Influence of tapping time on rubber yield and the physiological status of rubber trees southeastern Côte d'Ivoire in a context of climate change

Received 25 July, 2022  Revised 8 September, 2022  Accepted 12 September, 2022  Published 26 September, 2022

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Rubber tree cultivation, the main source of natural rubber, is suffering the adverse effects of climate change characterized by a scarcity of rain, an increase in temperature and a drop in relative humidity, leading to a reduction in yields. For the purpose of solving this problem, a study was conducted in southeastern Côte d’Ivoire, in order to assess the influence of earlier tapping on rubber yield and the physiological status of rubber trees. Four rubber tree clones were subjected to two treatments (normal tapping starting at 6:00 a.m. and earlier morning tapping starting at 4:30 a.m.) in a completely randomized Fisher blocks design with 4 repetitions over a total surface area of 178 ha. The results showed that latex flow duration is greater with the tapping starting at 4:30 a.m. The gains in rubber yield caused by the tapping starting at 4:30 a.m. are 20%. Moreover, the tapping starting at 4:30 a.m. has no negative effect on the physiological status of the rubber trees. The tapping starting at 4.30 a.m. therefore appears as an alternative to reduce one of the harmful effects of climate change, namely the drop in relative humidity leading to a decrease in rubber yield.

Keywords: Climate change, rubber tree, tapping time, yield, physiological status.

INTRODUCTION

The uncontrolled growth of greenhouse gas emissions is causing global warming, resulting in the melting of glaciers, the multiplication of extreme weather phenomena, and the shift in seasons (Nelson et al., 2009). Climate has a very strong influence on agriculture, which is considered to be the human activity most dependent on climatic variations (Oram, 1989; Hansen, 2002; Hansen et al., 2012).

Hevea brasiliensis, main source of natural rubber, is also suffering the effects of climate change. Indeed, rubber tree grows optimally in areas with mean annual temperatures of 25°C-28°C and rainfall above 1,500 mm (Gohet et al., 2021). High air moisture content facilitates latex exudation, but excessive rain can hinder harvesting (Compagnon, 1986). Soils should be acidic (optimally pH 4.5 to 5.5) and...
must be well drained to avoid waterlogging, root disease and dieback (Pinizzotto et al., 2021). Climate change makes some rubber traditional areas less favourable because of drought or excessive precipitation (Thaler et al., 2021; Vignes, 2021). Higher temperatures will likely reduce latex flow and thereby yield (Ismail and Gohet, 2021). Extreme events are also likely to affect rubber production. The drought can delay growth (resulting in a longer immature period) (Pinizzotto et al., 2021). However, precipitation may increase in some areas, leading to soil runoff and waterlogging (Thaler et al., 2021). Wind damage from the increased occurrence and strength of storms is also a concern. A high incidence of trunk snaps and broken branches within a short period can cause irreversible damage to a rubber plantation (Chen et al., 2021; Vignes, 2021). There may also be a higher risk of pests and diseases caused by more humid conditions (Pinizzotto et al., 2021; Vignes, 2021). In Songkhla province of Southern Thailand, climate change and climate variability trends to reduce latex yield because of an increase of rainfall leading to a reduction of tapping days (Sdoodee and Rongsawat, 2012).

Côte d’Ivoire, a West African country, whose economy is based on agriculture, is also bearing the brunt of the harmful effects of climate change with the increase in temperatures, the change in rainfall pattern making the land more arid and less fertile (Yao et al., 2013). With 950,000 tons produced in 2020, Côte d’Ivoire is the leading producer of natural rubber in Africa and the fourth globally (APROMAC, 2021). However, in Côte d’Ivoire, the rubber tree sector is suffering the effects of climate change characterized by the scarcity of rainfall, the increase in temperatures and the drop in relative humidity, thus leading to a reduction in yields (Yao et al., 2013).

Indeed, temperature is a climatic parameter which conditions latex flow at the time of tapping. The highest daily yields are reached with the coolest morning temperatures (14 to 18°C) (Compagnon, 1986). The time of tapping therefore influences the yield (An et al., 2014; Nayanakantha et al., 2022). Latex flow duration (thus ultimately rubber yield) depends on the atmospheric conditions at the time of tapping, and these vary during the day (Paardekooper and Sompong, 1969; Lacina, 1981; An et al., 2014; Nayanakantha et al., 2022). It is clear that significant deficits in water saturation of the air and high wind speeds will correspond to high leaf transpiration, lower water replenishment of latex vessels during tapping, and therefore a limited flow time (Compagnon, 1986). It is therefore essential to adapt rubber tree cultivation to climate change in order to maintain rubber yield and preserve the incomes and lives of all those who depend on this crop. This research work, whose general objective is to attenuate the effects of the rise in temperatures and the drop in relative humidity on rubber yields in rubber tree cultivation, falls in this perspective. Specifically, this study will help assess the effect of earlier morning tapping starting at cooler hours (4:30 a.m.) on latex flow, rubber yield and the physiological status of rubber trees compared to normal tapping starting at 6:00 a.m.

MATERIALS AND METHODS

Study site

The study took place at the Agroindustrial Unit of the Société Africaine des Plantations d’Hévéa (SAPH) in Touphah, in southeastern Côte d’Ivoire. Touphah is located at 52 km from Abidjan on the Abidjan-Grand-Lahou road (5°18’59”N ; 4°34’12”W). The relief is very uneven with a dominance of plains and low plateaus. Of ferrallitic type, the soil has a sandy-clay texture and has a gravelly horizon. This type of loose and airy soil makes it fertile and favorable for agricultural activity. The area has a humid tropical climate characterized by heavy rainfall. Four seasons including two rainy seasons and two dry seasons are observed. The annual rainfall varies between 1200 and 1700 mm and an annual average of 1660 mm (Brou, 2005). This area is characterized by dense forest vegetation with mainly rubber tree and oil palm plantations.

Plant material

The plant material used consisted of four Hevea brasiliensis clones spread over a surface area of 178 ha. These included clones IRCA 230, GT 1, RRIC 100 and PB 217, which combine all three metabolic activity classes.

Clone IRCA 230 is derived from GT 1 x IRCA 229 crossbreeding: it has very high vigor, good sucrose reserves and low dry cut incidence despite low thiol values. It is a slow-metabolism clone (Anonymous, 1993).

Clone GT 1 is the control clone in all large-scale trials, it was selected around 1930 and is relatively less susceptible to the different leaf diseases, to tapping panel dryness or wind damage. It is a moderate metabolism clone. Its yield per tree and per tapping is low (Soumahin, 2010).

Clone PB 217 stemming from PB 5/51 x PB 6/9 crossbreeding was created in Malaysia in 1955. Its vegetative growth before tapping is comparable to that of GT 1 (Obouayeba, 2005). Its productivity is about 20% higher than that of GT 1 with an intense stimulation regime. Its physiological characteristics are expressed by a slow metabolism, significant carbohydrate reserves. This clone is susceptible to wounds and Colletotrichum gloeosporioides (leaf disease).

Clone RRIC 100 originates from Malaysia. It stems from RRIC 52 x PB 86 crossbreeding. It has a physiological profile limited by low thiol content (RSH). Its productivity is greater than or equal to that of GT 1 with average vigor. Its physiological characteristics are expressed by an moderate metabolism, hence its belonging to the moderate metabolic activity class (Anonymous, 1993).

The selection of these clones is justified by the fact that they combine the three main metabolic classes (slow metabolism, high metabolism and moderate metabolism) and are clones with sought-after agronomic characteristics (good productivity with resistance to diseases, stress, harsh climates). Table 1 provides information on the characteristics of experimental plots.
Table 1. Characteristics of experimental plots

<table>
<thead>
<tr>
<th>Clones</th>
<th>Tapping systems</th>
<th>Tapping year</th>
<th>Number of year of latex harvesting</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRCA 230</td>
<td>S/2</td>
<td>2010</td>
<td>3</td>
</tr>
<tr>
<td>PB 217</td>
<td>S/2</td>
<td>2010</td>
<td>2</td>
</tr>
<tr>
<td>GT 1</td>
<td>S/4U</td>
<td>1999</td>
<td>13</td>
</tr>
<tr>
<td>RRIC 100</td>
<td>S/4U</td>
<td>1999</td>
<td>14</td>
</tr>
<tr>
<td>GT 1</td>
<td>S/4U</td>
<td>1996</td>
<td>16</td>
</tr>
</tbody>
</table>

Technical material

The technical material used in this study consisted of field equipment and laboratory equipment for biochemical analysis.

The field equipment consisted mainly of knives (Fauna) and gouges for tapping trees, digital cameras for taking photos, notebooks for reporting the production of each tapper, scales to weigh farm gate yield, personal protective equipment kits for the personal protection of tappers (raincoat, rubber boots, goggles, jumper dress), flashlights for lighting tapping panels during unusual working hours, a cooler containing ice for conserving latex samples.

As for the laboratory equipment, it essentially consisted of micropipettes (EPPENDORF, 4924000053) for pipetting, precision electronic scales (KERN, PCB1000-2) for weighing latex samples, a water bath (JULABO, 9550522) for incubation, pillboxes for packaging the latex, an oven (MEmMERT, 764.300160.00) for drying the latex, a spectrophotometer (JENWAY, 7410) for reading the optical densities of the solutions.

Experimental design

The experiment was a comparative study of two tapping times according to tapping orientation (half-spiral downward tapping (S/2) and quarter-spiral upward tapping (S/4U)). The experimental design was in completely randomized Fisher blocks with two treatments and four repetitions. Each repetition constituted an elementary tapping plot. The trees were tapped every four days (d4) which gave four elementary plots per tapper.

In downward as well as in upward tapping, the treatments were therefore as follows:
- T0: Tapping from 6:00 a.m. (control)
- T1: Tapping from 4:30 a.m. The two treatments were made up of several elementary plots or tapping task. Each tapper tapped an elementary plot or tapping task per day. The plot of T0 and that of T1 had the same surface area (89 ha). The number of trees tapped per tapper and per day was 750. The trial was conducted from Monday to Saturday during three months.

Parameters measured

Latex yield depending on time

The sampling unit was the tapping portion. Ten trees were sampled per tapping portion and repeated 4 times in 5 tappers of each treatment, that is, a total of 400 sampled trees. Latex quantity measurements were carried out every 1 hour 30 minutes from tapping start for 6 hours of latex flow. A precision scale was used to measure the latex flow quantity every 1 hour 30 minutes. Labeled cups were positioned on the selected trees right after tapping and removed after 1h30min and then replaced automatically during these 6-hour flow. The volumes obtained were expressed in ml. The flow period of the treatment T1 was from 4:30 a.m. to 10:30 a.m. and that of the treatment T0 was from 6:00 to 12:00 a.m.

Dry rubber yield

The daily yield was harvested per tapper, it was then weighed using a scale. The farm-gate weight at the end of this weighing was converted into dry weight using a coefficient (0.65). The dry rubber yield was expressed as: - Gram per tree per tapping (g/t/t).

Physiological status (latex biochemical parameters)

Latex sampling

A sample of 10 trees was made up per tapping portion (elementary plot), on the 4 alternations. The sampling unit was the tapping task. The trees were chosen randomly. Latex samples were taken from under the gutter after tapping. A polyethylene tube was positioned under the gutter to collect 10 drops of latex per tree. After this phase, 1 ml of latex was taken with an automatic micropipette and placed in the corresponding pillbox for latex biochemical parameters assay.

Laboratory analysis

The serum obtained in the 30 ml pillboxes was filtered with Wattman filter paper and used for measuring physiological parameters’ concentration. The analysis was based on thiol, inorganic phosphorus (Pi) and sucrose content and on the dry rubber content represented here by the TSC (Total Solid Content) of the latex. The results of the sucrose, thiol and phosphorus (Pi) assay were expressed in millimoles per liter (mmol/l) from the coefficients of the standard ranges.

Thiol analysis

The thiol compounds (R-SH) were measured according to
the method of Boyne and Ellman (1972). The thiol compounds (R-SH) were assayed with dinitro-2,2'-dithio-5-5'-dibenzoyl acid or DTNB: the R-SH compounds react with DTNB to give TNB; the TNB was revealed by the Tris buffer (yellow coloration). To a volume of 1.5 ml of serum was added 0.5 ml of DTNB and then 1 ml of 0.5 M Tris. After shaking, the absorbance was read at the wavelength of 412 nm and compared to the control (1.5 ml of 2.5% TCA + 50 μl of DTNB + 1 ml of 0.5 M Tris).

**Phosphorus analysis**

The inorganic Phosphorus (Pi) was measured by the method of Taussky and Shorr (1953). The inorganic phosphorus (Pi) was assayed using Molybdate/Vanadate: the phosphorus is complexed by an excess of Molybdate/Vanadate; the complex formed is then reduced by ferrous sulfate, giving a blue color. To a volume of 0.5 ml of serum was added 1 ml of 2.5% TCA and then 3 ml of reagent. After cooling, the absorbance was read at the wavelength of 640 nm and compared to the control (1.5 ml of 2.5% TCA + 50 μl of DTNB + 1 ml of 0.5 M Tris).

**Sucrose analysis**

Sucrose was measured by the Ashwell anthrone method (Ashwell, 1957). In the presence of concentrated acid, the hexoses dehydrate to give furfural which reacts with anthrone giving a blue-green color. A volume of 0.1 ml of serum was added to 0.4 ml of 2.5% TCA; 3 ml of anthrone reagent was then added. The solution was homogenized and immersed in a boiling water bath for 15 min. After cooling, the absorbance was read at the wavelength of 627 nm and compared to the control (0.5 ml of distilled water + 1 ml of 2.5% TCA + 3 ml of reagent).

**Total Solid Content analysis (TSC or dry rubber content)**

The 15-ml pillboxes containing 1 ml of latex were weighed (Wf). These pillboxes were weighed beforehand empty (W0). The pillboxes were placed in an oven at 70°C for 24 hours. After these 24 hours, the pillboxes were weighed in order to determine the dry weight (Wd). The following formula was used for the calculation of the TSC (Total Solid Content) expressed as a percentage:

\[
TSC = \frac{(Wd - W0) \times 100}{(Wf - W0)}
\]

With: Wd: Pillbox weight + dry latex, Wf: Pillbox weight + 1 ml fresh latex, W0: Empty pillbox weight.

All these values of the biochemical parameters were assessed compared to the threshold values (Table 2).

**Data processing method**

The data obtained were subjected to statistical analyses carried out using R software version 3.3.1. The Student’s t-test was performed to compare the means of the parameters of two sample groups. A significant difference was observed when the probability (p) value of this test was below 5% threshold.

**RESULTS**

**Effect of tapping time on latex flow of the rubber tree clones studied**

Figures 1, 2, 3, 4 and 5 show the quantities of latex collected per time interval depending on the treatment (tapping from 6:00 a.m., T0 and tapping from 4:30 a.m., T1) and the clones. The quantities of latex were high for the first few hours, and decreased considerably over time regardless of the tapping time. The flow of latex from each treatment decreased considerably over time and tended to become nil for T0 in all clones. In contrast, the quantity of latex of the first period of flow (4:30 - 6:00 a.m.) of the tapping starting at 4:30 a.m. (T1) was always greater than that of the tapping starting at 6:00 a.m. (T0). However, the amount of latex in the tapping starting at 4:30 a.m. (T1) remained greater than that of T0 for clones IRCA 230 and GT 1. Conversely, for clones PB 217 and RRIC 100 the quantity of latex of T1 fell below that of T0 around 7:30 a.m. Thus, for clone IRCA 230 with treatment T1, the quantity of latex flow decreased from 95 to 55 ml and was greater than the one obtained with treatment T0, which decreased from 80 to 25 ml (Figure 1). The quantity of latex from the tapping starting at 6:00 a.m. tended to become nil at the end of these 6 hours of flow, while that of the tapping starting at 4:30 a.m. was still high.

In clone PB 217, the quantity of latex flow during the first period of flow between 4:30 and 6:00 a.m. of T1 was very abundant. It decreased considerably and fell below the quantity of latex of T0 from 7:30 a.m. (Figure 2). And both tended to become nil at the end of the 6 hours of flow. The quantity of latex flow decreased from 117 to 25 ml for T1

| Table 2. References values of latex biochemical parameters (Jacob et al., 1987) |
|-----------------|-----------------|-----------------|-----------------|
|                | TSC (%)          | Sucrose content (mmol/l) | Pi content (mmol/l) | Thiol content (mmol/l) |
| Very high      | > 43             | > 12              | > 25             | > 0.90            |
| High           | 38 - 43          | 9 - 12            | 20 - 25          | 0.80 - 0.90       |
| Average        | 33 - 38          | 6 - 9             | 15 - 20          | 0.60 - 0.80       |
| Weak           | 29 - 33          | 4 - 6             | 10 - 15          | 0.50 - 0.60       |
| Very weak      | < 29             | < 4               | < 10             | < 0.50            |

References values of latex biochemical parameters (Jacob et al., 1987)

- TSC: (Total Solid Content) or dry rubber content
- Sucrose: measured by the Ashwell anthrone method
- Pi: measured by the method of Taussky and Shorr
- Thiol: assayed with dinitro-2,2'-dithio-5-5'-dibenzoyl acid or DTNB
and was greater than the one obtained with treatment T0 which decreased from 85 to 20 ml.

In clone RRIC 100, the quantity of latex flow during the first flow period, between 4:30 and 6:00 a.m. of T1, was greater than that of the other periods, but fell below that of T0 around 7:30 a.m. with a small gap (Figure 3). The quantity of latex flow gradually dropped from 205 to 98 ml for T1 and was greater than the one obtained with method T0 which decreased from 175 to 20 ml. The quantity of latex of T0 tended to become nil at the end of these 6 hours of flow while that of T1 always remained high.

The clone GT 1 with 16 years of latex harvesting (year of planting: 1996), showed latex flow variation different from the one with 13 years of latex harvesting (year of planting: 2001).
For GT 1 (1996), the quantity of latex flow during the first flow period, between 4:30 and 6:00 a.m. of T1, was greater than that of the other periods (Figure 4). It always remained greater than that of T0; the latter tended to become nil after these 6 hours of flow. The quantity of latex decreased from 135 to 75 ml for T1. The one obtained with treatment T0 decreased from 104 to 37 ml.

For GT 1 (1999), the quantity of latex flow during the first period of flow, between 4:30 and 6:00 a.m. of T1, was very abundant, it decreased considerably and fell below that of T0 between 7:30 and 9:00 a.m (Figure 5). The quantity of latex decreased from 163 to 75 ml for T1 and from 125 to 45 ml for T0.

**Effect of the tapping time on dry rubber yield in gram per tree per tapping (g/t/t)**

Figure 6 shows the effect of tapping starting at 6:00 a.m.
(T0) and tapping starting at 4:30 a.m. (T1) on dry rubber yield expressed in grams/tree/tapping (g/t/t) for each clone studied. The average rubber yield obtained with the tapping starting at 4:30 was 111 g; 101 g; 126 g; 130 g and 112 g respectively for clones IRCA 230, PB 217, GT 1 (1996), GT 1 (1999) and RRIC 100 against 87 g; 78 g; 94 g; 101 g and 101 g for tapping starting at 6:00 a.m. The Student's t-test carried out showed that the average rubber yield obtained by tapping starting at 4:30 a.m. (T1) was significantly greater than the one obtained with tapping starting at 6:00 a.m. (T0) for the clones studied except clone RRIC 100 where the average yield of both methods remained statistically identical.

Effect of tapping time on the physiological status of rubber tree clones studied

The comparative analysis of latex biochemical parameters of the different clones studied subjected to the treatments revealed differences at the intra-clonal and extra-clonal level in S/2 and in S/4U.

Clone PB 217

The contents of latex biochemical constituents of clone PB 217 rubber trees and the total solid content (TSC) varied depending on the treatments (Table 3). The sucrose and Pi contents of the both treatments were higher than the mean reference values. However, the thiol contents were within the range of the reference values. Moreover, the TSC of tapping starting at 6:00 a.m. was included in the range of reference values while that of tapping starting at 4:30 a.m. was higher than these values. The average sucrose, thiol and inorganic phosphorus contents of rubber tree latex of the control treatment (T0) (15.35; 0.68 and 25.51 mmol/l respectively) were significantly higher than those of the test treatment (T1) (11.01; 0.60 and 20.24 mmol/l respectively). However, the TSC of the latex obtained with treatment T1 (38.04%) was significantly higher than that of treatment T0 (32.84%).

Clone IRCA 230

The contents of latex biochemical constituents of clone IRCA 230 rubber trees and the total solid content varied depending on the treatments (Table 4). The sucrose contents of the latex of the rubber trees from the tapping tested were lower than those of the reference values. The thiol and Pi contents of rubber tree latex of both treatments were within the reference range. The TSC values of both treatments were higher than the average reference values. The sucrose, thiol and Pi contents and the TSC for tapping starting at 4:30 a.m. (4.76, 0.53, 20.15 mmol/l respectively and 40.50%) were higher than those of tapping starting at 6:00 a.m. (4.17, 0.51, 18.03 mmol/l and 39.97%). However, these values were statistically identical for both treatments.

Clone RRIC 100

Table 5 presents the results of the analysis of the biochemical parameters of clone RRIC 100. The sucrose, thiol and Pi contents of the latex of the rubber trees of both treatments had an average level. Conversely, the total solid content (TSC) was very high for both treatments. The
**Figure 6**: Dry rubber yield (g/t/t) depending on the tapping time

\( t \): student's test value \hspace{1cm} \( p \): probability associated to student's test

**Table 3.** Biochemical parameters of the latex of clone PB 217 depending to the tapping time

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Biochemical parameters</th>
<th>T0</th>
<th>T1</th>
<th>( t )</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clone IRCA 230</td>
<td>Sucrose contents (mmol/l)</td>
<td>15.35 ± 1.16</td>
<td>12.01 ± 1.56</td>
<td>7.059</td>
<td>0.0000013</td>
</tr>
<tr>
<td></td>
<td>Thiols contents (mmol/l)</td>
<td>0.68 ± 0.006</td>
<td>0.60 ± 0.09</td>
<td>7.059</td>
<td>0.000002</td>
</tr>
<tr>
<td></td>
<td>Pi contents (mmol/l)</td>
<td>25.51 ± 1.80</td>
<td>20.24 ± 5.1</td>
<td>4.23</td>
<td>0.0013</td>
</tr>
<tr>
<td></td>
<td>TSC (%)</td>
<td>32.84 ± 0.20</td>
<td>38.04 ± 4.9</td>
<td>3.65</td>
<td>0.0052</td>
</tr>
</tbody>
</table>

\( t \): student's test value \hspace{1cm} \( p \): probability associated to student's test
biochemical constituents of tree latex were influenced by the practice of tapping starting at 4:30 a.m. The sucrose, thiol and Pi contents of tapping starting at 4:30 a.m. (9.43; 0.76 and 18.44 mmol/l respectively) were significantly higher than those of tapping starting at 6:00 a.m. (7.34, 0.56 and 10.98 mmol/l respectively). However, the total solid content of tapping starting at 6:00 a.m. (45.91%) and that of tapping starting at 4:30 a.m. (45.13%) were statistically equivalent.

**Clone GT 1**

Table 6 shows the effect of the different treatments on the biochemical parameters of the latex of clone GT 1 (year of planting: 1996). The sucrose, thiol and Pi contents of the latex of the rubber trees of both treatments had an average level. In contrast, the total solid content (TSC) of tree latex of each treatment was very high. The sucrose content of tapping starting at 4:30 a.m. (8.62 mmol/l) and that of tapping starting at 6:00 a.m. (8.21 mmol/l) were statistically identical. However, the thiol and Pi contents as well as the total solid content of the latex of trees subjected to tapping starting at 4:30 a.m. (0.69 mmol/l, 15.41 mmol/l respectively and 50.89%) were higher than those of latex from trees subjected to tapping starting at 6:00 a.m. (0.55 mmol/l, 12.80 mmol/l respectively and 48.68%).

The contents of latex biochemical constituents of clone GT 1 (tapping year: 1999) rubber trees and the total solid content (TSC) varied depending on the treatments (Table 7). The sucrose, thiol and Pi contents of the latex of the rubber trees of both treatments had an average level. However, the total solid content (TSC) was very high for both tapping methods. The sucrose, thiol and Pi contents of the latex of trees subjected to tapping starting at 4:30 a.m. were statistically identical to those of trees subjected to tapping starting at 6:00 a.m. The sucrose contents of tapping starting at 4:30 a.m. (8.87 mmol/l) were statistically equivalent to those of tapping starting at 6:00 a.m. (8.21 mmol/l). However, the thiol and Pi contents of the latex of trees subjected to tapping starting at 4:30 a.m. (0.72 mmol/l and 14.66 mmol/l respectively) were significantly higher than those of trees subjected to tapping starting at 6:00 a.m. (0.59 mmol/l and 12.48 mmol/l respectively). Similarly, the TSC obtained with tapping

### Table 4. Latex biochemical parameters of clone IRCA 230 depending on the tapping time

<table>
<thead>
<tr>
<th>Biochemical parameters</th>
<th>Treatments</th>
<th>T0</th>
<th>T1</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose contents (mmol/l)</td>
<td></td>
<td>4.17 ± 0.85</td>
<td>4.76 ± 0.29</td>
<td>2.07</td>
<td>0.063</td>
</tr>
<tr>
<td>Thiol contents (mmol/l)</td>
<td></td>
<td>0.51 ± 0.09</td>
<td>0.53 ± 0.09</td>
<td>0.48</td>
<td>0.637</td>
</tr>
<tr>
<td>Pi contents (mmol/l)</td>
<td></td>
<td>18.03 ± 1.8</td>
<td>20.15 ± 6.75</td>
<td>4.23</td>
<td>0.3818</td>
</tr>
<tr>
<td>TSC (%)</td>
<td></td>
<td>39.97 ± 1.67</td>
<td>40.50 ± 2.80</td>
<td>3.65</td>
<td>0.6095</td>
</tr>
</tbody>
</table>

**t**: student’s test value  **p**: probability associated to student’s test

### Table 5: Latex biochemical parameters of clone RRIC100 depending on the type of tapping time

<table>
<thead>
<tr>
<th>Biochemical parameters</th>
<th>Treatments</th>
<th>T0</th>
<th>T1</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose contents (mmol/l)</td>
<td></td>
<td>7.34 ± 0.50</td>
<td>9.43 ± 0.41</td>
<td>14.30</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Thiol contents (mmol/l)</td>
<td></td>
<td>0.56 ± 0.003</td>
<td>0.76 ± 0.016</td>
<td>51.87</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Pi contents (mmol/l)</td>
<td></td>
<td>10.98 ± 0.43</td>
<td>18.41 ± 1.65</td>
<td>19.49</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>TSC (%)</td>
<td></td>
<td>45.91 ± 6.26</td>
<td>45.13 ± 3.08</td>
<td>0.50</td>
<td>0.6172</td>
</tr>
</tbody>
</table>

**t**: student’s test value  **p**: probability associated to student’s test

### Table 6. Latex biochemical parameters of clone GT 1 (1996) depending on the tapping time

<table>
<thead>
<tr>
<th>Biochemical parameters</th>
<th>Treatments</th>
<th>T0</th>
<th>T1</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose contents (mmol/l)</td>
<td></td>
<td>8.21 ± 2.21</td>
<td>8.62 ± 2.01</td>
<td>0.86</td>
<td>0.93</td>
</tr>
<tr>
<td>Thiol contents (mmol/l)</td>
<td></td>
<td>0.55 ± 0.09</td>
<td>0.69 ± 0.06</td>
<td>8.43</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Pi contents (mmol/l)</td>
<td></td>
<td>12.00 ± 2.60</td>
<td>15.41 ± 4.30</td>
<td>3.25</td>
<td>0.0018</td>
</tr>
<tr>
<td>TSC (%)</td>
<td></td>
<td>48.68 ± 2.29</td>
<td>50.89 ± 2.20</td>
<td>3.76</td>
<td>0.0003</td>
</tr>
</tbody>
</table>

**t**: student’s test value  **p**: probability associated to student’s test
starting at 4:30 a.m. (51.56%) was higher than the one obtained with tapping starting at 6:00 a.m. (49.88%).

**DISCUSSION**

**Effect of the tapping time on latex flow**

The two curves of the quantity of latex obtained from trees belonging to both treatments of each clone showed a decreasing trend. This reflects that the flow of latex from each treatment decreased considerably over time. The initial quantity and the flow variation of the studied clones differed. This result shows that the yield differs depending on the clones and the year of latex harvesting. Our result is similar to those of Lioret et al. (1978) who showed that the flow rate of latex from rubber clones PR 107 and RRIM 501 decreases considerably over time with different initial quantities. Clone PR 107 had an initial flow of 17 ml/min with a flow time of 300 min and clone RRIM 501 had an initial flow of 5.3 ml/min with a flow time of 550 min. The curve of the quantity of latex from the tapping starting at 6:00 a.m. dropped considerably and tended to become nil during the last hours of flow. That of tapping starting at 4:30 a.m. gradually decreased and remained at a high level after these 6 hours of flow. The quantity of latex from the first flow period in all the clones subjected to tapping starting at 4:30 a.m. was more abundant than that of tapping starting at 6:00 a.m. Indeed, this larger initial quantity of latex which is obtained with the tapping starting at 4:30 a.m. could be explained by the fact that during this period, the temperature is low, the hygrometry is high and the turgor pressure of the laticiferous vessels is strong (Compagnon, 1986). These conditions induce a great elasticity of cell walls and laticiferous vessels hence a great expulsion of the contents of laticiferous vessels. However, a sunny period during which the temperature increases with low humidity, would reflect the low quantity of latex (which tends to become nil) obtained during the last period of these 6 hours of flow in rubber trees subjected to tapping starting at 6:00 a.m. These environmental conditions would favor a reduction in the diameters of the plasmodesmata and a low turgor pressure of the laticiferous vessels due to the obstruction of the laticiferous vessels which results from latex coagulation (Compagnon, 1986).

According to Yeang (2005), the rapid latex flow observed immediately after tapping is attributed to the high phloem turgor pressure (that is of an order of 10 atmospheres) of the laticifer system before tapping. The sharp decrease in latex flow immediately after tapping is explained by turgor loss. According to An et al. (2014), phloem turgor pressure is the initial driving force for latex flow after a rubber tree is tapped and therefore plays an important role in rubber tree latex production. The daily change of PTP in the foliation season suggests that a high PTP can ensure a high latex yield and tapping could be moved forward to midnight or earlier in the night. On the other hand, the effect of latex vessel plugging, in which lutoid damage plays a role, becomes more prominent towards the end of flow (Ribaillier, 1970; Pujarnisquelle and Ribaillier, 1970; Yeang, 2005). The two variables, turgor pressure and cumulative latex vessel plugging, when taken together account for 99% of the variation in flow rate from the time of tapping until the cessation of flow. Latex flow rate can be expressed as a function of the laticifer turgor pressure and time (Yeang, 2005).

Our results confirm that tapping time is crucial for the yield, the more it is very early in the morning, the higher it favors good latex flow. The earlier start of tapping allows a slowing down of latex coagulation and an increase in harvests.

**Effect of the tapping time on dry rubber yield**

The average dry rubber yield in grams per tree and per tapping (g/t/t) showed a significant difference between treatments T0 and T1 with an average yield of T1 higher than that of T0 in clones IRCA 230, PB 217 and GT 1. This result confirms that treatment T1 is more productive for these clones. This assertion is confirmed by the results of Diarrassouba et al. (2012) who obtained an average dry rubber yield of 50 g/t/t in clone PB 217 which is half of the yield (101 g/t/t) obtained with the practice of tapping starting at 4:30 a.m. for the same clone. Coulibaï et al. (2017) obtained a dry rubber yield of 73 g/t/t in clone PB 235, lower than that obtained by tapping starting at 4:30 a.m. (111 g/t/t) in this study in clone IRCA 230 belonging to the same metabolic activity class.

For clone RRIC 100, both types of tapping induced statistically identical average dry rubber yields. This result attests that both types of tapping are productive for this clone and that treatment T1 does not influence the yield.

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**Table 7. Latex biochemical parameters of clone GT 1 (1999) depending on the tapping time**

<table>
<thead>
<tr>
<th>Biochemical parameters</th>
<th>T0</th>
<th>T1</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose contents (mmol/l)</td>
<td>8.14 ± 2.46</td>
<td>8.87 ± 1.71</td>
<td>0.64</td>
<td>0.399</td>
</tr>
<tr>
<td>Thiols contents (mmol/l)</td>
<td>0.59 ± 0.11</td>
<td>0.72 ± 0.07</td>
<td>7.36</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Pi contents (mmol/l)</td>
<td>12.48 ± 3.20</td>
<td>14.66 ± 3.80</td>
<td>3.12</td>
<td>0.0022</td>
</tr>
<tr>
<td>TSC (%)</td>
<td>49.88 ± 3.80</td>
<td>51.56 ± 3.60</td>
<td>4.07</td>
<td>0.0004</td>
</tr>
</tbody>
</table>

* t: student's test value  p: probability associated to student's test
Our results confirm the works of Nayanakantha et al. (2022) in the district of Moneragala (Sri Lanka). These authors showed that on clone RRIC 121, tapping during 04:00 a.m.-06:30 a.m., 03:00 a.m.-05:30 a.m. and 02:00 a.m.-04:30 a.m. may contribute to an increase in latex crop respectively by 1.6%, 3.3% and 5.1% compared to the tapping during 05:00 a.m.-07:30 a.m. (control).

In view of all these results, it appears that tapping starting at 4:30 a.m. gives better yield than normal tapping. Indeed, the earliest tapping favors a high flow rate and an extension of the latex flow time, thus increasing rubber yield.

**Effect of the tapping time on the physiological status of clones**

Analysis of the physiological condition of the trees showed an overall difference between the trees of T0 and T1 with an intra and extra-clonal variation.

In clone IRCA 230, a similarity in biochemical parameter contents was observed at the level of both treatments. This result allows us to confirm that biochemical parameters are not influenced by the tapping time. The functioning of the trees is normal, because the values obtained are within the norm of the mean values defined by Jacob et al. (1987).

The latex diagnosis of clone PB 217 showed biochemical parameter values that were significantly different between both treatments tested. These values obtained were either within the norm of the mean values, or higher than these mean values. The sucrose and Pi contents of both times of tapping start were high compared to the mean values, clone PB 217 belonging to the slow-metabolic activity class. Clones of this class have a very high sucrose content; in contrast, they have a low inorganic phosphorus (Pi) content (Anonymous, 1993). The latex from tapping starting at 6:00 a.m. had high sucrose and Pi contents compared to those from tapping starting at 4:30 a.m. Conversely, the total solid content of tapping starting at 6:00 a.m. were lower than those of tapping starting at 4:30 a.m. The higher total solid content from tapping starting at 4:30 a.m. could be explained by the fact that a large quantity of carbohydrate reserves is used for the production of rubber. This would explain the lower sucrose contents of the latex of trees subjected to tapping starting at 4:30 a.m. However, the high sucrose content with lower total solid content of the latex from tapping starting at 6:00 a.m. reflects a low biosynthetic activity for rubber production. This explains the greater production obtained with tapping starting at 4:30 a.m. compared to tapping starting at 6:00 a.m.

The average sucrose content with higher total solid content justifies significant biosynthetic activity for the production of rubber in clone RRIC 100. The sucrose, thiol and phosphorus contents of tapping starting at 4:30 a.m. were significantly higher than those of tapping starting at 6:00 a.m. However, their total solid content remained identical and very high compared to the mean reference values. The average sucrose, thiol and Pi contents of both periods of tapping favor good rubber production. This result is similar to those of Adou et al. (2017) who, in a study of tapping and stimulation frequencies in clone RRIC 100 (with tapping every four days and 8 annual stimulations) obtained high total solid content with average sucrose, thiol and Pi contents.

In clone GT 1 (clone planted in 1996 and 1999), the average sucrose, thiol and Pi contents of the latex of the trees of each period of tapping were average. These values show a good metabolism in this rubber tree clone whatever the tapping time.

In short, the physiological profile analyzed on the basis of the references defined by Jacob et al. (1987) makes it possible to assert that tapping starting at 4:30 a.m. has no negative effect on the physiological condition of trees. The thiol group contents in the latex were of an average level. These RSH values reflect a certain stability of rubber tree latex as shown by Coulibaly et al. (2017) on clone PB 235. The average Pi contents of the latex of tapping starting at 4:30 a.m. trees indicate an availability of energy necessary for the activation of the metabolism within the lactiferous vessels. These results are in agreement with those of Lacote et al. (2010) who showed that the metabolic activation of energy within lactiferous vessels is governed by the average intrinsic energy produced by Pi.

**CONCLUSION**

At the end of this comparative study between tapping starting at 6:00 a.m. (normal tapping) and tapping starting at 4:30 a.m. (earlier morning tapping), with a view to reducing the effects of climate change on rubber yields in rubber tree cultivation, it appears that the tapping starting at 4:30 a.m. is more beneficial than the tapping starting at 6:00 a.m.

Indeed, with the tapping starting at 4:30 a.m., the quantities of latex are greater in the first hours and remain high at the end of 6-hour flow, while with the one starting at 6:00 a.m., the quantities of latex are less significant in the first hours and tend to stop at the end of 6-hour flow. Latex flow time is therefore longer with the tapping starting at 4:30 a.m. compared to the one starting at 6:00 a.m.

Moreover, the tapping starting at 4:30 a.m. induces dry rubber yield gains per tree and per tapping (g/t/t) of 20% on average compared to the tapping starting at 6:00 a.m. regardless of the clone (GT 1, PB 217, IRCA 230 and RRIC 100).

Finally, the tapping starting at 4:30 a.m. has no negative effect on the physiological profile of the rubber trees. On the contrary, it improves their physiological status with values of physiological parameters higher than those of the tapping starting at 6:00 a.m.

The tapping starting at 4:30 a.m. therefore appears as an alternative to reduce the harmful effects of climate change characterized by an increase in temperatures and a drop in relative humidity leading to a decrease in rubber yield.

This study on earlier morning tapping is not exhaustive.
Further work should be done in the following areas:
- Assess the effect of earlier morning tapping on the growth and tapping panel dryness rate of trees;
- Assess the effect of earlier morning tapping on tapping quality and tappers' health condition;
- Extend this study to other rubber tree clones, in other rubber-growing regions and over the long term.

ACKNOWLEDGMENTS

We are thankful to the Société Africaine de Plantation d'Hévéa (SAPH) for providing the financial and technical facilities to conduct this research.

Conflict of interests

The authors declare that they have no conflicting interests.

REFERENCES


