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Influence of rhizome size on the vegetative cycle of ginger (*Zingiber officinale* Roscoe) grown in Daloa, CÔte d'Ivoire

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Abstract

In Côte d'Ivoire, ginger production is limited to small areas. Moreover, the production system does not follow any technical itinerary. The aim of this study is to assess the influence of rhizome size on vegetative cycle of ginger. It is being conducted with a view to developing an appropriate technical itinerary and ideal number of buds on rhizome for growers. Ginger collected in the Zoukougbeu department (Côte d'Ivoire) was used for this study. Four rhizome sizes, namely R1 (rhizome with one bud), R2 (rhizome with two buds), R3 (rhizome with three buds) and R4 (rhizome with four buds) were sown in a complete randomised block design with three replications. Statistical analysis showed that the number of buds on the rhizome had no effect on germination time. However, rhizomes of size R3 and R4 showed a better profile of the germination rate. Development was weakly influenced by the number of buds on the rhizome. In terms of agro-morphological characteristics, rhizome sizes R3 and R4 gave the best growth parameters. Ginger can be regenerated with three-bud rhizomes (rhizome sizes R3). Ginger growers are faced with the problem of using more than half their production as seed for the next crop. This study, the first one in Côte d'Ivoire, provides a solution (using three-bud rhizomes) and enables growers to reduce the cost of crop's establishment, thereby increasing their income.

Keywords: Buds; Ginger; Rhizome size; Zingiberaceae; Germination; Growth

1. Introduction

Ginger (*Zingiber Officinale* Roscoe) is an annual herbaceous plant. It is one of the most important spices in the world. The plant is cultivated from its fleshy, elongated rhizome with several tuberous branches [1]. Ginger originates from South-East Asia and is represented by a large family comprising 47 genera and 1,400 species [1 ; 2]. It grows well in tropical or subtropical climates. The temperature needs to be relatively high, at least 21°C for most of the year, to enable the species to grow optimally [3]. This species is of major economic importance throughout the world [4]. It generates substantial income for producers. In 2023, global ginger production was estimated at over 103,0978 million tonnes [5]. The main producing countries are India (275,000 tonnes) and China (259,719 tonnes). In Africa, Nigeria (110,000 tonnes) is the biggest producer, followed by Cameroon (79,273 tonnes). Côte d'Ivoire's production was estimated at 7,085 tonnes [6]. Estimates of production levels and the organisation of the sector are unreliable, rare and outdated, revealing the low level of production in Côte d'Ivoire. Ginger is produced mainly in the Bongouanou, Divo, Gagnoa, Soubré, Tiassalé and Koun-Fao areas [5].

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Recent pharmacological studies on *Zingiber officinale* have revealed a broad spectrum of biological activities. Ginger inhibits colon cancer cell proliferation [7]. This species contains numerous compounds including gingerols, gingerdiols and gingerdiones [3]. These compounds have a high antioxidant activity [8; 9].

Ginger is used as a spice in Asian (Japanese and Indian) and African cuisine. Ginger is also used in baking to flavour biscuits and cakes [10]. In Africa, the fresh rhizome is generally used to make a drink called Gnamakoudji in Côte d'Ivoire [5]. It is used as an aphrodisiac. Ginger is used to flavour tea in Swahili growing areas [11]. Despite its nutritional and therapeutic virtues, and despite the fact that it is very much involved in the socio-economic activities of the people of Côte d'Ivoire, ginger cultivation is faced with a number of factors threatening the sector. Ginger is regarded as a marginal crop, and its roaming nature is not conducive to its development. The area under cultivation and yields remain average. What's more, growers are not trained and educated in good ginger farming practices. For example, they use raw plant material. Ginger spreads from rhizomes [12]. Ginger growers are faced with the problem of using a large part of their harvest as seeding material for future ginger planting, around 2,000 kg per hectare [13]. It is with a view to resolving this problem that the present work, which is part of a programme aimed at identifying high-producer varieties and improved ginger production techniques, was initiated. Its aim is to develop a technical itinerary to improve ginger production. To achieve this goal, specific objectives are assigned to the present study. These are (i) to evaluate the effect of the number of rhizome buds on ginger germination, (ii) to study the effect of the number of rhizome buds on ginger development.

2. Material and methods

2.1. Study area

The study was set up during the first rainy season at the Jean Lorougnon Guédé University experimental farm [14]. The University is located to the north-east of Daloa, at latitude 6° 52‘ 38 north and longitude 6° 27’ 0 west. Daloa belongs to the Haut-Sassandra region in central western Côte d'Ivoire [15]. The Haut-Sassandra region is dominated by vegetation consisting largely of dense forest. Soil studies carried out in the area reveal that the soils are generally ferralitic with moderate leaching [16. They have good agricultural potential for all types of crop [17]. The topography is relatively flat and unvaried, dominated by plateaux at altitudes of 200 to 400 m [18]. The seasons are divided into two rainy seasons, the first of which, from March to July, is irregular and the second of which varies from July to September. Annual temperatures range from 24.65°C to 27.75°C [19]. June represents the peak of the long rainy season and September the peak of the short rainy season.

2.2. Plant material

The plant material used in this study consisted of plants regenerated from ginger rhizomes (Figure 1). The rhizomes were collected from farmers in the Haut Sassandra administrative region, more specifically in the locality of Zokougbeu.

Figure 1 Ginger rhizomes

2.3. Methods

2.3.1. Preparing the plot

The installation began with land clearing. This was done manually using a daba and machete over an area of 260 m2 (length 20 m and width 13 m). The dried grasses were collected and burnt. The soil was loosened up, then stones and plant debris were removed with a daba to aerate, moisten and drain the soil. A daba was used to place the ridges (Figure 2).

2.3.2. Preparation of rhizomes

Figure 2 Sowing ridges

The rhizomes were first cleaned of clumps of soil and other impurities. The rhizomes were then cut into pieces using a knife, according to the desired rhizome dimensions. Pieces of rhizomes with a different number of buds were cut. These were rhizomes with one bud, two buds, three buds and four buds (Figure 3). These pieces of rhizome constitute the seedling used for the trials.

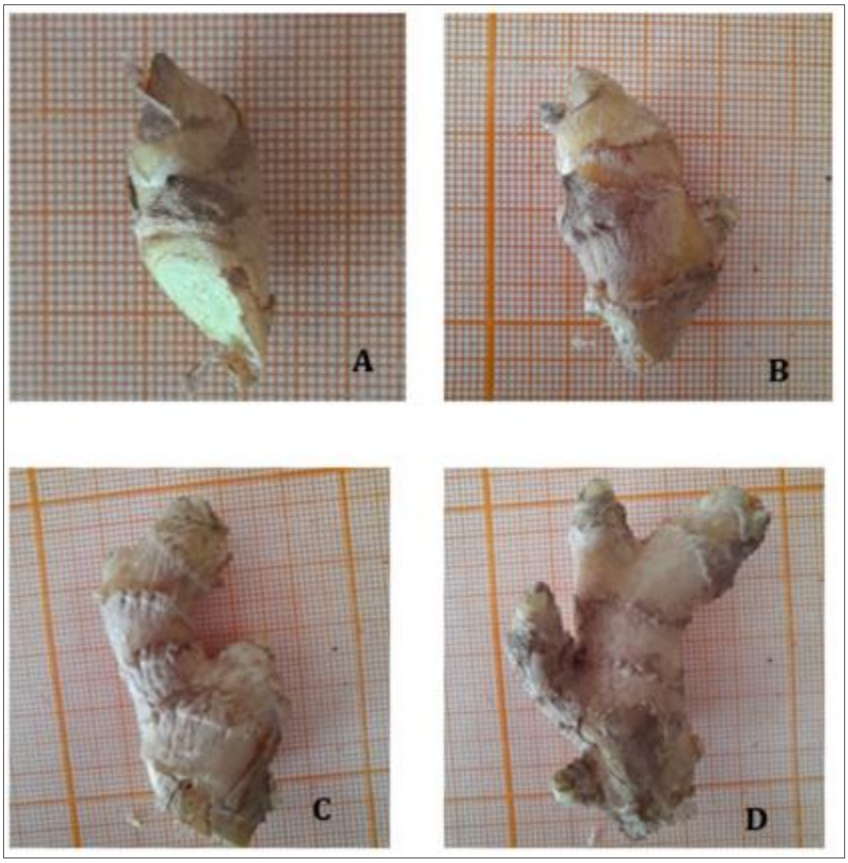

Figure 3 Rhizomes of different sizes (A) Rhizome with one bud; (B) Rhizome with two buds; (C) Rhizome with three buds; (D) Rhizome with four buds

2.3.3. Sowing rhizomes

Ridges measuring 2 m x 0.8 m were prepared and amended with 5 kg of chicken droppings. Each ridge consisted of two rows assigned to the same type of rhizome. Each line was made up of five stakes. In each poquet, a piece of rhizome was sown to a depth of 9 cm. The spacing between seedpots on the rows was 30 cm, and between rows 20 cm. These spacings were defined using a tape measure. Each ridge consists of 10 ginger rhizomes with the same number of buds on the rhizome. The seed is sown so that the buds are on the upper side of the seed holes. After sowing, straw was placed on the ridges to maintain humidity.

2.3.4. Experimental set-up

A completely randomised set-up with three blocks was designed to study the influence of the number of rhizome buds (Figure 4.). The distance between the blocks is 1 m. Each block consists of three rows of ridges. This makes a total of 12 ridges per block, each 2 m long and 0.8 m wide. Each ridge has 10 sowing points spaced 0.3 m apart along the row and 0.2 m between rows. The distance between ridges is 0.5 m. One ridge in a row represents one type of rhizome. The rhizomes are divided into four levels, i.e. rhizomes with one bud, rhizomes with two buds, rhizomes with three buds and rhizomes with four buds.

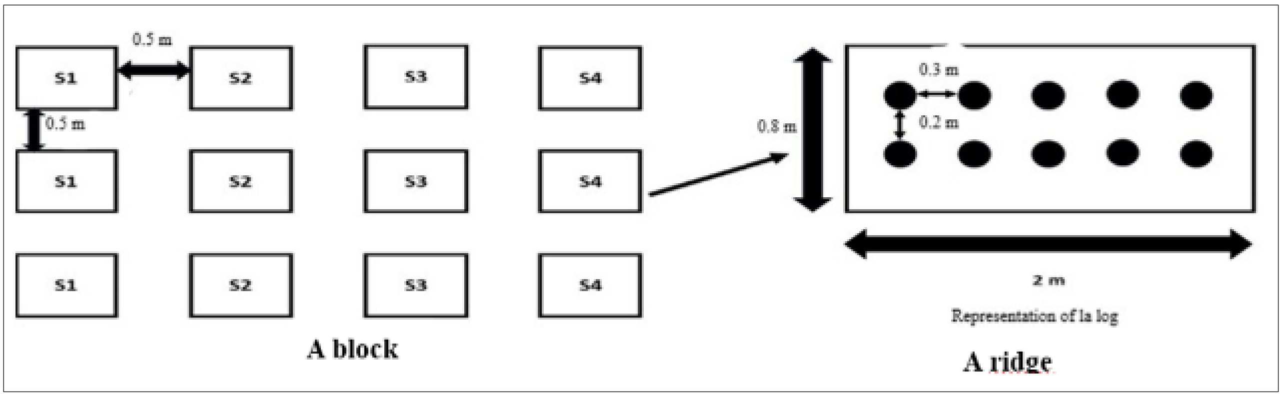

Figure 4 Experimental set-up

2.3.5. Plot maintenance and plant treatment

The mulch was gradually removed when the ginger stalks appeared. Apart from mulching, manual weeding was carried out using a hoe, two times a month. This was to avoid competition between weeds and ginger plants. A traditional drip irrigation system was installed on each ridge to maintain humidity on the ridges, given the scarcity of rainfall.

2.3.6. Data collection

Regular daily monitoring was carried out from emergence onwards in order to record data relating to germination and the agro-morphological characterisation of the ginger plants. Five morphological characteristics were selected for morphological evaluation. These were leaf length, leaf width, number of leaves, diameter at stem base and plant height. The codes for the various characters and their measurement methods are summarised in Table 1.

Table 1 Characteristics selected for morphological assessment of *Z. officinale* plants

Mesured charateristics	Codes	Sample measurement methods	Sample size
Leaf length	LI	Leaf length is the distance between the point of insertion of the leaf on the stem and the upper tip of the leaf. It is measured three months after sowing using a tape measure. It corresponds to the average of thirty measurements.	30
Leaf width	Lw	The width of the leaf is the distance between the lateral edges of the leaf. It is measured three months after sowing using a tape measure. It corresponds to the average of thirty measurements.	30
Height of the plant	Hp	Measured three months after sowing, it corresponds to the length of the main stem. It is the distance between the collar and the top of the last leaf. It is the average of thirty measurements.	30

Diameter at stem base		The diameter at stem base is the distance between the lateral edges of the stem base. It is measured three months after sowing using a calliper. It corresponds to the average of thirty measurements.	30
Total number of leaves		The number of leaves on the main stem. This is counted three months after sowing. It corresponds to the average of thirty counts.	30

The influence of rhizome size on germination was evaluated using the germination time and the germination percentage. Mean germination time is the average time from germination of the first rhizome to germination of the last rhizome during the trial period. The germination percentage is the ratio of the total number of rhizomes germinated to the number of rhizomes sown. The formula used is as follows (1).

$$Germination\ percentage(\%) = \frac{total\ number\ of\ germinated\ rhizomes}{total\ number\ of\ \text{rhizomes}\ sown} \times 100\ (1)$$

2.3.7. Statistical analyses

One-factor analysis of variance (ANOVA 1) was carried out for each of the five agromorphological traits tested. This analysis was used to determine whether there was a morphological difference between plants from each type of rhizome. When a significant difference was observed ($P < 0.05$) at the $\alpha = 0.05$ threshold, Tukey's multiple rank test at the 5% threshold was adopted to separate the means. All statistical tests were performed using Minitab for Windows version 17.

3. Results

3.1. Effect of rhizome size on germination

The rhizome germination responses expressed by the four rhizome types were represented by the germination delay. These results are shown in Table 2. Analysis of variance revealed no significant difference in germination time between the four rhizome types (P= 0.356). Whatever the type of rhizome used for sowing, the germination time was statically identical.

Table 2 Effect of rhizome size on germination

Rhizome type	Germination time mean (days)
R1	28.878 ± 6.32
R2	28.382 ± 6.79
R3	27.615 ± 7.09
R4	26.721 ± 7.30
F of Fisher-Snedecor	1.09
Probability P	0.356

R1: rhizome with one bud, R2: rhizome with two buds, R3: rhizome with three buds, R4: rhizome with four buds.

3.2. Influence of the number of rhizome buds on the germination percentage

Figure 5 shows the germination rate of rhizomes as a function of the number of buds on rhizome. Analysis of figure 05 shows that the highest germination rate is observed with rhizomes R3 and R4 (64.17%), followed by rhizomes R2 with a rate of (56.67), while rhizomes R1 is associated with the lowest germination rate (44.17%). Rhizomes R3 and R4 gave identical germination percentages. In general, the germination rate evolved as a function of the number of buds on the rhizome.

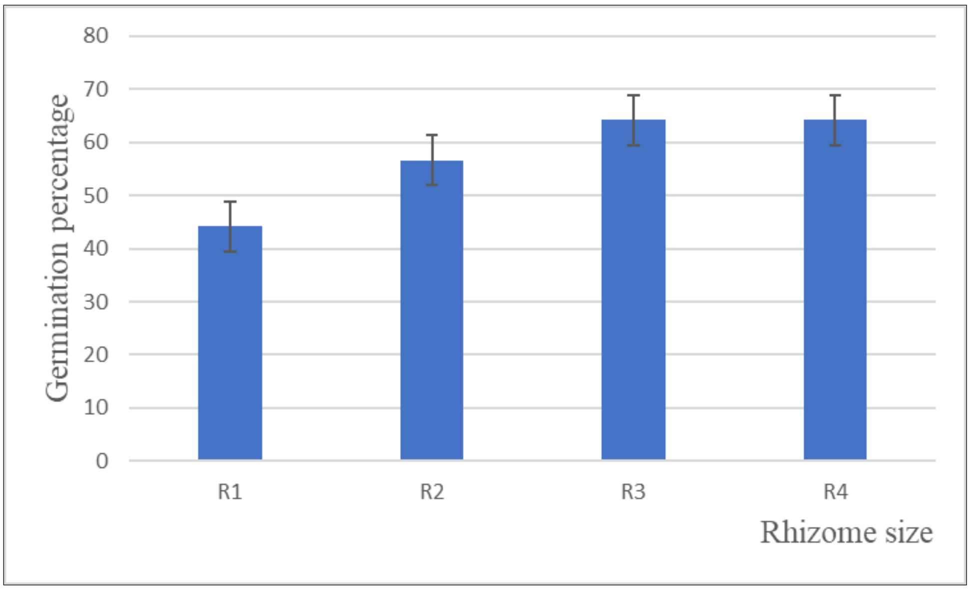

Figure 5 Germination percentage of rhizomes as a function of rhizome size

3.3. Effect of rhizome size on leaf length

Table 3 shows the mean of leaf length produced by the ginger rhizome types. Analysis of variance showed that there was a highly significant difference in leaf length between rhizomes type (P = 0.002). The highest mean of leaf length (10.050 ± 4.971 cm) was obtained in plants from R4 rhizomes. On the other hand, the lowest mean of leaf lengths (7.831 ± 3.729 cm) and (8.566 ± 4.572 cm) were obtained in plants from rhizomes R1 and R2 respectively. Plants from rhizome R3 gave a mean intermediate of leaf length (9.360 ± 5.024 cm) close to that of rhizome R4.

Table 3 Length of the leaves in relation to rhizomes size

Rhizome type	Mean of leaf length (cm)
R1	7.831 ± 3.729^{b}
R2	8.566 ± 4.572^{b}
R3	9.360 ± 5.024^{ab}
R4	10.050 ± 4.971^{a}
F of Fisher-Snedecor	5.14
Probability P	0.002

Means in a column followed by the same letter are not significantly different at the 5% threshold (Tukey multiple comparison test). R1: rhizome with one bud, R2: rhizome with two buds, R3: rhizome with three buds, R4: rhizome with four buds.

3.4. Effect of rhizome size on leaf width

The mean of leaf width measured is shown in Table 4. Analysis of variance showed no significant difference in leaf width between rhizome types.

Table 4 Leaves width in relation to rhizomes size

Rhizome type	Mean of leaf width (cm)
R1	1.575 ± 0.484
R2	1.667 ± 0.512
R3	1.731 ± 0.613
R4	1.756 ± 0.597
F of Fisher-Snedecor	2.22
Probability P	0.084

R1: rhizome with one bud, R2: rhizome with two buds, R3: rhizome with three buds, R4: rhizome with four buds.

3.5. Effect of rhizome size on leaves number

The mean number of leaves per plant as function of the rhizome size is summarised in table 5. Analysis of variance showed a significant difference in the number of leaves produced between the different rhizomes size (P = 0.010). The highest mean number of leaves (12.476 ± 3.792) was obtained with the rhizomes size R4, followed by the R2 and R3 rhizomes size, which obtained statistically identical values. The lowest mean number of leaves (9.962 ± 2.749) was recorded for R1 rhizomes size.

Table 5 Number of leaves as function of rhizome size

Rhizome type	Mean of leaves number
R1	9.962 ±2.749^{a}
R2	11.829 ± 2.810^{ab}
R3	11.469 ± 2.987^{ab}
R4	12.476±3.792 ^{b}
F of Fisher-Snedecor	3.90
Probability P	0.010

Means in a column followed by the same letter are not significantly different at the 5% threshold (Tukey multiple comparison test). R1: rhizome with one bud, R2: rhizome with two buds, R3: rhizome with three buds, R4: rhizome with four buds.

3.6. Effect of rhizome size on plant height

Table 6 shows the mean height of regenerated ginger plants as function of rhizome size. Analysis of variance showed that there was a highly significant difference in plant height between rhizomes size (P = 0.010). The greatest mean height was obtained with R4 rhizomes size (17.256 ± 10.205 cm). This was followed by the heights of rhizomes size R2 and R3, which had statistically identical means. Plants from R1 rhizomes size obtained the lowest height (9.253 ± 4.737 cm).

Table 6 Plant height as function of rhizome size

Rhizome type	Mean of plant height (cm)
R1	9.253 ± 4.737[a]
R2	12.874 ± 7.543[b]
R3	14.912 ± 7.766[b]
R4	17.256 ± 10.205[c]
F of Fisher-Snedecor	19.55
Probability P	< 0.001

Means in a column followed by the same letter are not significantly different at the 5% threshold (Tukey multiple comparison test). R1: rhizome with one bud, R2: rhizome with two buds, R3: rhizome with three buds, R4: rhizome with four buds.

3.7. Effect of rhizome size on plant diameter at stem base

Analysis of variance showed a very highly significant difference in plant diameter at stem base between rhizomes size (Table 7). The rhizome size had a significant impact on plant diameter at stem base growth. The largest diameter at stem base was obtained with rhizome R4 (4.231 ± 1.787 cm). The smallest diameter at stem base (2.970 ± 1.239 cm) was observed with the R1 rhizome size.

Table 7 Plant diameter at stem base as function of rhizome size

Rhizome type	Mean of plant diameter at stem base (cm)
R1	0.297 ± 0.123[a]
R2	0.346 ± 0.155[ab]
R3	0.390 ± 0.142[bc]
R4	0.423 ± 0.178[c]
F of Fisher-Snedecor	14.44
Probability P	< 0.001

Means in a column followed by the same letter are not significantly different at the 5% threshold (Tukey multiple comparison test). R1: rhizome with one bud, R2: rhizome with two buds, R3: rhizome with three buds, R4: rhizome with four buds

4. Discussion

The present study showed that the rate and time of germination of *Zingiber officinale* rhizomes were not significantly influenced by the number of rhizome buds. This could be explained by the fact that imbibition of the embryo, which is crucial for germination, takes place mainly via the bud and not across the entire surface of the rhizome, which would be related to size. On the other hand, the fraction of rhizome reserves consumed for germination is a varietal constant and does not seem to depend on rhizome size. In fact, germination begins with the water absorption phase, which triggers the setting up and functioning of the enzymatic systems. Swelling of the embryonic tissues causes the bud to burst. The emergence of the radicle marks the end of germination. Bruckler [20] showed that germination proper is preceded by an imbibition phase which depends solely on the water status of the rhizome and the seedbed. Our results are in agreement with those obtained by Muchena and Trogan [21] in an intra-genotypic study, who did not observe variations in germination rate as a function of rhizome size under normal water conditions. The same results were reported by Graven and Carter [22]. These authors noted that the germination controls revealed no significant difference linked to size (number of rhizome buds). Despite the size of the R1 rhizome (rhizome with one bud), no difference was observed between its germination time and that of other rhizome sizes. This result could be explained by the environmental conditions during the field trials. The experiments ran from a dry season to a rainy season (March-June). Because of the scarcity of rainfall, the plots were watered regularly every two days. In a stressful situation, small rhizomes with a bud easily reach their imbibition threshold and trigger germination. Similar results were obtained by Muchena and Trogan [21]. These authors looked at the effects of seed size on germination under water stress, simulated in the laboratory by adding a mannitol solution of given concentration.

Concerning germination percentages, they were high in rhizomes size R3 (rhizome with three buds) and size R4 (rhizome with four buds) compared with the other rhizomes. Indeed, this same observation was made by Stougaard and Xue [23] during their studies on wheat. These studies have shown that seed size has a profound effect on yield and the competitive ability of the crop. In general, there is a positive correlation between seed size and seed nutrient reserve [24]. This means that large seeds contain sufficient nutrients for the future plant before it becomes autonomous through photosynthesis. Thus, the total dependence of the seedlings on the nutrient stock contained in the seeds could explain this result. Similar results were recorded in the present study on *Zingiber officinale* Roscoe. This could be explained by the large amount of reserves contained in the rhizome. Furthermore, this result could be linked to the environmental conditions that prevailed in the field during the field trials. Given the scarcity of rainfall, this would have resulted in a shortage of water for the plants. Despite daily watering, the water supply certainly did not meet the plants' needs. With the high temperatures during the trials, the water supplied to the plants was probably evaporated before it reached the rhizomes. Under these conditions, the lack of water may justify these results. According to Lima *et al* [25], under conditions of water stress, large seeds, such as R4 rhizomes, with their large surface area, can maximise the little water available in the soil. The phytohormones contained in the seeds could also lead to such a result. Indeed, Sun *et al* [26], working on Jatropha seeds, have shown that large seeds contain a significant amount of auxins compared with other phytohormones. In parallel, Miransari and Smith [27] reported that seed germination and seedling development are strongly controlled by auxin and gibberellin.

The significant difference in the agromorphological parameters studied, observed between the different types of rhizomes after sowing, could be explained by the presence of nutritional reserves, making it possible to ensure the initial nutrient requirements for the growth and development of young seedlings. In fact, seedlings from rhizome size R4 (rhizome with four buds) through the buds mobilise a much greater quantity of reserves in a given time and therefore grow faster than those from rhizomes size R1 and R2. However, the speed of development remains unchanged. The date of transition to autotrophy depends closely on the fraction of reserves mobilised and the physiological stage reached. Seedlings from large rhizomes start their photosynthetic period with a higher chlorophyll organ weight. This could have important consequences for the development of the exponential growth phase, whose initial state is thus favourably modified. According to Cooper and Macdonald [28] seedling growth is linearly related to the quantity of reserves consumed. Pommel [29] found this to be the case for several seed sizes. The greater growth of seedlings from large seeds compared with those from small seeds can therefore be explained by a greater consumption of reserves in absolute terms per unit of time. The results observed in the present study are similar to those of Abdul-Hamid [30], who showed that plant development is linked to size and nutrients. In the case of small plants, the reserves still available at the time of the transition to autotrophy are smaller. This constitutes a safety margin for seedlings from small seeds, which are more vulnerable to environmental conditions such as structural obstacles, dark periods and, above all, temperature. Derieux *et al* [31] have shown that the start of photosynthesis requires more nutrient reserves.

5. Conclusion

The results indicate that the number of rhizome buds has no influence on germination time. However, rhizomes size R3 and R4 showed a better germination rate profile. Similarly, in terms of agro-morphological characteristics, rhizomes size R3 and R4 (rhizomes with three buds and rhizomes with four buds) provided the best growth parameters. Rhizomes with three buds and rhizomes with four buds gave similar results. Ginger can be regenerated with three-bud rhizomes, reducing the quantity of rhizomes needed to establish a new crop.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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