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Physicochemical and nutritive characteristics of the residues deriving from the oranges (*Citrus sinensis* L.) consumed in Côte d'Ivoire

V. C. LAGOU [1*], N. Y. KONAN [2], R. R. ASSA [1]

[1] Laboratory of Biochemistry and Food Sciences, Training and Research Unit of Biosciences, Felix Houphouët Boigny University, 22 PO Box 582 Abidjan, Côte d'Ivoire
[2] Biochemistry and Genetics Department, Training and Research Unit of Biological Sciences, Peleforo Gon Coulibaly University, PO Box 1328 Korhogo, Côte d'Ivoire

*Corresponding author: vclagou80@gmail.com

Abstract – The orange (*Citrus sinensis* L.) are of edible fruits enjoyed in Côte d'Ivoire thanks to their delicious taste and nutritional properties. However, during the orange fruit consumption, the peels, membranous endocarp and seeds are residues considered as garbage and therefore thrown away. The current report focuses the physicochemical and nutritive parameters of the residues deriving from this citrus fruit in order to search ways for their valorization. The investigation was performed using orange collected in four (4) communes from Abidjan District, Southern Côte d'Ivoire. The data show homogeneous rates per type of residue whatever the origin of oranges, with means of 10.97% peels, 12.48% membranous endocarp and 6.26% seeds from the full fruit weight. Overall residues samples felt acid, displaying pH values between 4 and 5. The nutritive composition varies according to the type of residue and the fruit origin. Proteins are more accumulated in orange seeds (7.12 to 27.44 mg/100 g) compared to the endocarp and peels (4.34 to 8.51 mg/100 g). The seeds are also more provided in lipids (20.22 to 37.74 g/100 g) and fibre (21.18 to 33.45 g/100 g) from overall origins; whereas peels displayed higher ash content (5.34 to 7.06 mg/100 g). On the other hand, the orange residues deriving from each commune record unvarious glucides content. Otherwise, the peels are more provided in polyphenols compounds, specifically for oranges collected from plateau commune (444.89 mg/100 g). The oranges peels and membranous mesocarp could be valorised as sources of minerals and polyphenols since they account greater ash and polyphenols contents; whereas the oranges seeds could support the production of essences and could record other functional properties regarding their significant fat matter, protein, and fibre contents.

Keywords: *Citrus sinensis*, residues, physicochemical properties, valorization, Côte d'Ivoire

1. Introduction

The orange *species* (*Citrus sinensis* L.) is a plant belonging to the systematic family of *Rutaceae* and originating from the South-Eastern Asia (Nicolosi, 2007). It's a tropical plant growing in several countries with tropical and humid climate (Suryawanshi, 2011). The main use of this plant deals with the production of fruits known as oranges (USDA, 2014). Indeed, the orange fruits are among the most cultivated *Citrus* fruits, with an estimated world production about 66,400,000 tons/year (Loeillet, 2010). In Côte d'Ivoire, the orange groves are over 500,000 hectares in monoculture, of which 90% are hold by agro-industrial companies. Oppositely to the exports crops as cocoa, coffee, coconut, and cashew, no rather individual producers are met in the orange channel (Assa *et al.*, 2006; Konan *et al.*, 2013). Unfortunately, the local production of oranges hardly evaluable since significant oranges volumes are marketed following casual ways (Lagou *et al.*, 2017). However, the available reports regarding the volumes of processed oranges are estimated at 112,700 tons/year mainly for the production of essences (FAO, 2013). The rare individual orange farms found are generally in associations with other cultures and recover smaller lands. Besides, in the agglomerations, the orange trees are used as ornamental plants for populations.

The oranges have a juicy pulp enjoyed by consumers for its therapeutic, nutritional, and sensory properties (namely the sweet flavor). Indeed, according to Mbogo *et al.* (2010), the oranges fruits juice is strongly richer in vitamin C (22.5% to 50.4%), carbohydrates as sucrose and fructose (11% to 33%), and mineral such as potassium and calcium. Otherwise, the consumption of oranges fruits is so growing in Côte d'Ivoire that significant imports are steadily required from neighbour countries as Ghana to complete the national production and to fit the needs of the populations (Lagou *et al*., 2017).

However, during the consumption of the oranges fruits or while they are processed into raw juice, significant parts of the full fruits are assimilated as garbage and thrown away. Those oranges parts deal with the seeds, the membranous mesocarp, and the peels. Over the world, many companies working in the oranges fruits processing for juice production have suitable machines and apparatus for recycling the residues produced thereby. The technological practices account these residues as an important deposit for many compounds valorizable in food, cosmetic, and therapeutic interests (Singh, 2010). Other valorizations deal with the extraction of fibres as cellulose and pectin (Wang *et al*., 2014) for health food processing. Unfortunately, in Côte d'Ivoire, excepted for the works of Assa *et al*. (2013), scanty investigations are performed about the residues deriving from the oranges consumption which are therefore not really valorised. Consequently, the oranges residues represent organic and mineral garbage and are so considerable source of environmental pollution (Djilas *et al*., 2009; Ledesma and Luque, 2014).

Thus, the current investigation targets the main physico-chemical and nutritive properties of the oranges residues for finding suitable ways of their valorizations. The data could contribute in increasing the profitability of the trade of *Citrus* fruits.

2. Materials and Methods

2.1. Plant material

The plant material was constituted of residues recovered from oranges (*Citrus sinensis* L.), namely the peels, the whitish membranous mesocarp, and the seeds. These residues were collected from whole oranges fruits marketed in Côte d'Ivoire.

2.2. Methods

2.2.1. Sampling of the oranges and residues

The oranges were bought on four fruits markets from various communes of Abidjan, Côte d'Ivoire, between April and June, 2016. The markets were located in the communes of Adjamé, Plateau, Port-Bouët, and Yopougon, which were really accessible and continuously provided in fruits all year round. Besides, they are the main sites of provision in fruits and vegetables for populations. From each market, three (3) traders were considered regardless the gender. Only the full mature stage and the undamaged condition of the fruits were required. So, the healthy oranges fruits displaying epidermis colour between green and yellow were selected. Thus, 60 oranges were collected by trader, leading to 180 oranges per market. The fruits were collected in triplicate. At overall, 2160 oranges were purchased and conveyed to the Laboratory of Biochemistry and Food Sciences (LaBSA), Biosciences Unit, Felix Houphouet-Boigny University, for analysis. These fruits were batched according to the market taken as origin, leading to 4 batches. The oranges were then washed in tap water and rinsed with distilled water before residues extraction and analysis.

2.2.2. Collection of the oranges residues

Each full orange fruit was weighed using a three digit electronic scale (Sartorius), and thereafter peeled with stainless knife and the peels collected. The white membranous mesocarp was then recovered from the peeled oranges. Finally, the oranges seeds were recovered from after carving and pressing of the oranges pulpy endocarp. The overall oranges residues were duly batched before analysis.

2.2.3. Oranges residues analyses

The oranges residues contents in dry matter and ashes were respectively recovered by submitting due samples to drying into an oven (MEMMERT) at 50±10°C for 72 h and incineration into a muffle furnace at 550 °C (AOAC, 1990). The dried oranges residues were then ground using a metallic grinder (BLENDER with mill attachment, FISTA, Africa), resulting in 0.3 mm diameter particles powders. These powders were sealed in plastic bags and kept at 37 °C free from any additive (Amrigi, 1980, Houinsou, 1990) till proximate chemical analyses.

The samples acidity (pH and titrable acidity) were determined according to the method described by Nout *et al*. (1989). The fat content was determined from the raw dry matter according to international standard (AFNOR, 1973) using Soxhlet device. The total and reducing soluble carbohydrates were measured by respective methods using phenol and sulphuric acid reagents (Dubois *et al*., 1956) and 3, 5- dinitro salicylic acid reagent (Bernfeld, 1955). Proteins were measured through the total nitrogen using Kjeldahl apparatus. The raw fibres content were determined according to the method described by Wolf (1968). The polyphenols were extracted using methanol solvent and measured with folin ciocalteus reagent (Singleton *et al*., 1999).

2.2.4. Statistical analysis

Overall experiments were performed in triplicate. The data recovered were statistically treated with the software Statistical Program for Social Sciences (SPSS 22.0, SPSS for Windows, USA). The statistical treatment consisted in an analysis of variances (2 ways ANOVA) regarding the oranges origin and type of residue taken as classification criteria at 5% significance. The averages were then compared with the post-ANOVA statistical test of Student Newman Keuls (SNK). The main results are reported as means with their standard deviations.

3. Results and Discussion

3.1. Results

3.1.1. Physical characteristics of the oranges residues

The statistical analyses show unvarious percentage from each residue whatever the orange fruits origin ($F=0.21$; $P=0.89$). Thus, from the full orange weight, the residues display percentages oscillating between 10.57% and 11.37% for external peels, 12.06% and 12.88% for membranous mesocarp; whereas the oranges seeds are only rated at 5.74% to 6.48% and are therefore the lower residues amounts per orange (figure 1). Besides, the dry matter ash contents are significantly diverging ($P<0.001$) from the oranges origins and residues. Thus, the membranous mesocarp is generally more provided with dry matter (36.23 to 40.87 g/100 g) than the oranges peels (33.12 to 36.28 g/100 g) and seeds (33.94 to 38.46 g/100 g), except for the oranges fruits collected from Adjamé which contain seeds with higher dry matter content of 38.46 g/100 g. Overall fruit epicarp (peels and membranous mesocarp) of the oranges collected from Plateau are more provided in dry matter (36.28 and 40.87 g/100 g, respectively) whereas their seeds record lower dry matter (33.94 g/100 g) compared to the other oranges fruits investigated (figure 2).

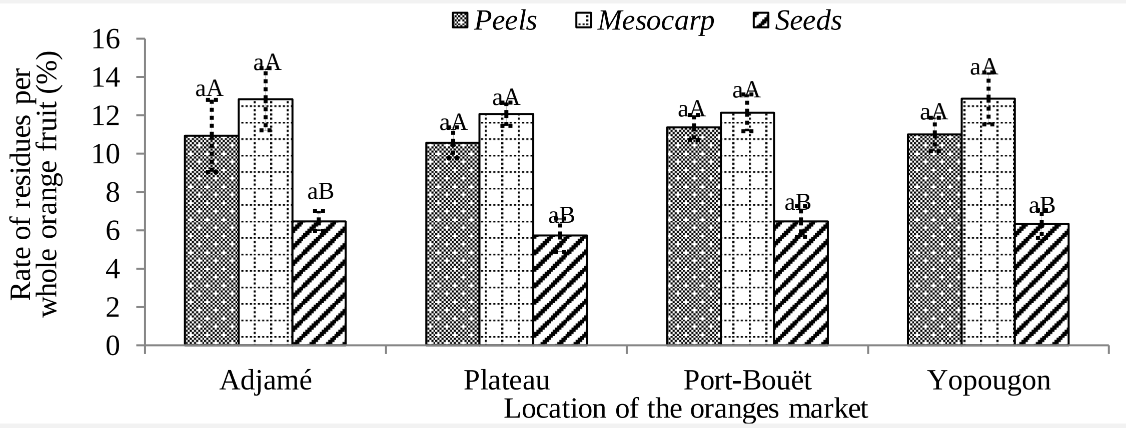

Figure 1: Percentages of the main orange residues from the full orange fruit weight

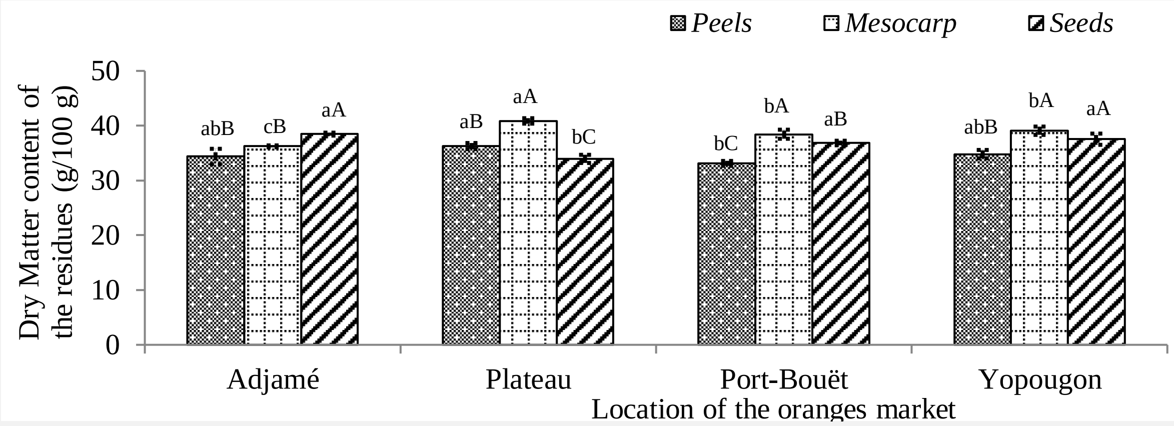

Figure 2: Dry matter contents of the oranges fruits residues

Per orange fruit residue/origin, lowerscripts / superscripts letters compare the orange origin/residues.

Whatever the oranges fruits origins, the external peels display more ash content (5.34 to 7.06 g/100 g) than both membranous mesocarp and seeds as shown in **figure 3**.

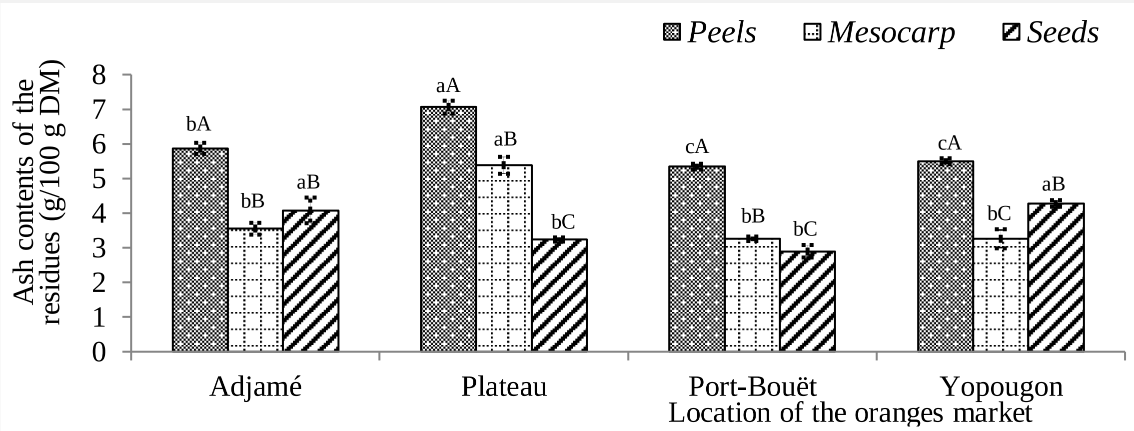

Figure 3: Ash contents of the oranges fruits residues

Per orange fruit residue/origin, lowerscripts/superscripts letters compare the orange origin/residues.

3.1.2. Chemical characteristics of the oranges fruits residues

The chemical data of the investigations reveal statistical interactions between the oranges residues and the fruits sampling areas ($P<0.01$).

The studied oranges residues provide various acidity traits ($P<0.05$). Thus, the oranges peels record more pH value from Yopougon (4.53) compared to other localities. But the oranges collected at Port-Bouët display higher pH values (4.51 and 5.45, respectively) regarding membranous mesocarp and seeds (figure 4). Paradoxically, the titratable acidity is more marked in the peels of the oranges bought at Yopougon (13.67 mg Eq H^+/100 g) and membranous mesocarp samples do not display any obvious change (6.33 to 6.67 mg Eq H^+/100 g) from overall communes. Among the oranges residues, peels are the more provided with titratable acidity (11.33 to 13.67 mg Eq H^+/100 g) compared to seeds and membranous mesocarp (2.50 to 6.67 mg Eq H^+/100 g) as shown in figure 5.

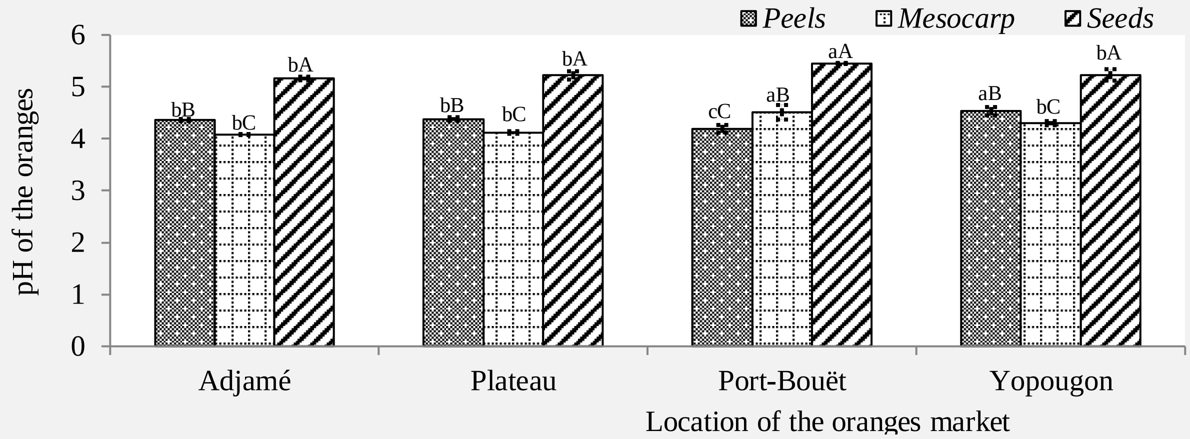

Figure 4: pH values of the oranges fruits

Per orange fruit residue/origin, lowerscripts/superscripts letters compare the orange origin/residues.

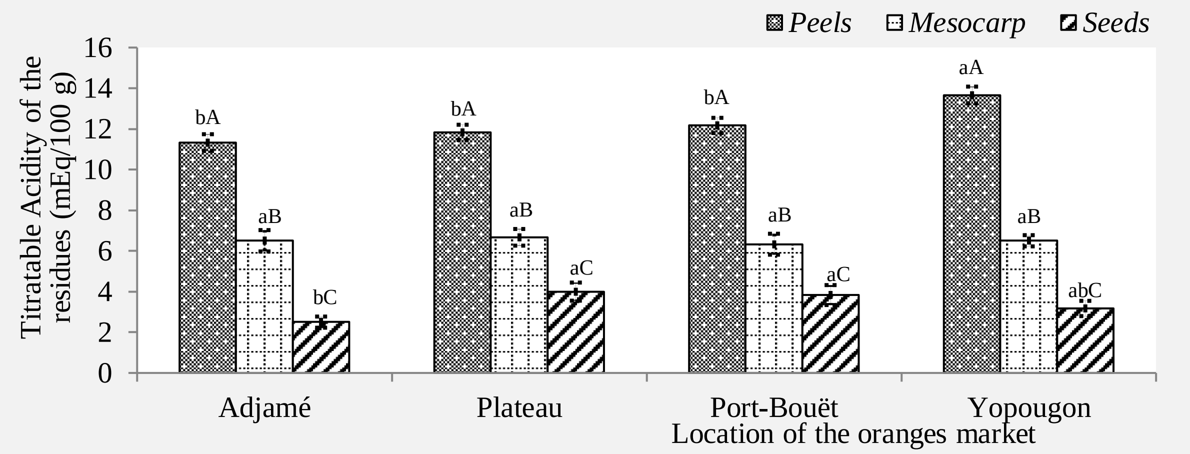

Figure 5: Titratable acidity of the oranges fruits residues

Per orange fruit residue/origin, lowerscripts/superscripts letters compare the orange origin/residues.

3.1.3. Macronutrients composition of the oranges residues

The following table highlights the global nutrients traits of the oranges residues. Except for the total carbohydrates contents (1.40 to 1.83 g/100 g), significant interactions ($P<0.01$) are found between the oranges markets and the type of residues for the others nutrients measured.

Thus, the fat matter content is found highest in the oranges seeds, especially in samples originating from Adjame (37.74%) and Port- Bouët (36.13%), against 2.24% to 3.40% for the oranges peels and mesocarp. Regarding proteins contents, the seeds samples are more provided for oranges collected from Adjamé, Port-Bouët, and Yopougon (19.07, 20.54, and 27.44 mg/100 g, respectively). The oranges bought at Adjamé and Yopougon also reveal the richest samples in proteins from peels (8.23 and 8.51 mg/100 g) and membranous mesocarp (6.55 and 7.19 mg/100 g). The oranges seeds originating from Port-Bouët and Adjamé display the most reducing carbohydrates contents (0.907 and 0.958 g/100 g, respectively) and Port Bouet also provides the richest oranges membranous mesocarp for this trait (0.885 g/100 g). Fibres contents are higher in seeds, especially from Adjamé, Port-Bouët and Plateau (29.62 to 33.45 mg/100 g). For the oranges mesocarp, Adjamé is more provided (26.57 mg/100 g). Oppositely, the oranges seeds showed unvarious ($P>0.05$) fibres contents between 20.76 and 22.06 mg/100 g.

3.1.4. Total Polyphenols contents of the oranges residues

The total polyphenols contents of the residues samples studied display various means (P<0.01) as drawn by figure 6. For overall oranges, peels are more provided in polyphenols compounds than the membranous mesocarp and seeds. The highest polyphenols content is recorded in oranges peels collected from the Plateau market (444.89 mg/100 g). Among the oranges mesocarp and seeds, the figure 6 shows that samples predominant in polyphenols contents are originating from Yopougon (256.46 mg/100 g) and Plateau (228.94 mg/100 g).

Table: Some nutritive parameters of the oranges residues studied

Residues	Markets	FMC (%)	CPT (mg/100g)	TCC (mg/100g)	RCC (mg/100)	CFC (%)
Peels	Adjamé	$2.7±0.38^{bB}$	$8.23±1.01^{aB}$	$1629.79±111.21^{aA}$	$765.42±171.09^{aA}$	$20.76±3.76^{aC}$
	Plateau	$3.4±0.1^{aB}$	$6±0.89^{bB}$	$1834.58±342.77^{aA}$	$742.99±96.9^{aA}$	$21.7±1.36^{aB}$
	Port-Bouët	$2.72±0.16^{bB}$	$5.09±0.87^{bB}$	$1590.53±135.37^{aA}$	$908.41±115.4^{aA}$	$21.73±1.59^{aB}$
	Yopougon	$2.36±0.19^{cB}$	$8.51±0.2^{aB}$	$1405.08±431.47^{aA}$	$740.81±91.21^{aA}$	$22.06±2.1^{aA}$
Mesocarp	Adjamé	$2.24±0.11^{aB}$	$7.19±0.42^{aB}$	$1551.87±319.64^{aA}$	$730.22±149.75^{abA}$	$26.57±1.02^{aB}$
	Plateau	$2.68±0.84^{aB}$	$5.68±0.43^{bB}$	$1663.02±193.42^{aA}$	$571.96±158.97^{bA}$	$24.24±1.88^{bB}$
	Port-Bouët	$2.51±0.18^{aB}$	$4.34±0.04^{cB}$	$1545.22±63.1^{aA}$	$885.98±83.76^{aA}$	$22.15±1.05^{cB}$
	Yopougon	$2.49±0.76^{aB}$	$6.55±1.21^{aC}$	$1644.29±164.13^{aA}$	$691.28±113.69^{bA}$	$23.08±1.24^{bcA}$
Seeds	Adjamé	$37.74±1.49^{aA}$	$19.07±7.87^{bA}$	$1835.18±291.41^{aA}$	$958.88±177.38^{aA}$	$29.84±0.99^{aA}$
	Plateau	$32.9±1.09^{bA}$	$7.12±1.03^{cA}$	$1573.61±117.39^{aA}$	$643.61±198.36^{bA}$	$29.62±5.31^{aA}$
	Port-Bouët	$36.13±1.64^{aA}$	$20.54±1.1^{bA}$	$1736.11±682.38^{aA}$	$907.79±92.06^{aA}$	$33.45±3.54^{aA}$
	Yopougon	$20.22±3.83^{cA}$	$27.44±1.05^{aA}$	$1622.55±96.68^{aA}$	$423.68±82.98^{cB}$	$21.18±1.1^{bA}$

FMC, Fat matter content ; **CPT**, crude proteins content ; **TCC**, total carbohydrates content ; **RCC**, reducing carbohydrates content ; **CFC**, crude fibre content.
Per column, superscript letters compare values from markets for each residue; and lowerscript letters compare values from residues for each market.

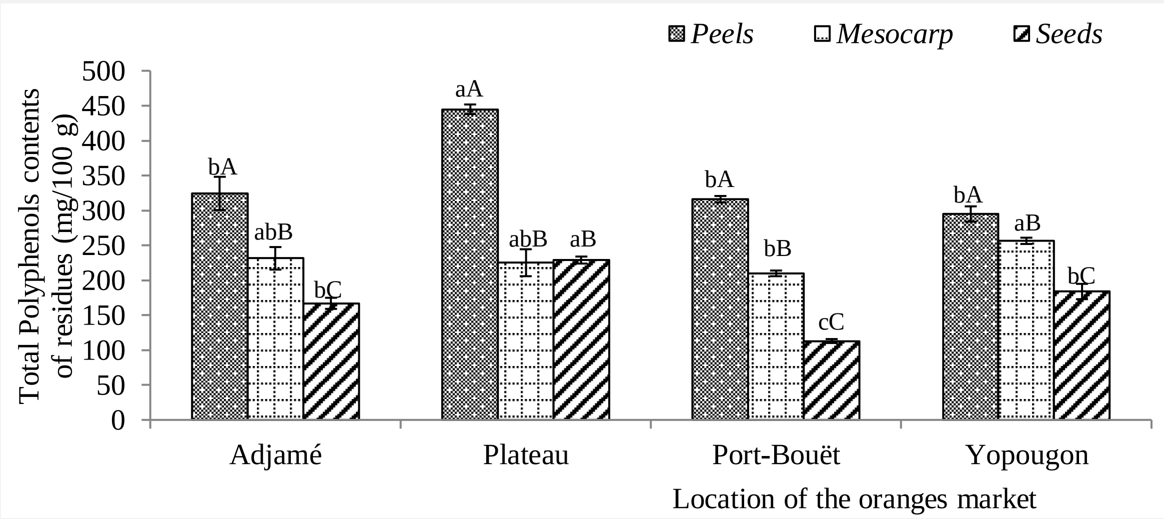

Figure 6: Total polyphenols contents of the oranges residues

Per orange fruit residue/origin, lowerscripts/superscripts letters compare the orange origin/residues.

3.2. Discussion

According to the current works, the oranges are source of important residues production. The residues are constituted of peels, membranous mesocarp and seeds at about 30% as general rate. Such a rate is below the report of Ledesma and Luque (2014) showing that the processing of Citrus fruits in juice produces 50% by-products as garbage. In our works, the residues have been only constituted of the oranges parts thrown during consumption of the raw oranges fruits. The investigation did not account the pulp residues generated during industrial processing of oranges and which could increase the final amount of residues as mentioned by the authors quoted. The oranges residues record important dry matter and ash contents, with variable means relating to the collection area, showing richness in organic and mineral substances which are advantageous for their valorization.

The oranges peels are more provided in ash (5.34 to 7.06 g/100 g), corroborating the works of Bampidis and Robinson (2006) who concluded about peels of *Citrus* fruits as source of compounds exploitable in food and feed. Overall oranges residues studied reveal acid trait. However, the results forecast that the pH and the titratable acidity of the orange residue can display positive correlation from a market but a negative correlation from another market. In fact, the pH results from the hydronium ions (H_3O^+) whereas the titratable acidity depends on the contents in acids volatile organic compounds as amino acids and fatty acids (Konan *et al*., 2013). The significant divergence found in the acid contents could depend on the oranges farms area, the period and the environment condition of their harvest. The samples collected at Adjame, Plateau and Yopougon have displayed pH values from peels and membranous mesocarp in the same trend as the titratable acidity. These oranges fruits could have been therefore produced in similar environmental conditions.

The oranges residues showed numerous biochemical compounds, namely fibres, glucides, lipids, and proteins, which are significant parameters focussed to fit many concerns in food, cosmetic and health industries. Indeed, previous studies found the pectin and cellulose extracted from *Citrus* fruits fibres as advantageous compounds for the dietary food processing (Wang *et al*., 2014).

Carbohydrates and fibres contents didn't show any obvious variation from the overall residues. But, the oranges seeds recorded right higher amounts of fat matter and proteins.

Fruits seeds are the main tissues allowing the plant's regeneration. So, they contain many nutrients reserves for sustaining the germination of the embryo (Ramadan and Morsel, 2003). Otherwise, the oranges pericarp which is constituted of peels and membranous mesocarp could be processed for production of essences (Singh, 2010). The similar fat matter contents of peels and mesocarp from our works forecasts the full use of both oranges residues, as indicated by the investigations of Farhat *et al*. (2011) who showed that these residues are source of 0.6% to 1% essences. The presence of organic substances in oranges residues could justify their incorporation as flavouring agent in food formulations as cakes, jams, etc. The results didn't show any obvious difference between carbohydrates contents relating to the oranges residues and the markets. However, overall residues record significant amount of glucides that could be valorised in several interests as food and bioenergy. Thus, this assertion is in accordance with the works performed by Kammoun *et al*. (2011) that showed that the *Citrus* fruits peels contain digestible compounds usable in healthy dietary for human and animal and also as food additive. The study also evidenced the presence of polyphenols compounds in overall arranges residues, especially in peels and mesocarp. In both residues, the greater polyphenols content could have been involved by the coloured pigments. According to Melendez-Martinez (2007), the degradation of these plant pigments induces the biosynthesis of carotenoids as polyphenols molecules. Many works have focussed the polyphenols. The foods richer in polyphenols as carotenoids are known to decrease numerous risks as cancer, muscular degeneration, skin damages due to the sun burns, and cardiovascular diseases (Wang *et al*., 2008). Such foods are considered functional foods since polyphenols strongly sustain the body's physiology. These compounds are secondary metabolites with bio-action against oxidant elements and free radicals in the living tissues (Xia *et al*., 2011), and they also display antimicrobial properties (Ramful *et al*., 2010).

The divergences between the observations from markets could have been caused by the various sources of the oranges fruits sold in large cities like Abidjan. Indeed, the markets are usually supplied in oranges fruits from various production countryside areas. According to the fruits sellers, the oranges marketed at Yopougon and Adjame could originate from the West and Centre of the country, whereas those sold at Port-Bouet and Plateau are produced from the Eastern regions and significant oranges imports are often requested especially during the counter season.

4. Conclusion

This investigation aimed a descriptive analysis of the main compounds of the residues thrown out during consumption of the oranges fruits in Côte d'Ivoire. These residues represent over the third part of the full oranges weight. They record significant physicochemical, macronutrients and polyphenols properties with important valorisation potential which can be successful for improving the oranges fruits profitability.

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