INNSPUB

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print), 2222-5234 (Online)
http://www.innspub.net
Vol. 19, No. 4, p. 95-107, 2021

RESEARCH PAPER OPEN ACCESS

Effect of sunshine on the evolution of morphological and physicochemical parameters of preharvest mangoes (*Mangifera indica* L.)

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Key words: *Mangifera indica*, Morphological and physicochemical parameters, Sunshine, Temperature, Harvest time

http://dx.doi.org/10.12692/ijb/19.4.95-107 Article published on October 27, 2021

Abstract

To reduce post-harvest losses due to an uncontrolled harvest date, the effects of sunshine on the ripening of mangoes on trees were studied in the Kent variety intended for export from Côte d'Ivoire. On trees, some mangoes exposed to direct daily sunlight (DDS) and others shaded by the leaves, therefore subject to indirect daily sunlight (IDS) were monitored. Mangoes growth and development were accessed through morphological (weight, length, circumference and volume) and physicochemical (firmness, pulp color, total sugars, reducing sugars, flavonoids and tannins) parameters. Furthermore, temperature induced by daily sunlight was recorded until harvest. The obtained results showed that, except for pulp firmness and coloration, indirect sun exposure (IDS) increased more rapidly morphological parameters than direct sun exposure (DDS). For example, 78 days after fruit set; IDS increased faster (0.46 kg/week) mangoes weight than DDS (0.37 kg/week). However, mangoes physicochemical parameters changed faster under DDS than under IDS. Investigation of daily temperature effect on mango parameters evolution revealed that low temperatures (28.72; 30.22; 30.53°C) promoted morphological growth while high temperatures (31.55; 31.56; 32.55°C) rapidly evolved mango internal physicochemical parameters. Consequently, sun direct exposition (DDS) reduce mangoes harvest time than indirect exposition i.e. shadiness under leaves (IDS). Sunshine can now be harnessed by dropping branches in orchards after the mango trees have fruited. This is so that the maximum number of mangoes are exposed to the sun on the tree. Thus, quality of the harvested mangoes is improved and mangoes will be competitive in the international market.

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Introduction

Mango is known as an edible stone fruit produced by the tree *Mangifera indica*. Mangos trees grow in tropical and subtropical climates throughout the world (Dambreville, 2012). This edible fruit includes a large and varied range of nutrients. This makes it an exceptional nutritional quality (Djioua, 2010). Mango production is approximately 36 % of the world's tropical fruit production (FAOSTAT, 2001). Since its exportation, mango holds a prominent place in the Ivorian economy; making it the top mango exporter in West Africa (Mieu, 2017). The North is currently the main mango producing area for export in Côte d'Ivoire (Hala *et al.*, 2007). Mango generates substantial incomes for the local population. The Kent variety by itself contributes 60-70 % of these exports (Rey *et al.*, 2004). This is due to its very slow and gradual ripening process, which prevents rotting and improves storage (Touré, 2012). Moreover, the Kent mango variety offers more interesting sensory qualities than other commercialized varieties (Belem *et al.*, 2017). That is why it was considered as the reference for mangoes traded in the European Union. However, each year producers and exporters who are the mango sector main actors encounter numerous losses due to the uncontrolled harvest time. In fact, when harvested too early, mangoes shrivel up without really ripening, whereas harvested too late, their shelf life remains very limited. According to FIRCA (2011), because of their extremely high perishability, the mangoes post-harvest losses range between 30 and 40%. According to FIRCA (2011), the postharvest losses of mangoes are between 30 and 40 % thus showing their high perishability.

In addition, the difficulties encountered for better marketing include the optimum stage determining for harvesting mangoes and maintaining fruit during transport (Gomez, 1997; Johnson *et al.*, 1997). In mango tree, fruit exposure or not to the sun in preharvest influences their suitability for transport, storage and ripening (Ferguson et al., 1999); i.r. the final quality of the mangoes offered to consumers. Therefore, obtaining and maintaining satisfactory quality levels, capable of meeting market requirements, involves controlling the harvest date and the suitability of mangoes for storage. For this, methods based on physicochemical parameters such as the level of sugar, acidity, dry matter, starch, color of the pulp and firmness exist. They make it possible to assess the level of maturity and the harvest date of the fruit (Valente *et al.,* 2004).

Therefore, morphology-based methods were used to determine the level of maturity and predict the harvest date of mangoes. However, these knowledge leads to a high degree of uncertainty on these methods due to climate change. So take into account Factors such as sunshine are essential for long-lasting and high-quality mango production. However, this knowledge leads to a high degree of uncertainty about these methods, due to climate change. So take into account factors such as sunshine are essential for long-lasting and high-quality mango production. Moreover, Ganry (1978) reported that in bananas, the amount of heat received by the fruits during ripening could allow an estimate of their harvest date. In the mango tree, very few studies were carried out in these areas.

Thus, knowing the evolution of the morphological and physicochemical parameters of mangoes under sunshine effect could be an interesting tool to estimate the harvest date. This will allow the mango harvesting campaign for export to be organized with great flexibility and dexterity. This, in order to improve the quality of mangoes from Côte d'Ivoire. Therefore, the aim of the present study was to reduce postharvest losses by controlling the harvest date of mangoes of Kent variety, intended for export.

Materials and methods

Plant material

The trial was carried out in an experimental orchard of the National Agronomic Research Center (CNRA), in Lavononka in the north of Côte d'Ivoire (9 ° 22'56 "N; 5 ° 33'39" W). The trial was conducted on 10-year-old cultivar Kent mango trees. Kent was the most cultivated cultivar of mangoes in Côte d'Ivoire and was intended for export. The mangoes on the tree were constituted the plant material (Fig. 1).

Methods

Selection of study plot, experimental mangoes and daily temperature measurements

Experiments were carried out in a square orchard of 100 Kent mango trees. Orchard was chosen based on the careful respect of the mango technical itinerary: regulatory spacing of mango trees (10 m on the lines and 10 m between lines) and field maintenance (pruning, weeding, fertilizers, phytosanitary treatments). In view of minimizing a possible effect of soil fertility heterogeneity, the mango orchard was subdivided into four identical blocks of 25 mango trees each (Figure 2) for random sampling. Within each block, blooms of the same age and exposed to direct daily sunlight (DDS) and indirect daily sunlight (IDS) were identified and tagged on trees. After their development, 30 mangoes of the same age (resulting from fruit set on the same date) were randomly selected and tagged with string within each block, of which 15 were outside the foliage and hence directly exposed to the sun (DDS) and the other, 15 inside foliage and therefore indirectly exposed to the sun (IDS). Fifty days after fruit set, three mangoes were harvested per block (hence 12 mangoes in the orchard) each week for morphological and physicochemical analysis. From fruit set to harvest, daily-occurred temperatures were automatically monitored with a thermo-hygrometer (tinytag) installed in the orchard.

Determination of mangoes morphological parameters

The morphological parameters concerned mangoes size (length, circumference and volume), weight and appearance. Mangoes length, from the point of peduncle insertion to fruit beak, was measured with a caliper. Each week, their weight was determined using an electronic balance (20 g sensitivity). Mango circumference was measured on the largest width using a tape measure. Fruit volume was determined by the difference in water displacement levels. Indeed, in a large graduated beaker of 2000 ml containing initial volume of water (Vi = 1000 ml), mangoes were immersed until complete submersion. The final volume (Vf) corresponded to the water (Vi) + the mango (Vm). Therefore, the mango corresponding volume (Vm) was determined by the difference between the final volume (Vf) and the initial volume (Vi) through the following formula: $Vm = Vf - Vi$, where Vm was mango volume, Vi was water initial volume and Vf was water final volume.

Determination of mangoes aspects and physicochemical parameters

The mango physicochemical parameters analyzed were ethano-soluble sugars, total sugars, phenolic compounds, tannins, fruit firmness and pulp coloration. Mango pulp ethano-soluble sugars were extracted using the method of Martinez-Herrera *et al.* (2006) and quantified using method of Bernfeld (1955). Total sugars were determined according to method of Dubois *et al.* (1956). Phenolic compounds were extracted and determined following Singleton *et al.* method (1999) and flavonoids, according to Meda and *al.* (2005). Tannins content was determined according to Bainbridge and *al* (1996). Mangoes firmness was measured with a crossbow penetrometer equipped with a 4 mm diameter tip. Determining the necessary force required to penetrate the tip into the pulp, the firmness was estimated on mango's two faces. Therefore, the mean value of both measurements constituted the mango firmness value. Mango pulp coloration was determined using the scoring method by a panel of 11 persons. The scores were attributed according to the colorations indicated in Figure 3 by each panelist. The arithmetic means of the total scores of each panelist resulted in each mango pulp coloring score.

Determination of weekly variations of kent mangoes morphological, physicochemical and aspect parameters

The weekly variations (ΔV) of mangoes morphological (weight, length, circumference and volume) and physicochemical (firmness, pulp color, total sugars, reducing sugars, flavonoids and tannins) parameters were determined using the following formula: $\Delta Vn = VWn - VWn - 1$, where ΔVn is the weekly variation of the studied parameter at week n, VWn the parameter value at week n and VWn-1, the parameter value at the previous week n-1.

Statistical analysis

The values of the morphological and physiological parameters of mangoes and the weekly temperature variations were compared with each other based on the two types of exposure (sun and shade) over time using a two-way analysis of variance (ANOVA 2). The comparison of the means was performed with Tukey's LSD test at 5% using Statistica Statistica 7.1 software.

Results

Effect of sunshine on mangoes morphological parameters

Indirect sun exposed mangoes (IDS) grow faster in weight than direct exposed mangoes (DDS) (Figure 4). So direct sun exposure delays weight accumulation in mangoes of the kent variety.

Similarly, analysis of Figure 5 indicates that under shade (IDS) mangoes grow faster in length than under direct sun exposure (DDS). Therefore, mango length growth was delayed under direct sun exposure.

Table 1. Weekly variation of mango morphological parameters according to ambient temperatures.

Time	Temperature (°C)	[3]ΔWeight (Kg)	ΔCircumference (cm)	ΔLength (cm)	ΔVolume (cm3)
0WAB[1]	28.41 ± 0.32[e2]	-	-	-	-
1st WAB	31.56 ± 0.21[b]	0.05 ± 0.17[c]	0.97 ± 0.6[d]	0.73 ± 0.32[d]	33 ± 0.59[e]
2nd WAB	31.55 ± 0.01[b]	0.05 ± 0.06[c]	0.69 ± 0.33[e]	0.92 ± 0.16[c]	39.25 ± 1.1[d]
3rd WAB	32.55 ± 0.50[a]	0.01 ± 0.04[d]	0.53 ± 0.8[f]	0.2± 0.27[e]	31.75 ± 1.15[f]
4th WAB	30.53 ± 0.11[c]	0.10 ± 0.08[a]	2.53 ± 1.05[b]	1.03 ± 1.04[bc]	49.73 ± 1.26[c]
5th WAB	30.22 ± 0.19[d]	0.07 ± 0.07[b]	1.17 ± 1.12[c]	1.13 ± 0.22[b]	74.77 ± 1.11[a]
6th WAB	28.72 ± 0.41[f]	0.11 ± 0.16[a]	2.63 ± 0.75[a]	1.78 ± 0.23[a]	61.4 ± 1.53[b]

[1]: WAB: weeks after bloom

[2]: In a column, values followed by the same letter aren't significantly different (Tukey HSD test at 5%)

[3]Δ: weekly variation of the considered morphological parameter.

Analysis of Figure 6 indicates that mango circumference increases greater under shade than under direct sun exposure. Direct daily sunlight therefore reduces mango length growth of the Kent variety. As for volume, it increases faster for mangoes hidden under the foliage than for those exposed directly before harvest (Figure 7). In short, mangoes exposed to direct sunlight reduce their growth in size, weight and volume compared to those exposed to shade in the Kent variety.

Table 2. Weekly variation of mango physicochemical parameters and aspect depending on the ambient temperature.

Time	Mean temperature (°C)	[3]ΔFirmness (Kg/mm2)	Δ Pulp Coloration score	ΔTotal sugars (mg/100g)	ΔReducing sugars (mg/100g)	ΔFlavonoids (mg/100g)	ΔTannins (mg/100g)
0 WAB[1]	28.41±0.3[e2]	-	-	-	-	-	-
1st WAB	31.56±0.2[b]	0.23±0.3[b]	0 ± 0.0[e]	2.04±1.0[b]	0.61±0.6[b]	1.66±0.5[a]	-0.22±0.5[b]
2nd WAB	31.55±0.0[b]	0.18±0.0[c]	0.7 ± 0.0[b]	1.57±0.6[c]	0.61±0.7[b]	1.33±1.0[b]	-1.74±0.7[d]
3rd WAB	32.55±0.5[a]	0.25±1[a]	0.77 ± 0.3[a]	2.44±1.2[a]	0.68±0.3[a]	0.77±1.1[c]	-3.97±1[e]
4th WAB	30.53±0.1[c]	0.11±0.6[d]	0.16 ± 0.6[c]	1.549±0.5[d]	0.44±0.8[d]	0.53±0.1[d]	-5.62±0.7[f]
5th WAB	30.22±0.2[d]	0.11±0.6[d]	0.15 ± 0.6[c]	0.927±0.5[e]	0.46±0.5[c]	0.44±0.3[e]	-0.71±0.9[c]
6th WAB	28.72±0.4[f]	0.05±0.0[e]	0.06 ± 0.7[d]	0.251±1.1[f]	0.34±0.8[e]	0.26±0.4[f]	-0.17±0.1[a]

[1]: WAB: weeks after bloom

[2]: In a column, values followed by the same letter aren't significantly different (Tukey HSD test at 5%)

[3]Δ: weekly variation of the considered morphological parameter.

Effect of sunlight on mangoes physicochemical parameters

The analysis of figures 10, 11 and 12 indicates respectively that the total sugars, reducing sugars and flavonoids contents increased faster in mangoes exposed to direct sunlight than in those under shade during their development. Tannin content decreased more rapidly in mangoes exposed to direct sunlight than in those under shade (Figure 13). Therefore, direct exposure of mangoes to the sun favors the decrease of their tannin content.

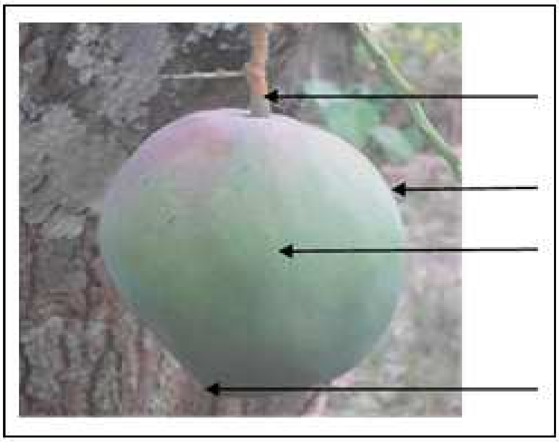

Fig. 1. Fruit of Kent mango cultivar on the tree.

Mangoes morphological evolution depending on pre-harvest ambient temperature

The table 1 indicates that in Kent mangoes, the greatest weekly variations of their morphological parameters were obtained at the lowest ambient temperatures (28.72; 30.22 and 30.53 °C) while the least significant were achieved at relatively highest ambient temperatures (31.55; 31.56 and 32.55 °C).

Effect of pre-harvest diurnal temperature on mango appearance and physicochemical parameters

The relatively highest ambient temperatures (31.55; 31.56 and 32.55) were promoted the highest weekly variations in mango physicochemical parameters while the lowest ambient temperatures (28.72; 30.22 and 30.53) generated these parameters lowest variations (Table 2).

Discussion

Preharvest of mangoes exposure to sunlight significantly affects their morphological and physicochemical development. Indeed, morphological parameters of mangoes weight, length and volume not exposed to the sun (under foliage) showed a more rapid growth than those of mangoes exposed to direct sunshine. This indicated that mangoes morphological growth resulting from the accumulation of leaf photosynthesized reserve nutrients in fruit cells was more accentuated in under-shaded mangoes (Thibault, 2014). This finding could be explained by the fact that under shade, mangoes undergoing low direct evapotranspiration therefore have more available water for cell turgor than those exposed to direct sunlight (Gabrielle, 2001).

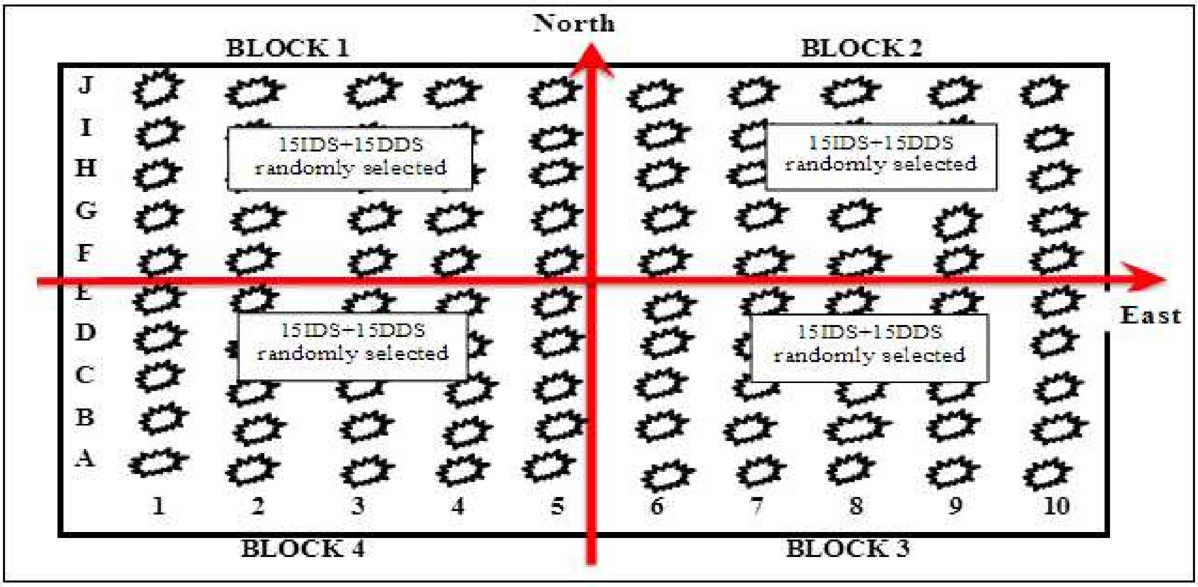

Fig. 2. Experimental design showing the four blocks where mangoes were collected.

In addition, compared to direct sunlight, exposition of mangoes under-shade improved their physicochemical parameters and appearance. So, mangoes remained more firm under direct sunlight than under shade. The relatively high temperatures induced by direct pre-harvest sunlight enhance fruit's ability to bear heat by favoring their progressive hardening (Woolf *et al.*, 1999).

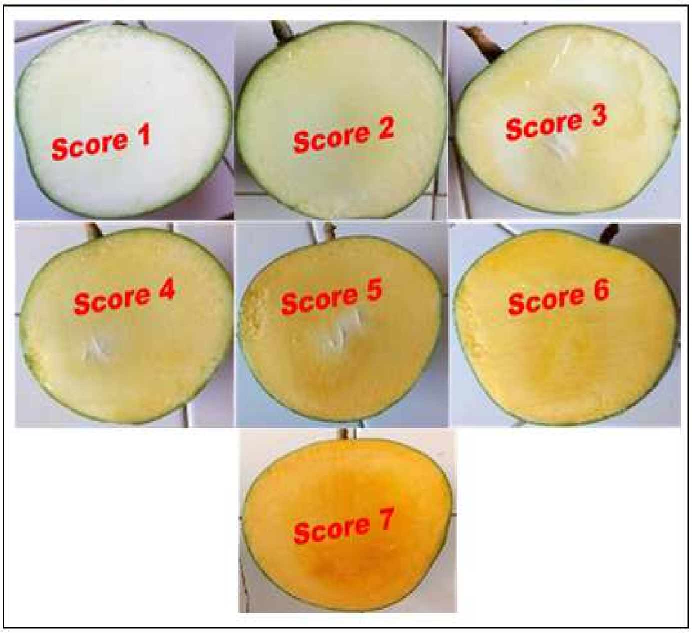

Fig. 3. Mango pulp staining scores after longitudinal sectioning.

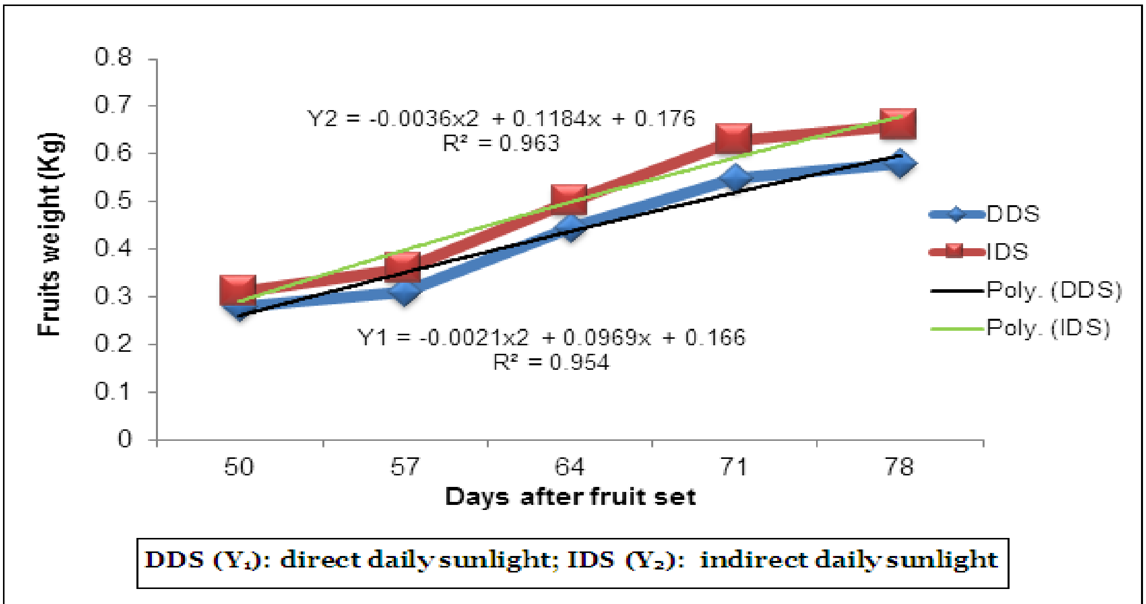

Fig. 4. Evolution of mango Kent variety weight during ripening.

The ripening characterized by a progressive change in pulp color could be explained because of chloroplast conversion into chromoplasts and an increased carotenoid synthesis, specifically β-carotene, the mango flesh main carotenoid (Godoy and Rodriguez-Amaya, 1989). However, this pulp coloration change differed following direct or indirect sunlight exposure. Besides, sunshine is one of the most important factors involved in carotenoids biosynthesis (Gautier *et al.* (2005).

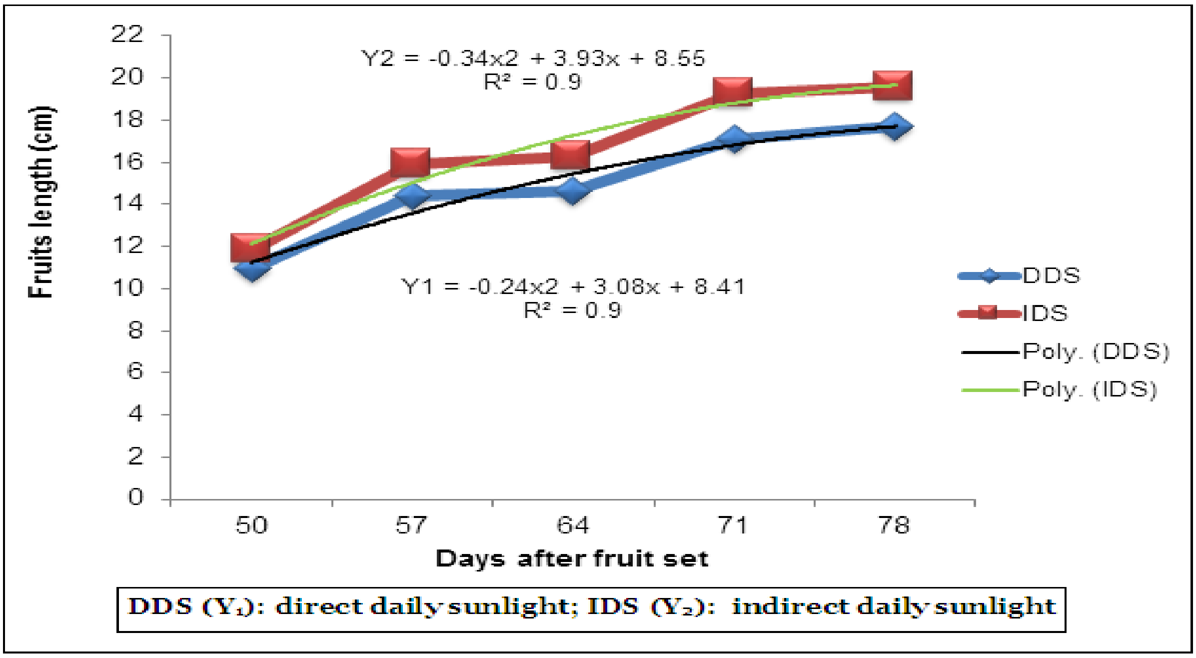

Fig. 5. Evolution of mango Kent variety length during ripening.

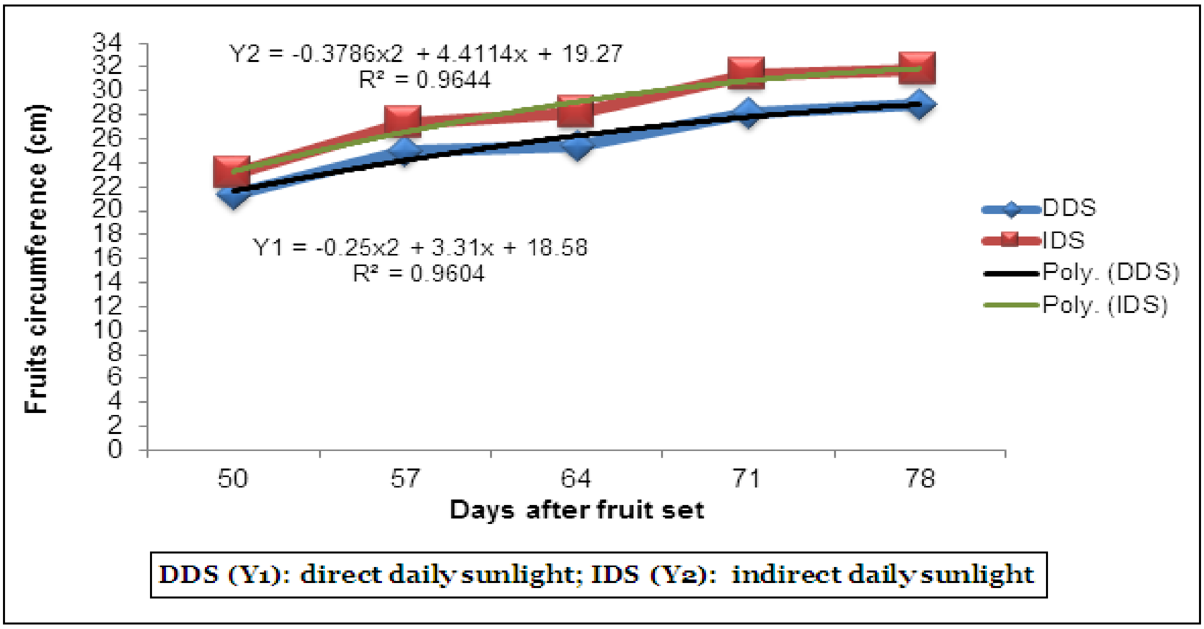

Fig. 6. Evolution of mangoes Kent variety circumference during ripening.

This is probably why mangoes exposed to direct sunlight ripened faster through a strong pulp coloration, contrary to those indirectly exposed to the sunlight (under shade).

Likewise, the mangoes exposure to pre-harvest sunlight also influenced the evolution of other physicochemical parameters like firmness, pulp coloring, and total sugars, reducing sugars, flavonoids and tannins. In fact, mangoes exposed to the direct sunlight favored their rapid accumulation of total sugars compared to unexposed mangoes left under shade. Sugars, on the other hand, represent a large proportion of chemical compounds in the ripen mango (Subramanyam *et al.*, 1975). Starch accumulates during fruit growth phase and then hydrolyzes to the reducing sugars (maltose and glucose) during ripening (Delroise, 2003). Therefore, this hydrolysis results in an increase of reducing sugars and a decrease of starch content in mangoes, which become sweeter (Kalra and Tandon, 1983). Indeed, this hydrolysis intensity was a function of temperature; it was intense at high temperatures and less intense at low temperatures (Paull *et al.*, 1999). Moreover, studies in pineapple showed that fruit quality depends mainly on climatic conditions (Yapo, 2013). In fact, sun-exposed mangoes had better grow under light and temperature conditions than those not exposed to sunlight (Larkindale and Knight, 2002).

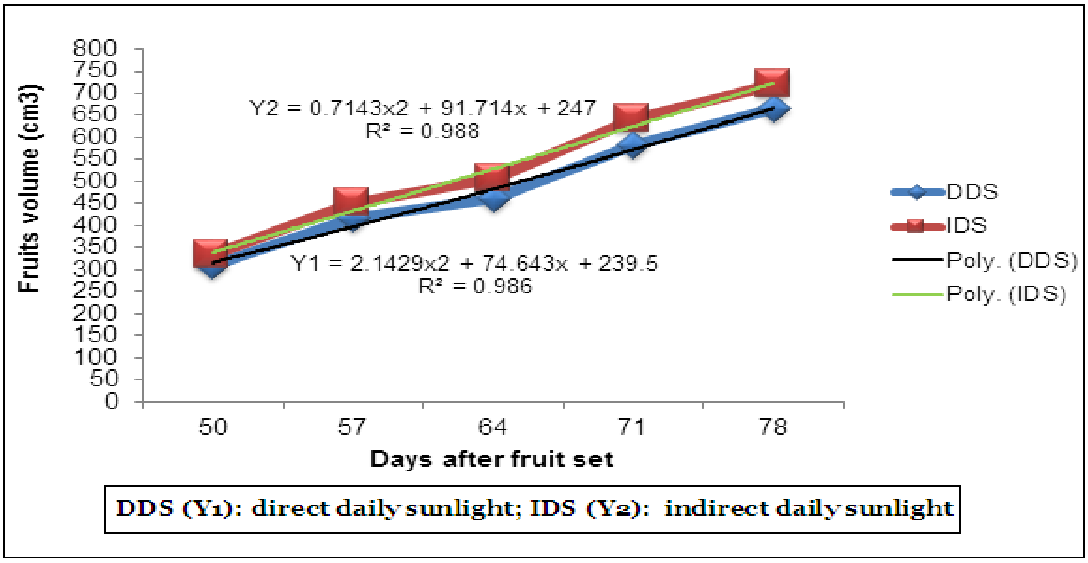

Fig. 7. Evolution of mangoes Kent variety volume during ripening.

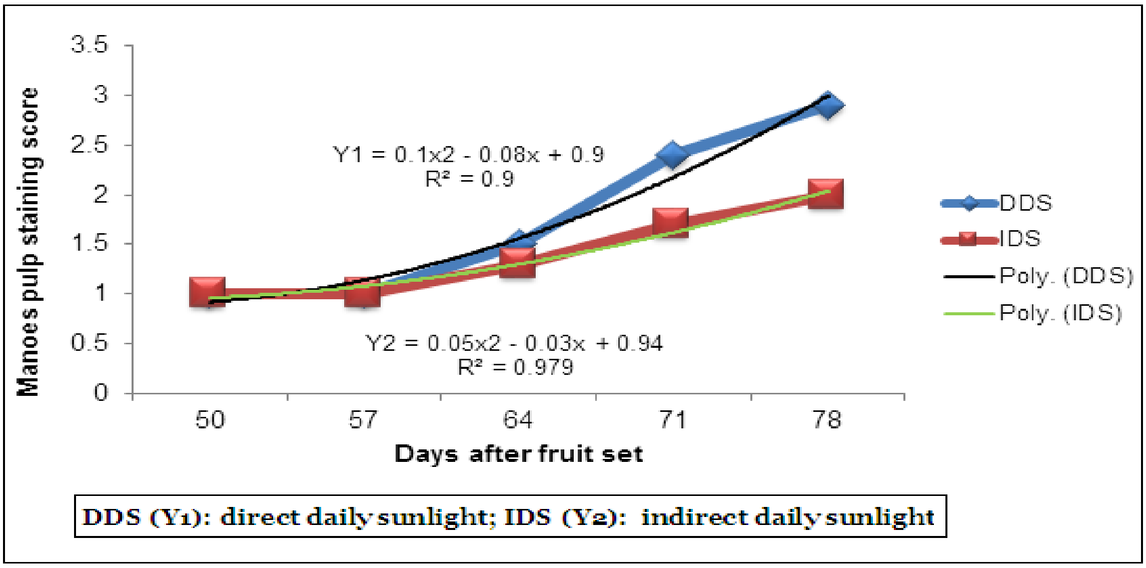

Fig. 8. Evolution of mangoes pulp coloring in the Kent variety during ripening.

Sunshine seems to affect mangoes flavonoid contents. Therefore, direct exposure of fruits to sunshine induces a greater synthesis of flavonoids comparatively to those hidden by the leaves (Bergqvist *et al.*, 2001). Sunshine during mangoes growth are beneficial effect on secondary metabolism, so on the fruit quality. Moreover, many studies on others speculations have clearly show that flavonoid synthesis induction and their associated enzymes in cuticle or epidermal cells were strongly influenced by sunshine exposure and especially to ultraviolet (UV) radiation (Beggs and Wellman, 1985; Mazza *et al.*, 2000; Wang *et al.*, 2000; Solovchenko and Schimitz-Eiberger, 2003).

Before harvesting, daily sunlight induced temperatures witch also influenced mango morphology. Indeed, the highest morphological growths were obtained at relatively high ambient temperatures (28.72, 30.22 and 30.53°C).

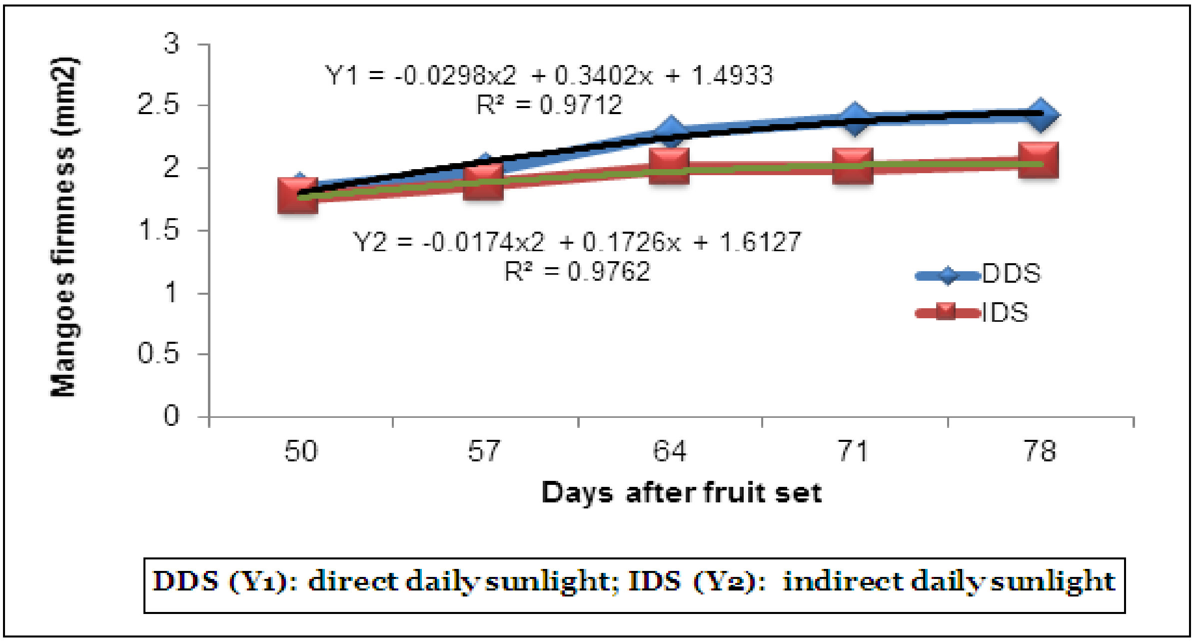

Fig. 9. Evolution of mango firmness in the Kent variety during ripening.

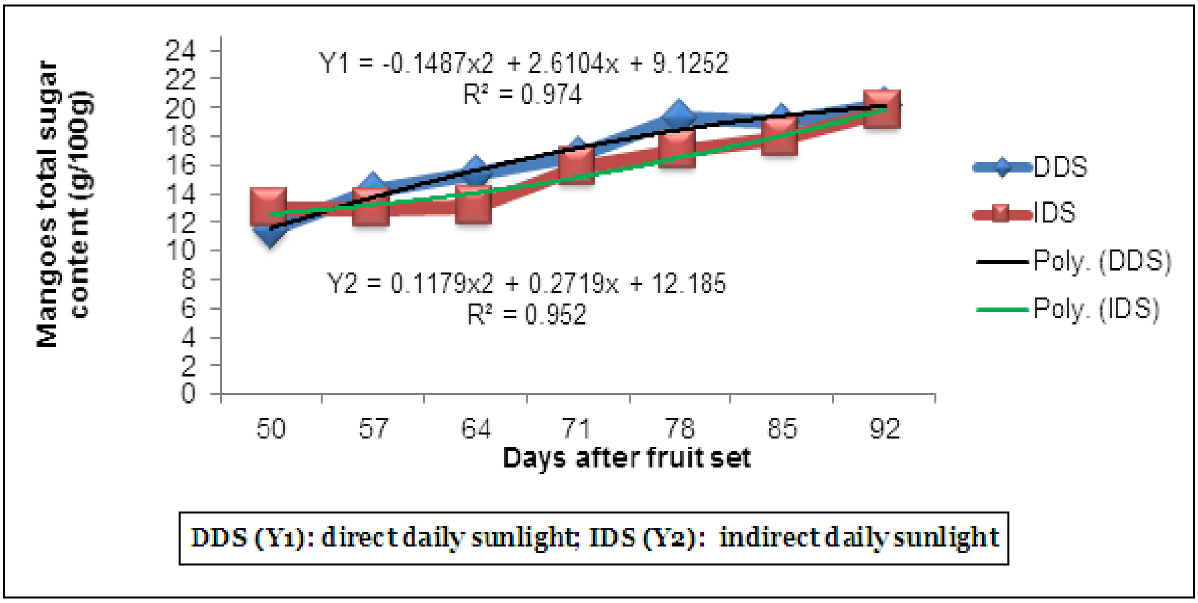

Fig. 10. Evolution of mangoes total sugar content following the type of sun exposure during ripening.

This seems to mean that temperatures influence fruit development by determining its growth rate (Monselise and Goren, 1987; Pantin *et al.*, 2011).

Furthermore, temperature influences enzymatic activities responsible for changes in physicochemical parameters and fruit appearance as mentioned Yao (2013) in papaya. Ultimately, sunshine and duration of exposure to high temperatures promote important metabolic changes in mangoes before harvest (Ferguson *et al.*, 1998). This has the advantage of predicting the harvest date, improving the quality of mangoes and facilitating their marketing on the international market where competition is tough.

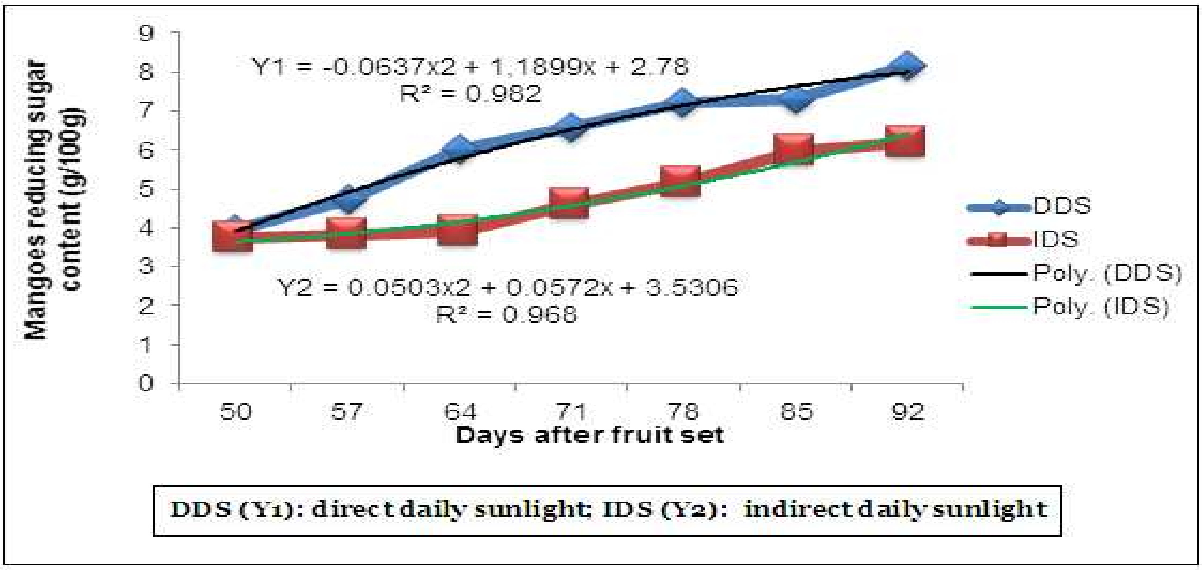

Fig. 11. Evolution of mangoes reducing sugars content following the type of sun exposure during ripening.

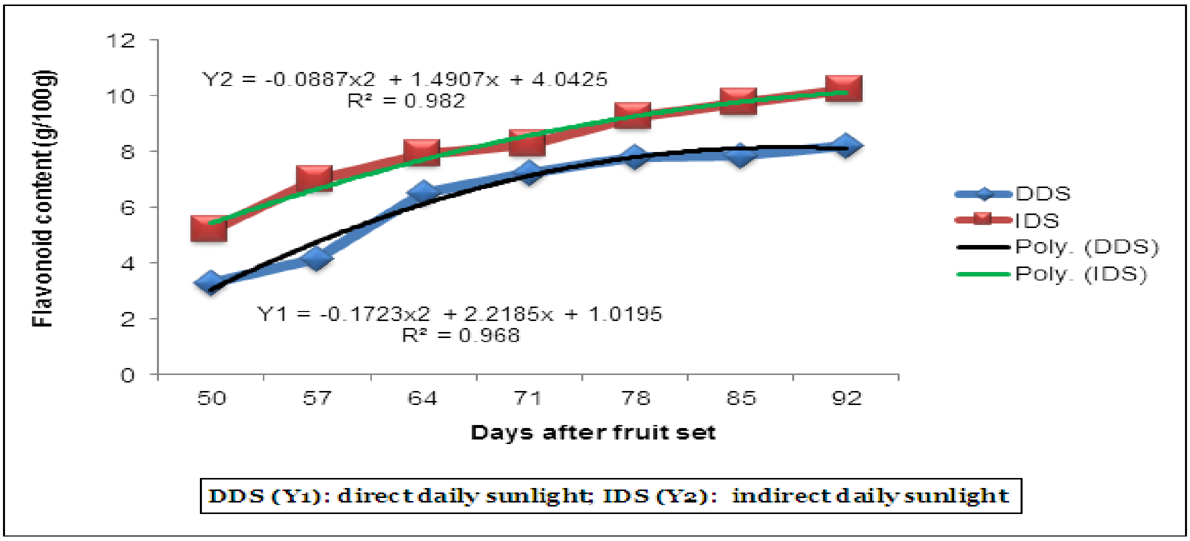

Fig. 12. Variation of mangoes flavonoid content depending on daylight exposure type during ripening.

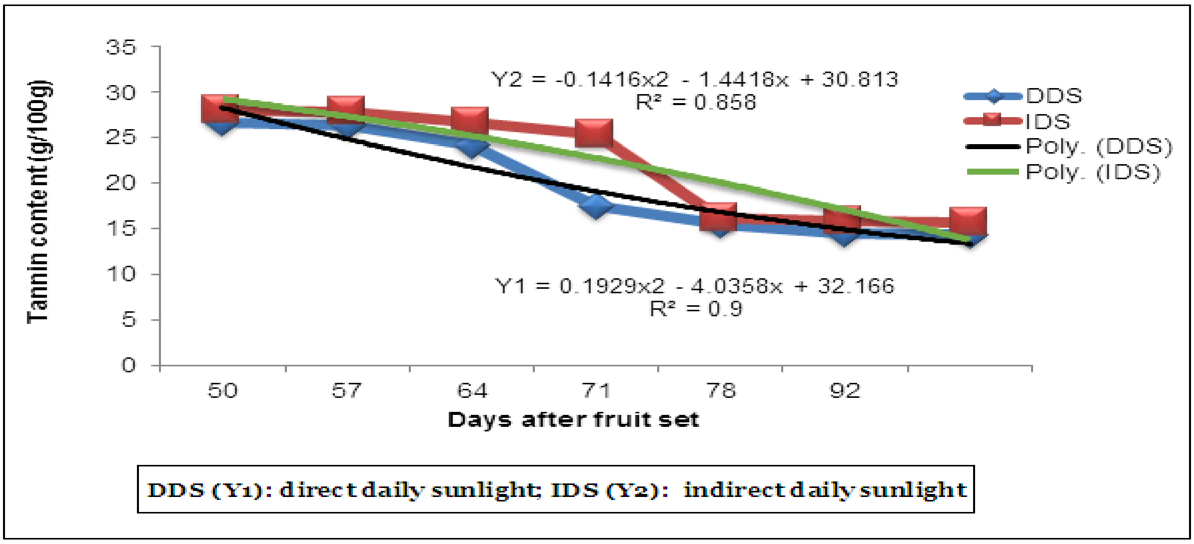

Fig. 13. Variation of mangoes the tannin content following daylight exposure type during ripening.

Conclusion

Direct exposure of mangoes in tree to sunlight retards their morphological evolution. On the other hand, it improves the physicochemical parameters (internal part) and the appearance of mangoes. The variation of these parameters was therefore closely linked to the sunshine. Indeed, the weak temperatures promoted morphological growth and while the high temperatures were beneficial to the rapid evolution of physicochemical parameters. Thus, mangoes directly exposed to sunshine (DDS) can be harvested earlier than those indirectly exposed (IDS) i.e. hidden under the foliage. Therefore, the mangoes position on the tree with respect to the sunshine was an important factor to take into account when harvesting mangoes of the Kent variety

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