ngoymuamba | 8.6 ± 2.1 b | 4.0 ± 1.0 b |
| Mound × Ngoymuamba | 25.0 ± 6.5 a | 11.2 ± 2.9 a |
| Ridge × Ngoymuamba | 24.0 ± 8.7 a | 10.5 ± 3.8 a |
| **Significance** | ** | ** |
| **Field Mean** | **13.6 ± 8.8** | **5.5 ± 3.7** |

Concerning the peelings, differences between planting methods have been observed ($p < 0.01$) for fresh and dry yield (Table 6). In both cases, ridge (4.6 $\text{Mg ha}^{-1}$ and 1.6 $\text{Mg ha}^{-1}$) and mound (3.8 $\text{Mg ha}^{-1}$ and 1.3 $\text{Mg ha}^{-1}$) had much higher values than flat (2.6 $\text{Mg ha}^{-1}$ and 0.9 $\text{Mg ha}^{-1}$). Landraces also had a significant effect on both fresh and dry peelings yield: Ngoymuamba was the most productive landrace (6.1 and 2.1 $\text{Mg ha}^{-1}$, respectively) and outyielded all the other landraces (which produced between 36 and 64% of the peelings yield of Ngoymuamba). The interaction "planting method × landrace" was significant ($p < 0.01$) for both fresh and dry peelings yield. Out of a general pattern of insensibility of the landraces to planting methods, Ngoymuamba only exhibits a distinctive pattern. When planted on mounted or ridged soil, this landrace produced a higher amount of peelings for both fresh and dry peelings.

### *3.4. Composition of Root Flour and Leaves*

As shown in Table 7, the nutrient content in cassava flour (tapioca) was dominated by starch, which represents 92.3% of dry matter; its content was similar in *Kasonie*, Ngoymuamba, Kakuanga, and Ndunda (91.7%), while it reached the highest value in Kasongoy (94.9%). On the contrary, the values of crude protein (mean 1.11%) and lipids (mean 0.59%) were extremely low, with similar values between the landraces. The fiber content (as NDF) was between 2.6 and 3.3% for all the landraces, as expected.

**Table 5.** Yields in fresh and dry leaves. *, **, and *** indicate significance at $p \leq 0.05$, 0.01, and 0.001, respectively. Within columns, different letters indicate differences among the means. Mean values ± standard deviations are reported. n.s.: no significance.

| | **Fresh Leaves Yield (Mg ha$^{-1}$)** | **Dry Leaves Yield (Mg ha$^{-1}$)** |
|---|---|---|
| **Planting method** | | |
| Flat | 0.72 ± 0.43 | 0.23 ± 0.13 |
| Mound | 0.86 ± 0.55 | 0.28 ± 0.16 |
| Ridge | 0.85 ± 0.38 | 0.27 ± 0.12 |
| **Significance** | **n.s.** | **n.s.** |
| **Landrace** | | |
| Kakuanga | 0.56 ± 0.34 b | 0.21 ± 0.11 b |
| Kasongoy | 0.62 ± 0.38 b | 0.19 ± 0.11 b |
| Kasonie | 0.74 ± 0.54 b | 0.22 ± 0.09 b |
| Ndunda | 0.72 ± 0.44 b | 0.24 ± 0.12 b |
| Ngoymuamba | 1.41 ± 0.38 a | 0.45 ± 0.09 a |
| **Significance** | *** | *** |
| **Planting method × Landrace** | | |
| **Significance** | **n.s.** | **n.s.** |
| **Field Mean** | **0.81 ± 0.45** | **0.26 ± 0.16** |

**Table 6.** Yields in fresh stems, fresh peelings, and dry peelings. *, **, *** indicate significance at $p \leq 0.05$, 0.01, and 0.001, respectively. Within columns, different letters indicate differences among the means. Mean values ± standard deviations are reported.

| | **Fresh Stems Yield (Mg ha$^{-1}$)** | **Fresh Peelings Yield (Mg ha$^{-1}$)** | **Dry Peelings Yield (Mg ha$^{-1}$)** |
|---|---|---|---|
| **Planting method** | | | |
| Flat | 6.9 ± 2.1 b | 2.6 ± 1.1 b | 0.9 ± 0.4 b |
| Mound | 9.3 ± 3.0 a | 3.8 ± 2.7 a | 1.3 ± 0.7 a |
| Ridge | 9.5 ± 2.9 a | 4.6 ± 2.3 a | 1.6 ± 0.6 a |
| **Significance** | * | *** | *** |
| **Landrace** | | | |
| Kakuanga | 7.3 ± 3.1 b | 3.9 ± 1.6 b | 1.3 ± 0.5 b |
| Kasongoy | 8.9 ± 4.1 ab | 3.4 ± 1.6 b | 1.3 ± 0.5 b |
| Kasonie | 8.9 ± 5.1 ab | 2.8 ± 1.4 b | 0.9 ± 0.4 b |
| Ndunda | 6.1 ± 2.9 b | 2.2 ± 1.4 b | 0.9 ± 0.4 b |
| Ngoymuamba | 11.7 ± 5.3 a | 6.1 ± 3.1 a | 2.1 ± 0.6 a |
| **Significance** | ** | *** | *** |
| **Planting method × Landrace** | | | |
| Flat × Kakuanga | 6.8 ± 2.7 | 4.0 ± 1.3 | 1.4 ± 0.4 |
| Mound × Kakuanga | 6.8 ± 2.8 | 3.4 ± 2.0 | 1.1 ± 0.6 |
| Ridge × Kakuanga | 8.2 ± 3.7 | 4.3 ± 1.8 | 1.5 ± 0.6 |
| Flat × Kasongoy | 8.0 ± 2.5 | 2.5 ± 0.5 | 1.0 ± 0.2 |
| Mound × Kasongoy | 6.8 ± 4.5 | 3.0 ± 1.9 | 1.1 ± 0.5 |
| Ridge × Kasongoy | 11.9 ± 3.4 | 4.7 ± 1.4 | 1.7 ± 0.6 |
| Flat × Kasonie | 5.1 ± 1.1 b | 1.7 ± 0.8 | 0.6 ± 0.3 |
| Mound × Kasonie | 11.1 ± 1.3 a | 2.8 ± 1.3 | 0.9 ± 0.4 |
| Ridge × Kasonie | 10.6 ± 3.2 ab | 3.9 ± 1.3 | 1.3 ± 0.4 |
| Flat × Ndunda | 5.8 ± 1.5 | 2.0 ± 1.1 | 0.8 ± 0.4 |
| Mound × Ndunda | 5.3 ± 1.9 | 1.8 ± 0.7 | 0.7 ± 0.2 |
| Ridge × Ndunda | 7.2 ± 2.1 | 2.7 ± 1.3 | 1.1 ± 0.8 |
| Flat × Ngoymuamba | 8.9 ± 1.9 b | 2.7 ± 0.6 b | 0.9 ± 0.2 b |
| Mound × Ngoymuamba | 16.4 ± 3.0 a | 8.3 ± 2.0 a | 2.9 ± 0.7 a |
| Ridge × Ngoymuamba | 9.8 ± 2.0 b | 7.4 ± 2.1 a | 2.5 ± 0.8 a |
| **Significance** | * | ** | ** |
| **Field Mean** | **8.6 ± 4.5** | **3.7 ± 2.3** | **1.3 ± 0.8** |

**Table 7.** Nutritional values of cassava flour for the 5 landraces studied (data on DM basis). *, **, and *** indicate significance at $p \leq 0.05$, 0.01, and 0.001, respectively. Within columns, different letters indicate differences among the means. n.s.: no significance.

| | **Starch (% d.m.)** | **Crude Protein (% d.m.)** | **Fiber (NDF) (% d.m.)** | **Lipids (% d.m.)** | **Ash (% d.m.)** |
|---|---|---|---|---|---|
| **Landrace** | | | | | |
| Kakuanga | 91.9 | 1.28 | 3.32 | 0.48 | 1.71 |
| Kasongoy | 94.9 | 1.09 | 3.00 | 0.85 | 1.14 |
| Kasonie | 91.4 | 1.06 | 2.82 | 0.53 | 1.38 |
| Ndunda | 91.0 | 1.03 | 3.28 | 0.60 | 1.16 |
| Ngoymuamba | 92.4 | 1.11 | 2.61 | 0.48 | 1.65 |
| **Significance** | **n.s.** | **n.s.** | **n.s.** | **n.s.** | **n.s.** |
| **Field Mean** | **92.3** | **1.11** | **3.01** | **0.59** | **1.41** |

In terms of the nutritional content of cassava leaves, the data in Table 8 show that all cultivars had similar compositions of crude protein (mean 28.3%). The ash content (mean 6.4%) showed differences between Kasongoy vs. Kasonie landraces (5.96% vs. 7.04% respectively; $p < 0.05$). The lipid content (mean 2.44%) showed a lower value in Ndunda (2.26%) and a higher value in Kakuanga (2.67%), while for the fiber content (NDF), Ndunda had a slightly higher content (53.0%) compared to other landraces.

**Table 8.** Nutritional values of the cassava leaves for the 5 landraces studied (data on DM basis). *, **, and *** indicate significance at $p \leq 0.05$, 0.01, and 0.001, respectively. Within columns, different letters indicate differences among the means. n.s.: no significance.

| | **Crude Protein (% d.m.)** | **Fiber (NDF) (% d.m.)** | **Lipids (% d.m.)** | **Ash (% d.m.)** |
|---|---|---|---|---|
| **Landrace** | | | | |
| Kakuanga | 29.0 | 46.1 c | 2.67 a | 6.33 ab |
| Kasongoy | 28.9 | 46.8 c | 2.44 b | 5.96 b |
| Kasonie | 28.3 | 49.7 b | 2.38 bc | 7.04 a |
| Ndunda | 27.2 | 53.0 a | 2.26 c | 6.19 ab |
| Ngoymuamba | 28.3 | 45.8 c | 2.45 b | 6.43 ab |
| **Significance** | **n.s.** | *** | *** | * |
| **Field Mean** | **28.3** | **48.3** | **2.44** | **6.39** |

No effect of the cultivation method was observed on the composition of root flour and leaves.

## 4. Discussion

### *4.1. Root Yield*

Crop genetic resources and appropriate agricultural practices constitute two main drivers for increasing smallholder crop yields in developing countries. As stated in the 2030 Agenda for Sustainable Development, one of the seventeen goals (SDG 2: Zero Hunger) is fighting hunger, ensuring access to safe, nutritious, and sufficient food for all people all year round, and eradicating all forms of malnutrition [41,42]. Selecting suitable technologies for the socio-cultural and economic traits area by area is essential to ensuring the success of any rural development attempt, which has to be based on imitation, or "spontaneous budding", starting from small experimental demonstrations [43,44].

Several reports suggested that a low-input approach is best appropriate for improving staple food production in Kabinda district (Lomami Province, DR of the Congo), where the population bases its diet on cassava as the main carbohydrate source [45]. This fact can increase the risk of malnutrition if the diet is not adequately complemented with proteins and other nutrients. This unbalanced nutritional value of the cassava could be improved by fortifying the affordable staple carbohydrate [46], mixing it with pulse flour [43], and improving the health of the vulnerable rural population. As an area of extreme poverty, the possibility of increasing agro-technological inputs among smallholder families is very remote. So, we decided to set up the improvement of cassava production—which is well adapted in that area and does not need advanced technologies [47]—through the study of the best planting methods and local landraces easily available. Both experimental factors are low capital-intensive, do not require a sudden change in farmers' working habits, and therefore are easily accepted [47]. Finally, having set up the trial together with students at the local university and in an area where smallholder farmers could easily see the new techniques, it was aimed at ensuring the widest involvement and dissemination of the results.

The three land preparation techniques for planting cassava cuttings considered in the present field study (flat, mound, and ridge) are characterized by an increasing demand for labor [48]. On sandy soils like that on which this trial was conducted, farmers merely slash weeds and plant cassava cuttings in flat soil. When traditional polyculture is replaced by monoculture for cassava production, soil erosion can become a main concern with flat planting. For that reason, other methods, such as mounding and ridging, were recommended because of their benefits for enhanced yield, better water infiltration, reduced soil erosion, easier weeding, and fertilizers distribution [49].

Our results corroborated the hypothesis that mound and ridge methods may be considered as more efficient planting techniques than flat planting techniques for cassava cultivation. Both planting methods indeed increased root parameters (i.e., numbers of tubers, total root yield, and peelings), and thus enhanced below-ground cassava yield. However, this was not the case for leaf and stem yield. Such a preferential increasing effect of mound and ridge methods on below-ground cassava traits can be explained by the fact that soil preparation in the flat method is less labor-intensive and does not promote root development above all in hard or shallow soils. These outcomes agree with findings by Ennin et al. [50] which found that cassava planted on ridges resulted in highest root yields compared to flat. Conversely, others reported no effect of land preparation on root yield in a study conducted under a highly leached clay-loam soil in the Kimpese area of the DRC [51]. To our understanding, the reason of this different behavior (absence/presence of responses) of cassava roots with changing the planting method lies in the fertility status of the soil. Ennin et al. [50] conducted their field experiment under relatively high soil fertility (dark brown loam soils, in a forest-savanna transition in Ghana), which is consistent with our soil condition. This favorable growing environment, together with increased soil porosity due to tillage, probably promoted a positive effect on cassava root development. Ezumah and Okigbo [51] instead reported results from trials under low to very low soil fertility conditions (highly leached, low-fertility, clay-loam soil in RDC), which probably limited the positive effect of ridges and mounds compared with the flat method. This is also corroborated by an average cassava production of only 6.2 Mg ha$^{-1}$ of fresh tubers.

A significant contribution in enhancing cassava production with the ridge and mound techniques in our experiment was due to the number of tubers per plant, which were 45% higher than with the flat method. The same was indeed observed by Ennin et al. [50], who reported a 12% increase in productivity with ridges compared with the flat method in a forest-savanna transition agroecosystem. No effects of the planting method were observed on tuber shape (data not shown), contrary to Ennin et al. [50], who reported that tubers harvested in mound soil were slender and cylindrically shaped, while those harvested in ridge soil were oblong.

In the present study, five local landraces of cassava (Ndunda, Kasonie, Kasongoy, Ngoymuamba, and Kakuanga) were demonstrated to affect all the measured yield components (i.e., tubers, leaves, and stems). Ngoymuamba was shown to be the more performant genotype; on the contrary, Ndunda had the worst values for all the measured yield parameters. For instance, fresh and dry tubers with Ngoymuamba were enhanced by almost three times as compared with those with Ndunda. The yield obtained with Ndunda is almost similar to the average productivity values under traditional farming practices, ranging between 5 and 8 Mg ha$^{-1}$ of fresh tubers [52]. These results demonstrate the importance of choosing the best varieties for improving cassava yield within each specific environment to face the zero-hunger challenge [42]. This may significantly increase the productivity of crops per unit of land and labor, thus keeping the increase of cultivated land and related environmental concerns under control [44,48,53,54].

Overall, the yield potential observed with the five landraces compared in the present study was in line with previous studies under favorable conditions [17,55–57]. El-Sharkawy [17] reported that even without chemical fertilizers the yield goals should range between 0.9 and 1.7 Mg ha$^{-1}$ for fresh leaves, between 2.0 and 3.1 Mg ha$^{-1}$ for fresh stems, and between 13.5 and 24.2 Mg ha$^{-1}$ for fresh tubers. If chemical fertilizers are available, the yield components may increase to 1.5–2.1 Mg ha$^{-1}$ for fresh leaves, 3.6–6.2 Mg ha$^{-1}$ for fresh stems, and 19.0–30.2 Mg ha$^{-1}$ for fresh tubers. The same range (9.3–27.8 Mg ha$^{-1}$ of fresh tubers) was reported by Bassey [58] in Nigeria for four locations and nine elite genotypes. Other authors reported that yield of cassava fresh tubers may be further enhanced by adopting improved cropping practices (e.g., 46.9 Mg ha$^{-1}$ in Zango et al. [59]), introducing best clones (e.g., 30.1 Mg ha$^{-1}$ in Toro [60]), and/or selecting genotypes for each specific environment (e.g., 35.3 Mg ha$^{-1}$ in Tadesse and Michael [61]). Yet, all these aspects could not be considered as low-capital-intensive inputs and involve a sudden change in farmers' working habits; therefore, they are not accepted everywhere.

### *4.2. Leaves, Stems, and Peelings*

Data on the production of cassava leaves and stems in response to planting methods and landraces are lacking in the literature [25], with leaves being picked up as vegetables continuously during the cropping season (and not only at the end as in our case) and stems not used at all for nutritional purposes but only as cutting sticks. As discussed before, most studies indeed concern the effect on root yield. However, in the present study, measuring leaf biomass at the end of the crop cycle was intended to assess (i) the morpho-physiological habitus of plants and (ii) the potential leaf yields, to be considered as a by-product (recycling organic matter in soil) as well as a rough idea of material that can be used from human and animal nutrition at the end of a tubers-driven cultivation. In a similar way, the unrevealing stem response here was aimed to measure (i) the potential production of cuttings for propagation and (ii) the biomass residue to be used as organic matter for soil improvement, mulching, or domestic fuel [62].

The lack of response to planting method suggests that this factor plays a minor role in affecting leaves and stems at the end of the crop cycle. In any case, the values obtained in this experiment are consistent with the range indicated by Hauser et al. [25], of 209 to 435 kg DM ha$^{-1}$ among varieties.

Concerning the effect of landraces, we observed a net productivity advantage with Ngoymuamba in fresh and dry leaf yield. Such a 2–3-fold higher leaf yield than with all the other landraces can be an important by-product for use as feed or food, both as fresh material (vegetables) or as flour after drying and milling [30] or, more pertinently, as mulching material or organic matter to recycle in soil.

In addition, for stems, the only difference was due to landraces, with Ngoymuamba being the top-yielding one. However, a significant "planting method × landrace" interaction in our study showed that Ngoymuamba increases its stem yield by adopting the mound method, like Kasonie, but then sharply reduces yield with the ridge method. This was the first time that Ngoymuamba showed a worsening in stem yield passing from the mound to ridge method, although the stem yield could not be considered the main aspect driving the choice of landrace to be cultivated.

Finally, results on peeling yield showed higher values where tuber yield was higher and vice versa. Both for fresh and dry yield, the most yielding treatments were mound and ridge as methods of planting and Ngoymuamba as landraces. In addition, the significant interaction between the experimental factors showed that Ngoymuamba responded very positively to the improved planting methods compared to the flat. This confirms the above observations for tuber yield and corroborates the hypothesis that combining mound or ridge methods with the

Ngoymuamba landrace could be considered a winning strategy to maximize the productive performance of cassava under the soil-climate conditions of the trial.

### *4.3. Chemical and Nutritional Properties of the Flour and Leaves*

In tapioca, the starch content was similar among the five landraces, representing the main component of the flour. The range shown in this trial (91.0–94.9%) agrees with the literature [27,46,47,57,63,64] and confirms that, among the starchy staples, cassava provides a very good carbohydrate production even in a smallholder farmer context, resulting in the cheapest source of calories for both human nutrition and animal feeding [65].

At least in comparison with the data of Vernier et al. [47], our data on proteins show slightly higher values, but they are still extremely low from a nutritional point of view. Fiber content (evaluated as neutral detergent fiber, NDF) is low, and lipids were similar among landraces and comparable to those found in the literature [63,64].

Concerning leaves, their crude protein content ranged from 27 to 29% on a dry matter basis, confirming the well-known good protein content in cassava leaves and being very near to other indigenous tree leaves consumed in the RD Congo, such as *Moringa oleifera* (26 to 27%) [45,66,67], but less than some leaf vegetables like amaranth (32 to 38%) [45,68] and sweet potato (24 to 35%) [69–71]. All values of crude protein of cassava leaves are similar between landraces and in agreement with those found in the literature [64,72]. Lipids and ashes are also typical of vegetative plant materials. However, of major nutritional interest are only protein (a very good supplier) and fiber, which is quite high in leaves. We suggest that the differences among landraces are not large enough to affect the nutrient supply depending on whether one variety rather than another is chosen for the human diet. However, the protein and fiber content in leaves is important to make up for the poor content of these nutrients in roots. Therefore, this data confirms what is commonly said in the Congo: roots and leaves of manioca can ensure an almost complete diet [34].

Considering the easy increase in yield obtainable with low-input agricultural improvement, the very high content of carbohydrates in the roots, and the good content of protein and other nutrients in the leaves, cassava as a whole confirms itself to be a powerful tool for achieving the second millennium goal (SDG 2: Zero Hunger) [42], even if it must be complemented with other foods for a proper diet. However, even if the Congolese people consider it a complete food, it remains a quite unbalanced food that can cause malnutrition and other disorders, particularly in children. Nevertheless, the FAO suggests that only a small amount of animal foods can correct the problem (also for micronutrients) [73].

## 5. Conclusions

The planting methods had an important effect on cassava yield; in particular, the ridge planting system gave the best results, followed by the mound method and, as the worst system, the flat method, the latter of which is commonly used by the Congolese. The tested landraces showed production differences, with Ngoymuamba giving the highest yield both in roots and leaves, while Ndunda was the worst. In terms of nutritional traits, the five landraces evaluated in this trial did not show substantial differences between one another and when compared with previous studies in the literature. From a nutritional point of view, the good protein content of the leaves suggests that their consumption could represent an interesting—even if not sufficient—intake of protein and fiber capable of ameliorating the malnutrition of the Congolese people, almost exclusively based on the consumption of dishes based on cassava flour.

However, this study was conducted only for one year. Although weather conditions during this period could be considered typical, future studies are needed to verify that results remain consistent in wetter and/or drier years and in the middle and long term. Further studies are needed to quantify the leaves that can be harvested during the vegetative phase of cassava, without causing a reduction in root yield.

Finally, we believe that in rural areas of developing countries, where the smallholder family farming is the very dominant model for agricultural production and nutrition security, the goal of "Zero Hunger" and improvement of quality of the diet quality can be achieved in a relatively short time by adopting a few agricultural and knowledge inputs that are readily available and easily incorporated into the culture of the local population. In this context, the selection, through a participatory approach, of the most performing landraces in the various pedo-climatic conditions represents both a powerful and cheap tool of agricultural promotion and a way of valorizing local biodiversity.

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