Exploring carbon allocation patterns using natural carbon isotope abundance in oil palm in a North Sumatra environment

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Introduction

Oil palm trees (*Elaeis guineensis* Jacq) produce more than 20 kilograms fruits per bunch. Such high productivity implies large carbon fluxes to reproductive tissues and high integrated leaf CO_2 assimilation to sustain lipid production. Here, we use $^{12}C/^{13}C$ isotope ratio as natural tracer to identify the origin of carbon atoms remobilized to produce fruit tissues until maturation. In fact, the carbon used for reproductive development may originate from trunk and roots (storage organs) or leaves. Therefore, in order to understand the patterns of carbon fluxes between autotrophic sources (leaves) and heterotrophic organs (fruits) within oil palm trees, the natural carbon isotope composition ($\delta^{13}C$) of total organic matter (OM) and soluble sugars as well as lipids and starch from samples collected in the field (in Sumatra) was investigated. Only leaves, trunk and fruits will be treated here. Our current study focuses on compound-specific isotopic analyses (starch, soluble sugar and lipids) so as to better characterize isotopic fractionations and draw hypotheses on tree-level carbon trafficking pathways between photosynthetic assimilates, carbon reserve pools and fruit/oil carbon.

1 The leaf

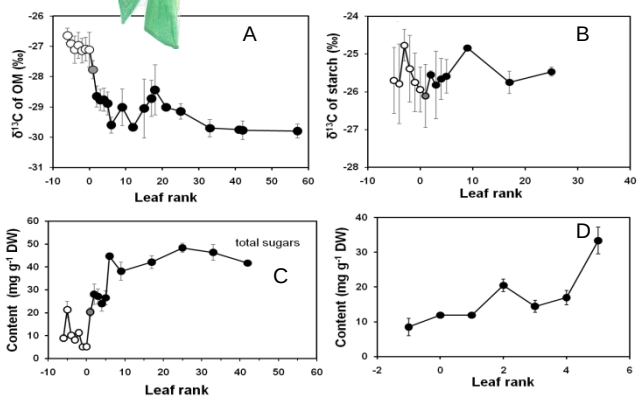


Fig. 1. A ,B,C,D. A: variation of carbon isotope composition ($\delta^{13}C$) of OM among leaf ranks. For A,B, C : white circles : heterotrophy, grey : rank 1, black circle : autotrophy. B: variation of isotope signature of starch along leaf ranks. C: variation of total sugars along leaf ranks. D : variation of starch content from -1 to rank 5. Data points : means SD.

Material & Methods

Sampling was conducted at Aek Pancur Research Station (3 30'N, 98 48'E, North Sumatra, Indonesia) since 2003 until 2007 on ten trees (clone material *Dura x Pisifera*) planted in 1995. Samples were freeze-dried and reduced in powder, which was used for extraction of soluble sugars, lipids and starch. The quantification of starch and lipids were carried out by weighting. Soluble sugars were analysed by HPLC which has no action on fractionnation (Duranceau et al.,1999). The Liquid Chromatography separation (803C-302, Gilson) is made with a cation exchange column and is detected by a refractometer (Gilson133). Carbohydrates are manually collected, dried and weighed in tin capsules. OM and individual compounds were transferred in tin capsules for isotope composition analyses using an elemental analyser (FlashEA 1112, ThermoFisher) coupled with an isotope-ratio mass spectrometer (Optima , Elementar). The isotopic values were expressed in delta notation (in ‰ unit) relative to VPDB.

Results

2 The bunch & the fruits

Fruit organic matter appears progressively ^{13}C-depleted as maturation proceeds, from –26.9‰ after 2 months to –-28.8 ‰ six months after pollination (Fig. 2A). This effect is related to the conversion of sugars –here starch seems to be more involved than soluble sugars (Fig. 2C,D) - to lipids (oleosynthesis, Fig. 2B), which are known to be strongly ^{13}C-depleted as compared to other metabolites. The transitory sugar could be the fructose (Fig. 2D) which increased between stage 2 and 3. Still, our results suggest that the $\delta^{13}C$ value at the beginning of fruit development is enriched compared to leaf-assimilated carbon, indicating that unless particular isotopic fractionations occur, carbon remobilization from other organs such as roots and trunk sustain fruit initiation.

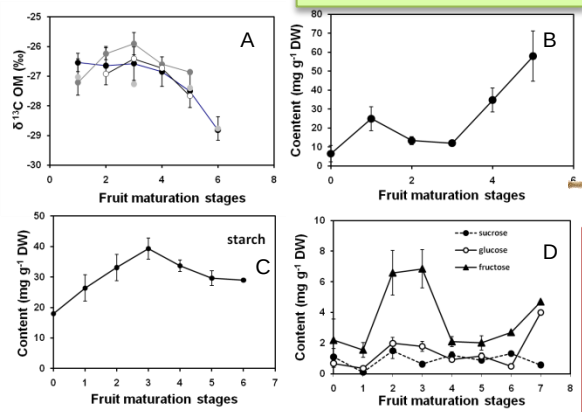
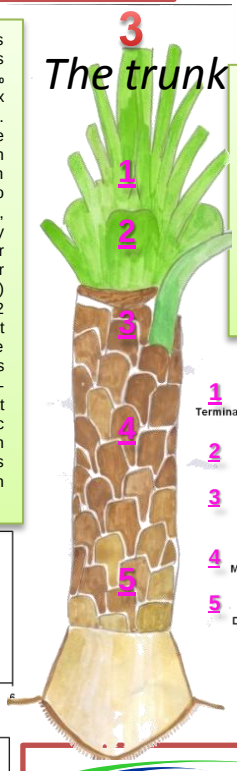


Fig. 2 A,B,C,D. Fruits evolution during maturation stages. A : variation of carbon isotope composition ($\delta^{13}C$) from stages 0 (before blooming), 1 : one month after pollination, 2 : two months after until 6 : six months after. B: variation of total lipids contents with maturation stages. C variation of starch contents with maturation stages. D: variation of soluble sugars with maturation stages. Data points : means SD.

3 The trunk



Our first results (Fig. 1 A,B,C,D) on leaves (Lamade et al., 2009) reveal significant difference in $\delta^{13}C$ of OM between young, heterotrophic leaves (leaf rank from –6 to 0), mature leaves (from rank 1, which is the first stage of leaf autotrophy) and old leaves (above rank 8): young leaves are significantly ^{13}C-enriched compared to older, autotrophic leaves. A strong increase of starch content from -2 to 5, during leaf growth, is observed especially at the full functioning of the leaf. After a small drop of the soluble sugars around rank 0, a strong increase of them is observed when the leaf is autotrophic corresponding to a strong photosynthetic assimilate production.
Along trunk height (Fig. 3 A,B,C) more ^{13}C-enriched OM is seen at the trunk top (Fig. 3A) where is located growth activity (meristem, terminal bud) and at the bottom related to the roots emergence. Starch (Fig. 3C), at the terminal bud, seems dedicated to new leaves elaboration. Sucrose (Fig. 3B), mostly located in the heart, could play a determinant role in sexualisation and bunch initiation.

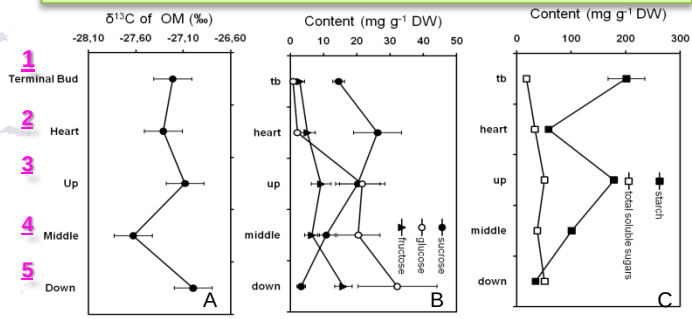


Fig. 3 A,B,C. A: variation of carbon isotope composition ($\delta^{13}C$) along trunk height from the top (terminal bud, heart , up) to the middle until the bottom (down). B: variation of solubles sugars content along trunk height (sucrose : black circle, glucose : white circle, , fructose : black triangle). C : variation of starch content and total soluble sugars along height . Data points : means SD.

Conclusion

Fruit filling is the result of a strong leaf activity (production of soluble sugars and starch) identified by a ^{13}C-depleted signature of OM at mature leaf rank, then a translocation of starch and sucrose in trunk (^{13}C-enriched signature at the trunk top), following by a remobilisation of the starch in the young fruits after pollination until oleosynthesis. At 6 months, a ^{13}C-depleted signature of OM in fruits shows the lipids elaboration most probably from a transitory soluble phase (fructose). $^{12}C/^{13}C$ isotope ratio may help to identify the origin of carbon involved in oil palm fruit bunches elaboration.

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