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The Physicochemical Characteristics of Coconut (*Cocos nucifera* L.) Kernels in Germination

Brou Roger Konan[1,2*] • Jean Louis Konan[2] • Rebecca Rachel Assa[3] • Mathias Oulé[4] • Georges Amani[5]

[1] Laboratory of Food Biochemistry and Technology of Tropical Products (UFR/STA), University of Abobo-Adjamé, 02 BP 801 Abidjan 02, Côte d'Ivoire
[2] National Agronomic Research Centre (CNRA) 07 BP 13 Abidjan 07, Côte d'Ivoire
[3] Laboratory of Food Sciences and Biochemistry, University of Cocody, 22 BP 582 Abidjan 22, Côte d'Ivoire
[4] Department of Biological Science, Faculty of Science, Collège Universitaire de Saint-Boniface. 200 Avenue de la Cathédrale, Winnipeg, Manitoba R2H 0H7 Canada

Corresponding author: * **rogerkonan022002@yahoo.fr**

ABSTRACT

This purpose of this study was to determine the physicochemical characteristics of coconut kernels in germination. The germinated nuts of three cultivars (West African Tall 'WAT', Malaysian Yellow Dwarf 'MYD' and improved hybrid 'PB121^{+}') were examined. Germinated 'WAT' and 'PB121^{+}' had the greatest physical characteristics (kernel weight and thickness). As for the chemical parameters, the amount of oil in the germinated nuts fluctuated from 48.98 to 72.05%, while the amount of protein and ash varied from 24.16 to 25.82% and 3.94 to 7.17%, respectively. The amount of total sugar in the germinated nuts consisted primarily of non-reducing sugar (amounts varying between 0.02 and 2.99%). The fatty acids in the oil were mostly saturated, with a significant proportion of lauric acid (amounts varying between 40.88 and 52.24%). The germinated 'WAT' and 'PB121^{+}' nuts, which are richer in lipids and lauric acid, are well suited to oil and soap production. The 'MYD' kernel from germinated nuts, which has the highest ash content, can be used as an additive in food for children suffering from mineral deficiencies.

Keywords: almond, biochemical parameter, cultivar, nut
Abbreviations: C8, caprylic acid; **C10**, capric acid; **C12**, lauric acid; **C14**, myristic acid; **C16**, palmitic acid; **C18**, stearic acid; **C18'**, oleic acid; **C18"**, linoleic acid; **%DM**, dry matter percentage; **MYD**, Malaysian Yellow Dwarf; **PB121^{+}**, hybrid PB121; **NRS**, non-reducing sugar; **RS**, reducing sugar; **TS**, total sugar; **WAT**, West African Tall

INTRODUCTION

Thanks to its multiple uses, the coconut (*Cocos nucifera* L.) is known as the "tree of life" (Bourdeix 1989; Mao and Qiu 1997). Indeed, human beings use all parts of this plant for manufacturing important products in the fields of food, crafts, cosmetics and health (van der Vossen and Chipungahelo 2007).

Ivorian coconut fields cover 50,000 ha of land and 95% of them are located along the coastal area. Coconut represents the main export crop for the majority of farmers (Konan *et al.* 2006). Coconut's importance is due in large part to its fruit or nuts (de Taffin 1993). The kernels of mature nuts and the water of immature nuts are the most exploited elements. Unprocessed mature nuts are sold among peasants. On occasion, they are transformed into oil (Assa *et al.* 2006). Several studies have examined the coconut's physicochemical parameters with the aim of improving its usage. Studies by Bachrach and Gardner (2002) on immature coconut water have shown that it is a delicious and nutritive drink when consumed without processing thanks to its high contents of sugar, vitamins and minerals. Its nutritive properties are widely recognized in infantile nutrition. Studies carried out on mature nuts (Konan 1997) have shown their composition to be 33% husk, 16% shell, 33% kernel and 18% water. Manufacturers transform the mature kernel into copra, oil and grated coconut. Copra oil is used in food and other industries (van der Vossen and Chipungahelo 2007).

And yet, there has been hardly any research done on coconut nut germination. The few studies concerning the kernel of germinating nuts (Balasubramaniam *et al.* 1973) are old and incomplete because they looked exclusively at a local Asian variety. In the Ivory Coast, there have been no studies done on the physicochemical characteristics of the most widely used cultivars. Very often, mature nuts germinate and rot in the plantations without being used. This situation has resulted in a decrease in the yield of kernel products, the most profitable part of the fruit, and significant losses for farmers. The present study seeks to analyze the physicochemical characteristics of germinating coconut kernels with the aim of proposing potential uses.

MATERIALS AND METHODS

This study used mature nuts of 13 months (rank 25) and 14 months (rank 26) from three coconut cultivars: the hybrid 'PB121^{+}' (coconut in extension), the Malaysian Yellow Dwarf 'MYD' and the West African Tall 'WAT'. The latter two cultivars are respectively the female and male parents of 'PB121^{+}'. These three types of coconut tree are typical to plantations of the Ivory Coast. The nuts were harvested from coconut trees that are 25 ('MYD'), 28 ('WAT') and 11 ('PB121^{+}') years old. This material was collected at the Marc Delorme Research Station of the National Agronomic Research Centre (CNRA), located in Port-Bouët, Côte d'Ivoire.

Sampling

Eight coconut trees from each cultivar were selected. For each cultivar, two batches of four nuts each were created. Each batch represents a repetition within the cultivar. They are composed of four bunches of mature nuts from ranks 25 and 26. For each rank in a given batch, four groups of eight nuts each were selected from four coconut trees. Within a batch, the eight nuts in each group were selected from four different bunches. The 16 groups per cultivar were used as kernel samplings in the first nut analyses.

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The first treatment (T0) of nuts was carried out less than 24 hours after the harvest. The nuts were then stored for one month before the second treatment (T1) was performed. The remaining nuts were put in a seedbed at the nursery. One and three months after being placed in the seedbed, treatments T2 and T3 were respectively carried out.

For each treatment, one cultivar group was selected per batch and per rank. The eight nuts from each group constituted the representative sample for the rank and the batch; thus, 16 kernel samples were treated per cultivar.

Determination of physicochemical parameters

Kernel weight was measured using a 1/100 precision scale (Sartorius). Kernel thickness was obtained using a micrometer (Ousitde Micrometer 0.25 mm). The kernel's dry matter percentage (% MS) was measured in an oven at 70°C for 10 hrs (BIPEA 1976). Oil content was obtained by the Soxhlet method (AFNOR 1973). The amounts of total and reducing sugar were evaluated respectively with the sulphuric phenol method (Dubois *et al* 1956) and with the 3.5 dinitro-salicylic acid (DNS) methods (Bernfeld 1955) by using a spectrophotometer (Spertronic Genesis 5). The non-reducing sugar content was measured by calculating the difference between the total sugar and the reducing sugar. The amount of protein in the kernel was determined by the Kjeldhal method (AOAC 2000). The fatty acids in the coconut oil were identified using an HP 689 Series I (Hewlett Packard) gas chromatograph. The amount of ash was obtained after total incineration in a muffle furnace at 550°C for 24 hrs (BIPEA 1976).

Statistical analysis

The data were subject to an analysis of variance (ANOVA) using the software SPSS 12 for Windows. Mean and standard deviations were calculated and, when *F*-values were significant at the $p < 0.05$ level, the mean difference was separated using the Newman Keul's test. These analyses were carried out to compare cultivars, ranks and treatments.

RESULTS AND DISCUSSION

Kernel weight

The analysis of variance showed a significant difference between cultivars and treatments. However, there was no significant difference between ranks during germination (**Table 1**).

The kernel weight increased one month after harvesting the nuts (T1) before dropping until the end of germination for all cultivars and maturity stages.

For 'WAT', the kernel weight increased from T0 to T1, with a maximum of 275.86 g for the nuts from rank 25. It later dropped during T3 (257.76 g) for the nuts from rank 25 (**Table 2**).

With respect to 'PB121$^+$', one month after harvesting (T1), the kernel weight increased to 300.14 g and 283.26 g respectively for the nuts from ranks 25 and 26. It then dropped at the end of the germination (T3) to 246.79 g for rank 25 and to 254.06 g for rank 26 (**Table 2**).

For 'MYD', the kernel weight for rank 25 nuts increased from 227.76 (T0) to 262.01 g (T1) and then dropped to 135.62 g (T3). For the nuts from rank 26, the kernel weight varied from 215.64 (T0) to 105.07 g (T3) (**Table 2**).

At the end of germination (T3), 'WAT' 'PB121$^+$' kernels remained significantly heavier than those from the 'MYD'.

For the three cultivars, the heaviest kernel was obtained during treatment T1, while the lowest kernel weight was observed during treatment T3.

According to the average of the data, 'WAT' 'PB121$^+$' had the highest kernel weight (267.26 and 278.75 g).

Kernel thickness

The analysis of variance showed a significant difference between the cultivars and treatments. However, there was no significant difference between the ranks during germination (**Table 1**).

Table 1 Statistical data of the kernel physical parameters of WAT, PB121$^+$ and MYD cultivars during germination.

		Average of squares	
Source of variation	**df**	**Kernel weights**	**Kernel thickness**
Cultivar	2	154832.13**	229.24**
Treatment	3	30782.93**	75.93**
Rank	1	51.22	1.87
Cultivar x treatment	6	21516.10**	24.56**
Cultivar x rank	2	6509.36	2.36
Treatment x rank	3	252.06	1.55
Cultivar x treatment x rank	6	2390.97	2.16
SE		2367.27	1.17

* Significant at probability level $p<0.05$, ** Significant at probability level $p<0.01$; df: degree of freedom; SE: Standard Error; WAT: West African Tall; PB121$^+$: Hybrid PB121; MYD: Malaysian Yellow Dwarf

The kernel thickness increased one month after harvest (T1) and then dropped until the end of germination for all cultivars and nut maturity stages.

For 'WAT', thickness increased up to a maximum of 13.77 mm (T1) before dropping to 12.23 mm during treatment T3 for nuts from rank 26. For nuts from rank 25, the greatest thickness (13.52 mm) was measured during treatment T1 (**Table 2**).

As for the hybrid 'PB121$^+$', one month after harvest (T1), the kernel thickness for nuts from ranks 25 and 26 increased to reach 13.63 mm and 13.46 mm respectively. These values continued to drop until treatment T3 to 11.12 mm and 11.36 mm for ranks 25 and 26 respectively (**Table 2**).

With regards to 'MYD', the kernel thickness of rank 25 nuts increased from 11.15 (T0) to 11.53 mm (T1) and then dropped to 7.84 mm (T3) (**Table 2**).

Regardless of the treatment period, the kernel thickness of 'MYD' (9.96 mm) remained statistically lower than that of 'WAT' (13.04 mm) and 'PB121$^+$' (12.26 mm).

During germination, 'WAT' 'PB121$^+$' demonstrated greater physical parameters (weight and thickness) than 'MYD'. Similar results have been confirmed by De Nucé and Wuidart (1981).

'PB121$^+$' seems to exhibit values close to 'WAT' with respect to its kernels' physical parameters (weight and thickness). Comparing the hybrid to its parents in this way reveals the potential dominance of 'WAT' over 'MYD'.

Nevertheless, the physical parameters of the kernels obtained from these three cultivars are weaker than those of the improved tall hybrids examined by Konan *et al.* (2008). This difference may be attributable to the two tall coconut trees that are used as parents for the improved tall hybrids.

The increase in kernel weight and thickness at the beginning of germination for the three cultivars is a result of the continuation of post-harvest nut maturation. These results have been supported by De Taffin (1993).

During germination, from T2 to T3, the decrease in kernel weight and thickness is due to the progressive appearance of haustorium inside the nut. This fungus gradually digests the kernel to nourish the developing young seedling (Assy 1986). This assertion has been confirmed by the nut kernel's total disappearance among young seedlings in a nursery.

Dry matter percentage

Statistical analysis indicated a significant difference between treatments, ranks and cultivars (**Table 3**).

The dry matter percentage (%DM) of the kernel generally increased a month after harvesting before dropping during germination.

The dry matter percentage of the local cultivar 'WAT' (%DM) increased to 56.72% (T1) and then decreased to 54.99% at the end of germination for rank 25 nuts. The dry matter percentage of rank 26 nuts dropped from 61.31 to

Table 2 Variation of weight, thickness and dry matter percentage of the kernel of WAT. PB121^{+} and MYD cultivars during germination.

Cultivars	Age of nuts	Treatments	Parameters		
			Weight (g)	Thickness (mm)	Dry matter (%)
WAT	Rank 25	T0	245.95 ± 64.62 d	13.14 ± 1.12 b	56.02 ± 1.06 b
		T1	275.86 ± 39.00 a	13.52 ± 1.01 a	56.72 ± 0.36 a
		T2	269.27 ± 67.52 b	12.95 ± 0.69 c	53.74 ± 0.40 d
		T3	257.76 ± 43.67 c	12.57 ± 0.76 d	54.99 ± 1.93 c
	Rank 26	T0	269.27 ± 50.56 b	13.25 ± 0.92 b	58.53 ± 0.97 b
		T1	275.47 ± 39.99 a	13.77 ± 1.06 a	61.31 ± 0.75 a
		T2	267.33 ± 55.45 b	12.97 ± 0.54 c	56.82 ± 0.79 c
		T3	264.98 ± 37.66 c	12.23 ± 0.99 d	56.62 ± 3.54 c
PB121^{+}	Rank 25	T0	257.94 ± 29.21 c	11.87 ± 1.09 b	43.66 ± 2.54 d
		T1	300.14 ± 53.64 a	13.63 ± 0.96 a	53.65 ± 1.34 a
		T2	284.93 ± 36.39 b	12.09 ± 0.74 c	45.26 ± 1.52 c
		T3	246.79 ± 49.63 d	11.12 ± 0.54 d	47.15 ± 4.59 b
	Rank 26	T0	260.72 ± 63.81 c	11.78 ± 0.99 b	50.42 ± 0.76 b
		T1	283.26 ± 28.67 a	13.46 ± 0.79 a	56.78 ± 0.82 a
		T2	267.59 ± 55.01 b	11.98 ± 0.85 b	47.65 ± 0.60 c
		T3	254.06 ± 64.88 d	11.36 ± 0.82 c	43.24 ± 4.55 d
MYD	Rank 25	T0	227.76 ± 30.36 b	11.15 ± 0.69 b	41.82 ± 1.48 b
		T1	262.01 ± 33.01 a	11.53 ± 0.30 a	47.37 ± 0.84 a
		T2	207.83 ± 40.67 c	10.14 ± 1.06 c	42.12± 1.39 b
		T3	135.62 ± 32.56 d	7.84 ± 2.6 d	46.26 ± 0.72 c
	Rank 26	T0	215.64 ± 60.96 a	11.57 ± 0.45 a	45.89 ± 1.63 b
		T1	229.26 ± 21.19 c	11.39 ± 0.85 b	46.73 ± 1.03 a
		T2	198.02 ± 40.18 b	9.57 ± 1.29 c	43.76 ± 1.08 c
		T3	105.07 ± 5.69 d	5.93 ± 2.80 d	46.89 ± 0.75 a

NB: Values with the same letter in the columns are not significantly different for each parameter. Rank 25: 13 months, Rank 26: 14 months, T0: 0 month after harvest, T1: 1 month after harvest, T2: 2 months after harvest, T3: 4 months after harvest, WAT : West African Tall, PB121^{+}: improved hybrid PB121, MYD: Malaysian Yellow Dwarf

56.62% during treatment T3 (**Table 2**).

The fluctuations recorded for 'WAT' also appeared in 'PB121^{+}'. Indeed, the dry matter percentage varied from 43.66 (T0) to 53.65% (T1), reaching 47.25% during T3 for rank 25. For rank 26 nuts, the %DM increased from T0 (50.42%) to T1 (56.78%) and then decreased to 43.24% during T3 (**Table 2**).

'MYD' yielded a %DM that varied between 47.37 (T0) and 46.26% (T3) for rank 25. For rank 26, the %DM was between 45.89 and 46.89% during germination (**Table 2**).

The growth of the kernel dry matter rate at the beginning of germination is related to the post-harvest maturation of the kernel. The kernel uses nutrients from the coconut water in its development (Jayalekshmy *et al.* 1988). This growth could also be due to dehydration, as the nuts were exposed under a hangar without watering. The effects of the heat result in the dehydration of the nut compartments, including the kernel. However, Assa's studies (2007) have shown that the husk of a mature nut that is exposed to the sun dehydrates more quickly than the other compartments.

The decrease in the dry matter percentage noticed from T2 to T3 for 'WAT' and 'PB121^{+}' is related to the intensification of nut respiration. This depends on factors such as temperature, moisture and oxygen quantity in the cells. In the presence of oxygen, sugars decompose in water, carbon dioxide and heat. However, the heat production during respiration can cause warming that result in a loss of dry matter (FAO 2007). This biochemical phenomenon is responsible for the drop in the kernels' dry matter content after the nuts are placed in a seedbed.

Sugar content

The statistical analysis of the sugar content showed a significant difference between the treatments. However, there was no significant difference between cultivars and ranks during germination for the three types of sugar (**Table 3**).

The results showed that the amount of total sugar (TS) and non-reducing sugar (NRS) for the three cultivar kernels increased from T0 to T1 (one month after harvest). These amounts dropped to minimal values at the end of germination regardless of the cultivar or maturity stage (**Table 4**).

For 'WAT', the amount of total sugar for rank 25 nut kernels increased to 3.15% (T1) and then dropped to 0.13% at the end of germination (T3). For rank 26, this amount increased to 3.57% (T1) and then decreased to 0.13% (**Table 4**).

The amount of total sugar for rank 25 nut kernels from 'PB121^{+}' rose to 3.23% during treatment T1 and then dropped to 0.10% during treatment T3 (**Table 4**).

As for 'MYD', the amount of total sugar for rank 25 nut kernels increased to 3.88% (T1) and then dropped to 0.09% (T 3) (**Table 4**).

The greatest amount of total sugar was observed in 'MYD' for ranks 25 (3.88%) and 26 (3.75%) during treat-

Table 3 Statistical data of the kernel chemical parameters of WAT, PB121^{+} and MYD cultivars during germination.

		Average of squares						
Source of variation	df	DM	TS	RS	NRS	Lipid	Ash	Protein
Cultivar	2	1168.99**	0.41	0.002	0.36	719.87**	12.53**	6.43**
Treatment	3	79.59**	72.07**	0.11**	67.34**	447.73**	5.90**	121.00**
Rank	1	111.74**	0.001	0.0001	0.01	65.76	2.78	0.22**
Cultivar x treatment	6	66.42**	0.15	0.002**	0.15	81.32**	1.62**	16.81**
Cultivar x rank	2	4.73	0.55*	0.007	0.52	11.12	0.41	1.97
Treatment x rank	3	21.08**	0.10	0.008	0.11	37.83	0.76*	7.29**
Cultivar x treatment x rank	6	19.06**	0.53*	0.008	0.53**	58.85**	0.93**	2.01
SE		3.53	0.17	0.007	0.17	17.84	0.26	1.28

* Significant at p<0.05,** Significant at p<0.01, df: degree of freedom, SE: Standard Error, DM: dry matter, TS: total sugar, RS: reducing sugar, NRS: non reducing sugar, WAT: West African Tall, PB121^{+}: improved hybrid PB121, MYD: Malaysian Yellow Dwarf

Table 4 Variation of total sugars, reducing sugars and non reducing sugars contents of the kernel of WAT. PB121^{+} and MYD cultivars during germination.

Cultivars	Age of nuts	Treatments	Parameters		
			TS (%)	RS (%)	NRS (%)
WAT	Rank 25	T0	2.91 ± 0.22 b	0.22 ± 0.02 a	2.69 ± 0.20 b
		T1	3.15 ± 0.39 a	0.14 ± 0.03 b	3.01 ± 0.36 a
		T2	0.18 ± 0.03 c	0.11 ± 0.01 b	0.06 ± 0.02 c
		T3	0.13 ± 0.13 c	0.07 ± 0.01 c	0.06 ± 0.06 c
	Rank 26	T0	2.16 ± 1.16 b	0.19 ± 0.03 a	1.97 ± 1.17 b
		T1	3.57 ± 0.19 a	0.15 ± 0.01 a	3.42 ± 0.19 a
		T2	0.21 ± 0.03 c	0.07 ± 0.02 b	0.13 ± 0.03 c
		T3	0.13 ± 0.02 c	0.07 ± 0.01 b	0.05 ± 0.01 d
PB121^{+}	Rank 25	T0	2.03 ± 0.71 b	0.25 ± 0.03 a	1.78 ± 0.72 b
		T1	3.23 ± 0.13 a	0.15 ± 0.02 b	3.07 ± 0.11 a
		T2	0.13 ± 0.04 c	0.08 ± 0.02 c	0.05 ± 0.02 c
		T3	0.10 ± 0.01 c	0.04 ± 0.01 c	0.07 ± 0.01 c
	Rank 26	T0	3.02 ± 0.14 b	0.24 ± 0.02 a	2.78 ± 0.13 b
		T1	3.48 ± 0.12 a	0.16 ± 0.02 b	3.32 ± 0.12 a
		T2	0.13 ± 0.02 c	0.08 ± 0.02 c	0.04 ± 0.03 c
		T3	0.11± 0.02 c	0.05 ± 0.01 c	0.06 ± 0.01 c
MYD	Rank 25	T0	3.19 ± 1.13 a	0.19 ± 0.03 a	2.99 ± 1.17 b
		T1	3.88 ± 0.12 a	0.19 ± 0.05 a	3.69 ± 0.14 a
		T2	0.13 ± 0.01 b	0.10 ± 0.01 b	0.02 ± 0.01 c
		T3	0.09 ± 0.04 b	0.08 ± 0.03 c	0.02 ± 0.02 c
	Rank 26	T0	2.51 ± 0.81 b	0.22 ± 0.07 a	2.28 ± 0.74 b
		T1	3.75 ± 0.13 a	0.17± 0.02 a	3.58 ± 0.14 a
		T2	0.15 ± 0.02 c	0.09 ± 0.01 b	0.058 ± 0.01 c
		T3	0.16 ± 0.02 c	0.09 ± 0.01 b	0.074 ± 0.02 c

NB: Values with the same letter in the columns are not significantly different for each parameter. Rank 25: 13 months, Rank 26: 14 months, TS: Total sugars, RS: Reducing sugar, NRS: Non reducing sugar, T0: 0 month after harvest, T1: 1 month after harvest, T2: 2 months after harvest, T3: 4 months after harvest, WAT: West African Tall, PB121^{+}: improved hybrid PB121, MYD: Malaysian Yellow Dwarf.

ment T1.

During germination, the amount of kernel reducing sugar (RS) dropped significantly depending on the treatment, for all the cultivars and maturity stages.

For 'WAT', values decreased from 0.22 (T0) to 0.07% (T3) for rank 25 nuts and from 0.19 (T0) to 0.07% (T3) for those from rank 26 (**Table 4**).

For 'PB121^{+}', during treatment T3, the amount of reducing sugar was 0.03% and 0.05% respectively for rank 25 and 26 nut kernels. They were initially (T0) 0.25% (rank 25) and 0.24% (rank 26) (**Table 4**).

With respect to 'MYD', the amount of reducing sugar (RS) dropped during treatment T3 to 0.07% for rank 25. One month after harvest (T1), the RS content was 0.19% and 0.17% respectively for ranks 25 and 26 (**Table 4**).

For 'WAT', the amount of non-reducing sugar for rank 25 nut kernels increased from 2.69 (T0) to 3.01% (T1) and then decreased to 0.06% (T3) (**Table 4**). The highest amount of reducing sugar for rank 26 was 3.42% (T1). It decreased to 0.05% during treatment T3.

During T0, the amount of non-reducing sugar (NRS) for 'PB121^{+}' was 1.78% (rank 25) and 2.78% (rank 26). These values increased to 3.07% (T1) and then decreased to 0.07% at the end of germination (T3) for nuts from rank 25 (**Table 4**).

For 'MYD', the values increased from 2.28 (T0) to 3.58% (T1) and then dropped to 0.07 % during treatment T3 for nuts from rank 26 (**Table 4**).

Our results showed that non-reducing sugar constitutes the majority of the kernels' total sugar content. Similar results during nut maturation have been recorded in studies by Assa *et al.* (2007). These studies noted a high concentration of reducing sugar in immature coconut water. This sugar is converted into non-reducing sugar in the kernel during maturation through biochemical processes (glucidic synthesis), which continues throughout the germination of the mature nuts.

The amount of total sugar increases at the beginning of germination because the kernel uses the coconut water sugar during maturation (Jayalekshmy *et al.* 1988). The significant drop in the amount of total sugar, beginning in the second month after harvesting the mature nuts, can be explained by the formation of the embryo. Indeed, the mature nuts start to germinate two months after harvesting (Wuidart 1981). This phenomenon takes advantage of the kernel's glucidic reserves to aid in the embryo's development.

Lipid content

Statistical analysis indicated a significant difference between cultivars and treatments. However, there was no significant difference between ranks (**Table 3**).

The results showed that the kernels' lipid content in all three cultivars dropped two months after harvesting (T2) before increasing during germination for all cultivars and maturity stages (**Table 5**).

The lipid content of 'WAT' kernels dropped from 72.05 (T0) to 60.22% (T2) before increasing to 68.21% at the end of germination (T3) for nuts from rank 25. The lipid content of kernels from rank 26 dropped from T0 (69.49%) to T2 (60.94%) before increasing to 66.76% during treatment T3 (**Table 5**).

For 'PB121^{+}', the lipid content also decreased regardless of nut rank before increasing. Rank 25 nuts decreased from 69.08 (T0) to 59.87% (T2) before increasing to 67.19% (T3). At the end of germination (T3), the lipid content of rank 26 nuts was 66.46% (**Table 5**).

With regards to 'MYD', the lipid content of kernels from rank 25 nuts decreased from 59.91(T0) to 45.42% (T2) and then increased to 67.55% at the end of germination (T3). As for kernels from rank 26 nuts, their lipid content dropped from 58.45 (T0) to 48.98% (T2) and then increased to 65.91% during treatment T3 (**Table 5**).

For all the cultivars, the average of the data showed that kernels from 'WAT' (65.94%) and 'PB121^{+}' (65.81%) contained more lipids than 'MYD' (57.66%). Between treatments, T0 yielded more lipids than the others (T1, T2 and T3). However, the lipid content in the kernels of all three cultivars was more than 60% at the end of germination (T3).

The drop in lipid content at the beginning of germination can be explained by a reduction in the kernels' fat content reserves. Hydrolysed in glycerol and fatty acids, these lipids are oxidized in acetyl–COA, transformed into simple carbohydrates and then transferred to the embryo as sucrose.

Table 5 Variation of lipids, ashes and proteins contents of the kernel of WAT. PB121^{+} and MYD cultivars during germination.

Cultivars	Age of nuts	Treatments	Parameters		
			Lipids (%)	Ashes (%)	Proteins (%)
WAT	Rank 25	T0	72.05 ± 0.68 a	3.96 ± 0.27 c	25.09 ± 1.91 a
		T1	62.91± 1.03 d	4.43 ± 1.35 b	22.04 ± 0.18 c
		T2	60.22 ± 4.26 c	4.36 ± 0.58 b	19.74 ± 0.35 d
		T3	68.21 ± 0.20 b	4.73 ± 0.43 a	24.32 ± 1.86 b
	Rank 26	T0	69.49 ± 1.25 a	3.94 ± 0.10 c	24.65 ± 1.26 a
		T1	61.88 ± 3.14 c	4.42 ± 0.31 a	22.03 ± 0.25 c
		T2	60.94 ± 0.63 c	4.10± 0.09 b	20.07 ± 0.12 b
		T3	66.76 ± 0.86 b	4.31± 0.63 a	23.04 ± 1.21 b
PB121^{+}	Rank 25	T0	69.08 ± 0.73 a	5.88 ± 0.28 b	24.16 ± 0.11 a
		T1	67.8 ± 4.24 b	4.18 ± 1.35 d	21.85 ± 0.11 b
		T2	59.87± 2.51 c	5.36 ± 0.58 c	20.44 ± 0.29 b
		T3	67.19 ± 5.39 b	6.60 ± 0.43 a	24.16 ± 0.11 a
	Rank 26	T0	66.74 ± 7.07 a	5.03 ± 0.10 b	24.16 ± 0.75 a
		T1	63.83 ± 4.60 b	4.78 ± 0.31 c	21.26 ± 0.73 c
		T2	61.55 ± 10.87 c	4.84 ± 0.09 c	20.86 ± 0.45 d
		T3	66.46 ± 0.19 a	6.39 ± 0.63 a	21.96 ± 2.52 b
MYD	Rank 25	T0	59.91 ± 3.60 b	4.92 ± 0.42 c	25.82 ± 0.65 a
		T1	45.86 ± 4.06 c	5.56 ± 0.26 b	22.44 ± 0.06 c
		T2	45.42 ± 0.55 c	4.93 ± 0.14 c	16.55 ± 0.68 d
		T3	65.55 ± 1.45 a	7.17 ± 0.99 a	23.95 ± 2.93 b
	Rank 26	T0	58.45 ± 0.65 b	5.17 ± 0.09 b	25.16 ± 0.54 a
		T1	56.72 ± 3.68 c	4.96 ± 0.22 c	22.63 ± 0.21 c
		T2	48.98 ± 10.29 d	4.79 ± 0.36 d	16.94 ± 0.26 d
		T3	65.91± 0.85 a	5.27 ± 0.27 a	23.62 ± 1.66 b

NB: Values with the same letter in the columns are not significantly different for each parameter. Rank 25: 13 months, Rank 26: 14 months, T0: 0 months after harvest, T1: 1 month after harvest, T2: 2 months after harvest, T3: 4 months after harvest, WAT: West African Tall, PB121^{+}: improved hybrid PB121, MYD: Malaysian Yellow Dwarf

Similar results were observed by Abigor *et al.* (1996) regarding palm seed germination.

The increase in lipid content at the end of germination can be explained by the role played by kernel sugars in the formation of acetyl–COA, the initiator of lipid synthesis. According to studies by Assa *et al.* (2007), kernel sugars intervene in the formation of acetyl-COA during lipid synthesis.

Moreover, the fluctuating lipid content of germinating seeds depends on lipases (Murphy and Cummins 1989). Their intense activity at the beginning of coconut germination leads to a drop in lipid content until treatment T2. The inactivation of lipases through biochemical processes close to the end of germination results in an increase in lipid content.

Ash content

Statistical analysis indicated significant differences between treatments, ranks and cultivars (**Table 3**).

For the local cultivar 'WAT', ash content fluctuated between 3.96 (T0) and 4.73% (T3) for rank 25 nuts. Nuts from rank 26 increased from 3.94 to 4.31% (**Table 5**).

The ash content of 'PB121^{+}' dropped significantly one month after harvesting (T1) before increasing at the end of germination (T3). For rank 25 nuts, the ash content varied from 5.88 (T0) to 4.18% (T1) and then increased to reach 6.6% during treatment T3. For rank 26 nuts, the ash content decreased from 5.03 (T0) to 4.78% (T1) before increasing to 6.39% during treatment T3 (**Table 5**).

For 'MYD', the ash content fluctuated between 4.92 (T0) and 7.17% (T3) for rank 25 nuts. Rank 26 nuts varied from 5.17 (T0) to 5.27% (T3) (**Table 5**).

For all the cultivars, the average of the data showed that 'MYD' (5.34%) and 'PB121^{+}' (5.38%) contained more ash than 'WAT' (4.28%). The highest ash content was recorded during T3, regardless of cultivar or rank.

The increase in kernel ash content during germination may stem from the mobilization of minerals contained in other parts of the nut (husk, shell and water). Moreover, Ouvrier's studies (1982) have shown an increase in nitrogen, phosphorus and sulphur content during the nuts' maturation. This phenomenon continues during germination.

Protein content

The statistical analysis showed a significant difference between cultivars and treatments. However, there was no significant difference between ranks (**Table 3**).

The results showed that the kernels' protein content dropped significantly until treatment T2 and then increased at treatment T3 regardless of cultivar or maturity stage.

For 'WAT' rank 25 nuts, the protein content fell from 25.09 (T0) to 19.74% (T2) and then rose to 24.32% during treatment T3. At the end of germination, for nuts from rank 26, the protein content was 23.04% (**Table 5**).

In 'PB121^{+}' from rank 26, the values dropped from 24.16 (T0) to 20.86% (T2) and then increased to 21.96% during treatment T3 (end of germination) (**Table 5**).

Forrank 26 'MYD' nuts, the protein content fell from 25.16 (T0) to 16.94% (T2) and then rose to 23.62% (T3). The lowest protein content was observed during treatment T2 (16.55%) in 'MYD' rank 25 (**Table 5**).

The 'MYD' nuts had the highest protein content before germination (25.82% for rank 25 and 25.16% for rank 26). For nuts from rank 26, the lowest protein content was observed in 'PB121^{+}' during treatment T3 (21.96%). At the end of germination (T3), the protein content varied from 21.96 to 24.32% for all the cultivars.

For all the cultivars, the average of the data showed that 'WAT' was significantly richer in protein (22.99%) than 'MYD' (22.13%) and 'PB121^{+}' (22.35%).

The drop in protein content at the beginning of germination is related to hydrolysis, which produces peptides, amino acids, amines and ammonia. The released amino acids are used to synthesize new proteins for the young seedlings (Goffner *et al.* 1988). The germination phenomenon, which mobilizes kernel proteins, ends after the first two months (T2). After this period, the young seedlings continue their development by using other resources, such as reserves contained in the embryo and roots. The increase in protein content at the end of germination can be attributed to the end of protease synthesis, which leads to an accumulation of protein.

Table 6 Statistical data of fatty acid contents of coconut oil of WAT, PB121^{+} and MYD cultivars during germination.

		Average of squares							
Source of variation	**df**	**C8**	**C10**	**C12**	**C14**	**C16**	**C18**	**C18'**	**C18"**
Cultivar	2	14.93	16.08*	140.07**	5.49*	71.99**	0.47	42.59**	10.19**
Treatment	3	0.44	1.09	0.49	1.11	0.32	0.07	0.08	0.28
Rank	1	1.78	6.77*	1.76	0.01	1.01	0.19	0.8	0.4
Cultivar x treatment	6	3.19	2.75	4.86	2.22	2.37	3.82	3.28	1.65
Cultivar x rank	2	5.45	4.28	3.66*	0.47	1.08	6.42	0.79	1.37
Treatment x rank	3	1.57	2.69	14.24	3.77	3.53	7.10	2.22	2.09
Cultivar x treatment x rank	6	2.26	3.38	5.96	1.29	0.79	4.98	1.27	0.92
SE		4.89	3.34	3.95	1.34	1.04	5.44	3.8	1.43

* Significant at p<0.05**, Significant at p<0.01, df: degree of freedom, SE: Standard Error, WAT: West African Tall, PB121^{+}: improved hybrid PB121, MYD: Malaysian Yellow Dwarf. C8: caprylic acid, C10: capric acid, C12: lauric acid, C14: myristic acid, C16: palmitic acid, C18: stearic acid, C18': oleic acid, C18": linoleic acid

Fatty acid content

Among all the cultivars, there were significant differences for the majority of fatty acids except for caprylic (C_8) and stearic (C_{18}) acids. A significant difference in capric acid (C_{10}) was also observed between the ranks. However, there was no significant difference between the treatments (**Table 6**).

The chromatographic profile of the coconut oil's fatty acids during germination revealed the same components for all three cultivars studied.

The oil of germinating nuts from the three cultivars contained mainly saturated fatty acids. The most common fatty acids were lauric (C_{12}) and myristic (C_{14}) acids.

The proportion of lauric acid (C_{12}) in the oil of rank 25 nuts from the 'WAT' cultivar fluctuated between 49.04 and 50.56%. For rank 26, this amount varied between 50.15 and 52.24%. The proportion of myristic acid (C_{14}) was recorded between 20.40 and 22.35% in the oil of rank 25 nuts (**Fig. 1**).

For the 'PB121^{+}' hybrid, the proportion of lauric acid (C_{12}) varied from 48.20 to 50.54% in the oil of rank 26 nuts. The proportion of myristic acid (C_{14}) was recorded between 19.68 and 23.61% in the oil of rank 25 nuts (**Fig. 2**).

In 'MYD's oil, the proportion of lauric acid (C_{12}) varied from 40.88 to 48.09% for rank 25 nuts. As for those from rank 26, the proportion oscillated between 43.10 and 47.71%. The proportion of myristic acid (C_{14}) was recorded between 21.53 and 24.03% for rank 26 nuts (**Fig. 3**).

The proportion of lauric acid in 'WAT' (50.46%) and 'PB121^{+}' (49.50%) was significantly higher than 'MYD' (44.92%). However, the proportion of myristic acid in 'MYD' (22.76%) was significantly higher than 'WAT' (21.64%) and 'PB121^{+}' (21.90%) cultivars.

Germinated coconut oil contains low proportions of caprylic (C_8), capric (C_{10}), palmitic (C_{16}) and stearic (C_{18}) acids.

In terms of unsaturated fatty acids, the proportion of linoleic acid ($C_{18"}$) was lower than that of oleic acid ($C_{18'}$).

For 'WAT', the proportion of oleic acid was recorded between 4.41 and 6.68%, while the proportion of linoleic acid oscillated between 1.06 and 3.11% (**Fig. 1**).

In 'PB121^{+}', the proportion of oleic acid fluctuated between 4.49 and 7.09%, and between 1.23 and 3.38% for linoleic acid (**Fig. 2**).

The respective proportions of oleic and linoleic acids were recorded between 6.49 and 10.45%, and 2.02 and 4.82% for 'MYD' (**Fig. 3**).

The proportions of oleic and linoleic acids in 'WAT' (5.75% and 2.03%) and 'PB121^{+}' (5.74% and 2.40%) cultivars were significantly lower than those of 'MYD' (8.57% and 3.56%).

The chromatographic profile of the fatty acids reveals that the coconut oil of all three cultivars is rich in saturated

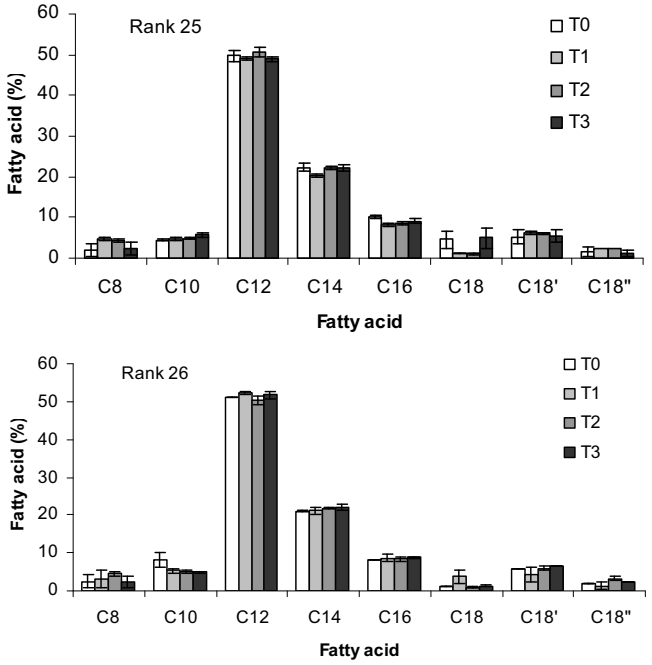

Fig. 1 Fatty acids proportions in kernel of cv. 'WAT' studied during germination. C8: caprylic acid, C10: capric acid, C12: lauric acid, C14: myristic acid, C16: palmitic acid, C18: stearic acid, C18': oleic acid, C18": linoleic acid. T0: 0 month after harvest, T1: 1 month after harvest, T2: 2 months after harvest, T3: 4 months after harvest.

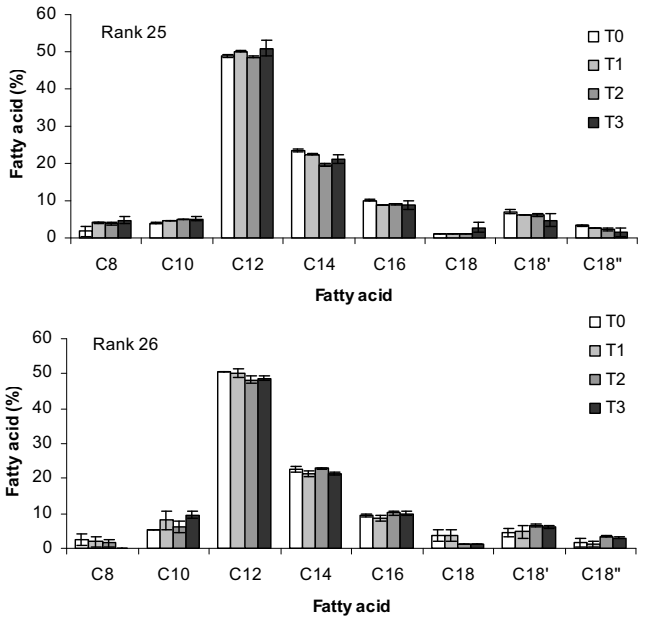

Fig. 2 Fatty acids proportions in kernel of cv. 'PB121^{+}' studied during germination. C8: caprylic acid, C10: capric acid, C12: lauric acid, C14: myristic acid, C16: palmitic acid, C18: stearic acid, C18': oleic acid, C18": linoleic acid. T0: 0 month after harvest, T1: 1 month after harvest, T2: 2 months after harvest, T3: 4 months after harvest.

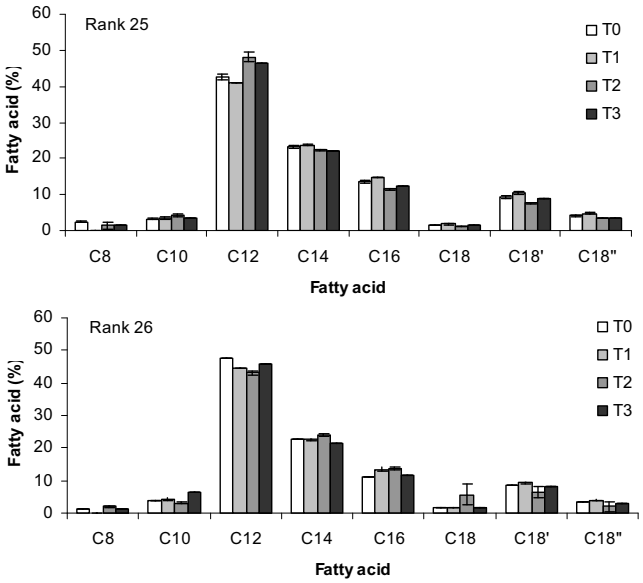

Fig. 3 Fatty acids proportions in kernel of cv. 'MYD' studied during germination. C8: caprylic acid, C10: capric acid, C12: lauric acid, C14: myristic acid, C16: palmitic acid, C18: stearic acid, C18': oleic acid, C18'': linoleic acid. T0: 0 month after harvest, T1: 1 month after harvest, T2: 2 months after harvest, T3: 4 months after harvest.

fatty acids, or lauric acid (C_{12}) and myristic acid (C_{14}). These results correspond with those observed by Konan *et al.* (2008) for the kernels of tall coconut hybrids. The amount of lauric acid found in the oils of the nuts from the three cultivars during germination supports the results of Berger and Andanar (1991).

Lauric acid (C_{12}) is considered a standard of quality for coconut oil because it gives soap its foaming property. This explains its importance for soap producers. Indeed, saturated fatty acids consist of strong bindings, which support temperature variations better than unsaturated fatty acids (Quinsac and Riballin 1998).

CONCLUSION

This study was carried out to determine the physicochemical characteristics of nuts in germination. The work focussed on the kernels of the three most widely grown coconut trees in the Ivory Coast: 'MYD', 'WAT' and 'PB121^{+}'.

The results showed that, before germination, the nuts' physical characteristics (kernel weight and thickness) were greatest in 'WAT' and 'PB121^{+}'. In terms of the chemical parameters, the lipid content was highest in 'WAT' (72.05%). The 'PB121^{+}' hybrid exhibited the greatest ash content (5.88%). The protein content was also high in the nut kernels from all three cultivars, with the highest content found in 'MYD' (25.82%). The highest amount of total sugar was observed in rank 25 nuts from 'MYD' (3.19%).

For germinated nuts, the lipid content (68.21% and 67.19%) and lauric acid content (51.71% and 50.88%) were greatest in 'WAT' 'PB121^{+}'. The greatest ash content (7.17%) was recorded in 'MYD'.

In terms of usage, the germinated nuts from 'WAT' and 'PB121^{+}', which are richer in lipids and lauric acid, are appropriate for oil and soap production. Thanks to their high ash content, the germinated nut kernels from the 'MYD' cultivar can be used as an additive in food for children suffering from mineral deficiencies.

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