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Agronomic and Culinary Evaluation of Cassava (*Manihot Esculenta* Crantz) Clones with Colored Flesh under Selection in Bouaké (Côte d'Ivoire)

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Abstract: ***In Côte d'Ivoire, with 5 million tons produced in 2019, cassava is the second food crop after yam. The varieties usually grown are white-fleshed but contain low beta-carotene. However, although less common, varieties with colored flesh may have the same potential for production, processing, marketing, and consumption than white-fleshed varieties. Of more, they are rich in beta-carotenes and could contribute to resorb the problems of vision, growth, reproduction, and immunity related to vitamin A deficiency in humans. This study on the agronomic and culinary characteristics of clones of cassava with colored flesh was conducted at Bouaké, Côte d'Ivoire. The general objective was to select varieties of cassava with colored flesh, high yield, rich in pro-vitamin A, and with multiple uses. Forty-one cassava clones with colored flesh were compared to three control varieties, namely Bonoua2, Yacé, and Bocou2, on the basis of 7 agronomic and culinary parameters. At the harvest of the tuberous roots, significant differences were observed between the 44 clones for each of the 7 parameters studied. Results showed that twenty-five (25) clones were more productive than the Bocou2 variety. The clone 15 (431) 29 had the highest yield with 48.28 t/ha. Yields and boiling quality of 11 clones were better than those of the control varieties. A total of 11 clones achieved the best conciliation between agronomic and culinary parameters, compared to the controls, and could be evaluated and confirmed in other research stations and on-farm before releasing them to producers.***

Keywords: *Manihot esculenta,* Cassava with colored flesh, Clone, Evaluation, Yield

1.Introduction

Cassava (Manihot *esculenta* Crantz) is one of the most important food crops in the humid tropical zone for its plasticity, the volume of production, and consumption (N'Zué *et al.,* 2004). It is grown mainly for its starchy roots (IITA, 1990). World cassava production in 2019 was estimated at 303 million tons, of which a proportion 61.3% from Africa (FAO, 2020). Cassava is the second source of energy food in developing countries where malnutrition is recurrent (Silva *et al*., 2008; Salvador *et al*., 2014). The leaves are used for vegetable sauce in Africa (Tanumihardjo *et al.,* 2010). Also, cassava plays an important role in the food security of most vulnerable populations (Djoulde, 2005). It feeds more than 500 million people in Africa and its production is increasing at a constant rate higher than that of cereals (Vernier *et al*., 2018). Cassava is used in the textile industry and for the manufacture of starch, flour, bread, and pellets (N'Zué *et al.,* 2005).

In Côte d'Ivoire, cassava ranks second among food crops after yam in terms of production quantity with 5 million tons in 2019 (FAO, 2020). Food-producing crops less susceptible to drought, cassava is grown almost throughout the country with predominance in forest areas (Brou *et a*l., 2005). It is both a subsistence and income for producers. Cassava cultivation and exploitation generate various activities that contribute to food security and thus make it possible to fight against poverty. It provides several products such as "attiéké", "gari", "placali", "tapioca", "foutou", etc. (N'Zué *et al*., 2005). In addition, cassava with colored flesh (cream, light yellow, yellow dark, orange) contains a high content of ß-carotene. This is essential for the achievement of multiple functions in humans, such as vision, growth, reproduction, and immunity (La Frano *et al*., 2013; Tanumihardjo, 2013).

However, the requirements of producers and consumers like high yield, resistance to pests and diseases, dry matter content, starch content and quality, and good cooking persist. Moreover, cassava varieties with colored flesh, rich in ß-carotene (Pro-vitamin A) are not widespread and are little known by the population, unlike white flesh varieties, poor in vitamin A, which are more widespread and cover 90% of cultivated areas (N'Zué *et al*., 2012). Previous works on the evaluation of cassava clones rich in beta-carotene were conducted in Côte d'Ivoire and elsewhere specifically in Africa by Adetero *et al.* (2018), Mukendi et al. (2018), and Coulibaly (2020). In this context the National Center for Agronomic Research (CNRA) introduced improved varieties of cassava with colored flesh from the International Institute of Tropical Agriculture (IITA) in 2005. Some of these selected varieties are potentially productive but unsuitable for cooking. This situation limits the exploitation of these varieties for making local dishes such as stew and "foutou". Since 2013, the research team of the CNRA Root Crops and Tubers Program has undertaken a process of creating new genotypes that can address the above concerns from hybridization between progenitors from the diversified *in vivo* cassava collection (traditional and improved varieties) of IITA and CNRA. A performance evaluation of these cassava new clones with colored flesh being selected is therefore important. This study was specifically initiated to contribute to answer this concern through the selection of new clones with high performance, rich in pro-vitamin A and suitable for multipurpose.

2.Material and Methods

2.1. Study site

The study was carried out at the Food Crops Research Station of the CNRA (7° 4' N and 5° 2 W) in Bouaké, Côte d'Ivoire (Figure 1). This region is located in the Guinean savannah, in Center Côte d'Ivoire (Traoré *et al.*, 2013). Moderately desaturated ferralitic soils dominate the region (Monnier, 1979). The rainfall regime is limited to two rainy seasons (April to July, and September to October) and two dry seasons (August, and November to March). The average annual rainfall ranges between 1100 and 1200 mm (Fondio, 2005).

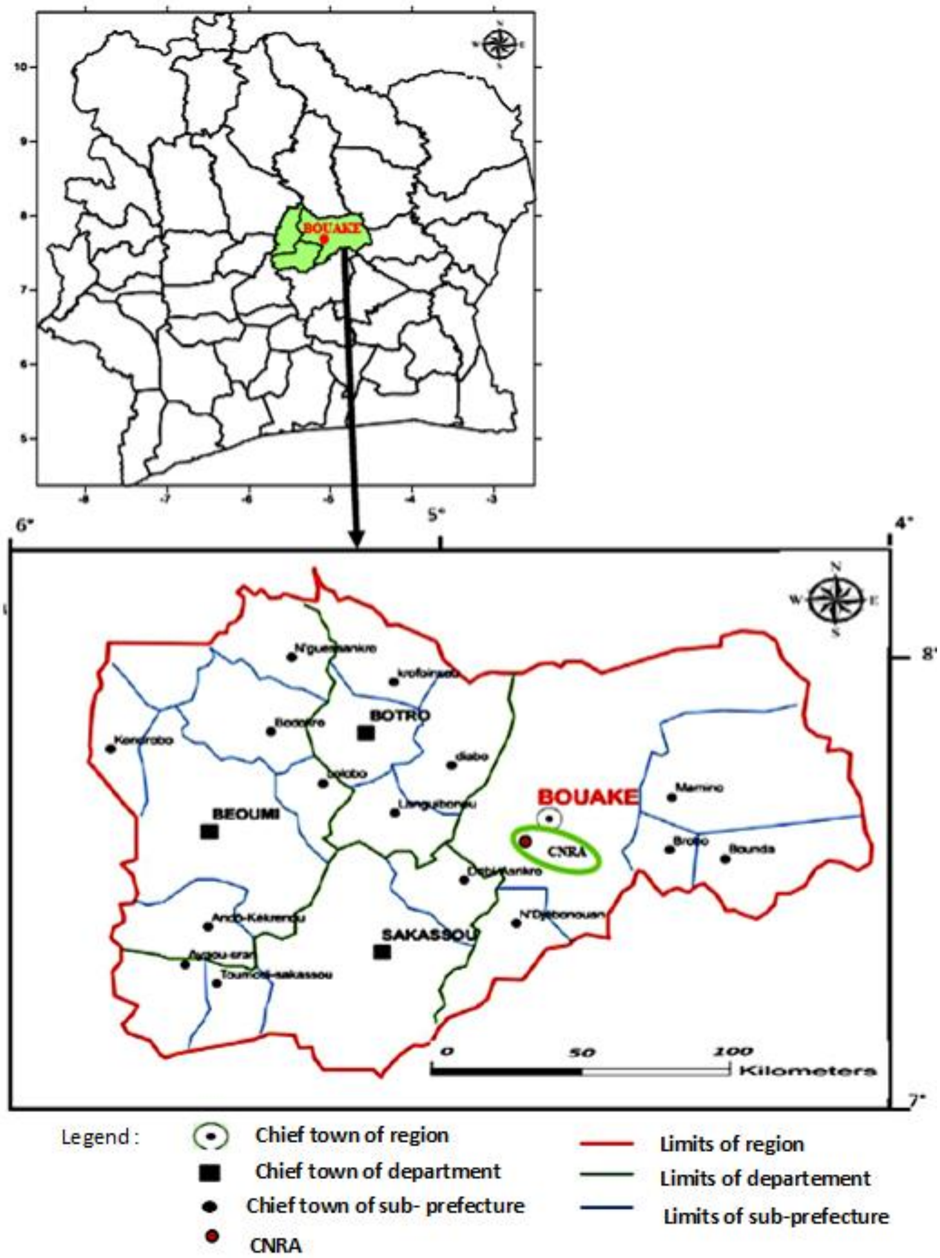

Figure 1: Study site, the Research Station of CNRA in Bouake (Kouassi, 2017)

2.2. Plant material

The planting material was composed of 44 cassava clones including 41 genotypes in the 6th year of selection and the Bonoua2, Yacé and Bocou2 varieties. Bonoua2 is a widespread cultivar in the West of Côte d'Ivoire used in the cooking of stew and "foutou". It is soft and has very good qualities for cooking in water. Yacé is a widespread cultivar in the South of Côte d'Ivoire around Abidjan the economic capital. This cultivar is used in making "attiéké" possessing an acceptable level of root production with a yield of around 25 t/ha, a high dry matter content (40%) and appreciated by users. Bocou2 is a new improved variety introduced from IITA and selected by the CNRA after a series of multilocal evaluations with a pro-vitamin A content of 6 ppm, an average yield around 32 t/ha and providing good quality of "attiéké" (CNRA, 2017). These three varieties served as reference controls for the taste and the cooking (Bonoua2), for the rate of dry matter (Yacé) and for the yield and the pro-vitamin A content (Bocou2).

3.Methods

3.1. Experimental design

The trial was conducted using a three-replicate Lattice design. Each replication included the 44 cassava clones and was divided into 2 blocks. Each block was subdivided into 22 elementary plots carrying 22 clones. Each elementary plot was made up of 4 rows of 6 plants. The spacing were 0.8 m between plants and between rows, i.e., a density of 15, 625 plants/ha; 1.5 m between elementary plots and 2 m between blocks.

3.2. Cultural practices

The plot was cleared and plowed in June 2018. After staking, the holes were made according to the spacing as mentioned above. Planting took place in July 2018. The cuttings were planted horizontally at a depth of less than 10 cm. A Roundup® herbicide application was done to the plot before planting cuttings to reduce the incidence of weeds. Field maintenance was carried out by weeding with the daba from one month after planting and whenever necessary. Harvest of tuberous roots took place in July 2019, 12 months after planting. The crossings (free and controlled) were carried out between the parents (with colored flesh and with white flesh) previously chosen taking into account their agronomic, culinary, and nutritional complementarities.

3.3. Data collection

The observations and measurements were related to the following parameters:

-The incidence of mites expressed in %, is established by the ratio of the number of plants attacked by pests to the total number of plants per plot, 6 months after planting.

-The severity of the mite attack was scored from 1 to 5 (1: absence of symptoms; 2: moderate damage, no reduction in the leaf area, scattered chlorotic spots on the young leaves; 3: strong chlorosis with slight reduction of leaf area); 4: severe chlorosis and noticeable reduction in leaf area of young shoots; 5: very strong chlorosis and significant reduction in leaf area and young shoots, generalized defoliation) of the leaves and young shoots of each clone according to the formula:

$$Sev = \Sigma Nombre\ de\ plants\ atteints\ x\ score / \ Nombre\ total\ de\ plants$$

-The average root production per plant expressed in kg/plant, was determined by taking the ratio of the weight of the tuberous roots of a clone to the total number of plants of this clone.

-The average weight of the roots expressed in kg/root was determined by taking the ratio of the weight of the tuberous roots of a clone to the number of its tuberous roots.

-The yield of tuberous roots at harvest is the weight of the tuberous roots of a plot weighed using a scale was determined by the following formulas:

$$Yield\ (t/ha) = Total\ weight\ of\ the\ tuberous\ roots\ of\ clone\ (t)\ /\ Plot\ area\ (ha)$$

-The dry matter content: the samples were weighed after drying in the oven; then the dry matter rate was estimated in %: A sample of 4 tuberous roots was taken randomly from each plot during harvest. These roots were peeled and cut into small slices of about 3 g each. Heaps, consisting of 200 g each, were spread on aluminum foil and dried in a SELECTA brand oven at 100°C for 24 h. The weight of dry matter obtained was then related to the fresh weight. The dry matter content was obtained by the following formula below:

$Dry\ matter\ content\ (DMC)\ (\%) = M2\ x\ 100\ /\ M1$, where M1 = sample weight before drying (g) and M2 = sample weight after drying (g).

-Cooking, taste and fiber content after cooking: for each clone: a sample of four tuberous roots, peeled and cut into pieces, was boiled in saucepans. After a cooking time deemed suitable, an assessment was made by three people according to a rating scale of: 1 (good), 2 (average) and 3 (poor) for cooking and 1 (mild), 2 (neutral) and 3 (bitter) for taste. For the fiber content, a visual assessment was also carried out by three people according to the rating scale defined as follows: 1 (no fiber), 2 (low fiber), 3 (fibrous) and 4 (very fibrous).

-Color of the flesh of the tuberous root: a visual observation was made according to the grading scale: 1 (white), 2 (cream), 3 (light yellow), 4 (dark yellow) and 5 (orange).

3.4. Data analysis

The data collected were subjected to analysis of variance (ANOVA) using Genstat 10 software. For each parameter the classification of the average values of the cassava clones was carried out according to the method of the smallest significant difference at 5%.

4. Results

4.1. Incidences and severities of mite attacks

The incidences of mite attack on the different clones varied significantly from 59.7 to 100%. Most clones presented a level of incidence of mites higher than those observed on the three controls, i. e., 88.92%, 97.13% and 97.80% for the Bonoua2, Yacé, and Bocou2 varieties, respectively. The lowest incidence was observed in clone 15 (313) 20 with 59.71% of plants attacked. The highest incidence was recorded in the majority of clones being selected like 15 (127) 21, 15 (415) 19, 15 (320) 11, 15 (358) 10, and 15 (239) 29 with 100% of plants attacked. The severity of the attack of the mites on the 44 clones ranged from 1.21 to 3.08. Clones 15 (94) 5 and 15 (193) 3 were the most susceptible compared to other clones and the controls. Clone 15 (313) 20 was the least susceptible with a severity of 1.22 (Table 1).

Table 1: Cassava clones with colored flesh having incidence percentages and indices of severity of mite attacks higher than or similar to those of the three control varieties (Bonoua2, Yacé, and Bocou2)

Clones	Incidence of mites %	Attack severity of mites
Bonoua2 (T1)	88.92	2.31
Yacé (T2)	97.13	2.55
Bocou2 (T3)	97.8	2.61
15 (313) 20	59.71	1.21
15 (295) 6	100	2.63
15 (336) 20	100	2.36
15 (304) 27	100	2.20
15 (431) 29	100	2.48
15 (397) 3	98.36	2.84
15 (409) 24	100	2.44
15 (176) 9	98.36	2.73
15 (263) 15	100	2.58
15 (407) 17	100	2.80
15 (324) 32	90.5	2.19
15 (402) 23	100	2.51
15 (338) 12	100	2.77
15 (377) 5	98.36	1.99
15 (127) 21	100	2.38
15 (198) 34	90.03	2.49
15 (456) 5	98.84	2.65
15 (165) 25	100	2.30
15 (193) 3	100	3.08
15 (197)	100	2.74
Overall average	97.52	2.53
SED	07.02	0.29
LSD (5%)	13.96	0.57
CV	08.80	13.90

SED: Standard Errors Differences in Means; LSD: Least Significant Difference; CV: Coefficient of Variation.

4.2. Yield of fresh roots

The yield of tuberous root of cassava clones varied from 11.24 to 48.28 t/ha. Twenty-five (25) assessed clones yielded more than the Bocou2 control with values between 48.28 and 30.05 t/ha. The smallest value was observed with the Bonoua2 control (11.24 t/ha) and the highest value was observed with the clone 15 (431) 29 (48.28 t/ha) followed by clone 15 (456) 5 with a yield of 47.09 t/ha.

4.3. Dry matter content

The dry matter content was between 27.69 and 43.45%. Twenty-one (21) clones recorded a higher dry matter content than the Yacé control with values ranging from 43.45 to 40.82%. The highest dry matter content was recorded in clone 15 (377) 5 with a value of 43.45%. The lowest dry matter content was obtained in clone 15 (263) 15 with a value of 27.69% (Table 2).

Table 2: Cassava clones with colored flesh having an average tuberous root weight, an average production per plant, a yield and dry matter content higher or similar than those of the three control varieties (Bonoua2, Yacé, and Bocou2)

Clones	Average of tuberous root weight (kg/plant)	Average of production/plant (kg/tuberous root)	Yield (t/ha)	Dry matter content (%)
Bonoua2 (T1)	2.05	0.43	11.24	41.67
Yacé (T2)	2.13	0.40	23.68	40.54
Bocou2 (T3)	2.20	0.42	28.31	41.79
15 (313) 20	2.75	0.46	34.97	39.93
15 (295) 6	2.88	0.54	38.44	40.14
15 (336) 20	3.45	0.48	39.31	39.41
15 (304) 27	3.74	0.59	40.17	40.62
15 (431) 29	4.09	0.52	48.28	39.69
15 (397) 3	2.60	0.45	33.52	41.50
15 (409) 24	2.79	0.44	37.28	42.97
15 (176) 9	3.25	0.47	39.60	38.83
15 (263) 15	3.05	0.51	40.46	27.69
15 (407) 17	2.65	0.45	40.46	41.34
15 (324) 32	2.6	0.53	31.49	37.93
15 (402) 23	2.48	0.37	36.41	43.18
15 (338) 12	4.39	0.73	33.23	39.47
15 (377) 5	2.70	0.44	35.54	43.45
15 (127) 21	2.62	0.45	39.02	42.67
15 (198) 34	2.39	0.46	34.10	41.33
15 (456) 5	3.89	0.71	47.09	38.67
15 (165) 25	3.07	0.50	30.92	41.29
15 (193) 3	2.53	0.43	28.02	36.99
15 (197) 32	2.00	0.27	26.86	42.77
Overall average	2.72	0.52	31.72	40.06
SED	0.52	0.33	07.49	02.85
LSD (5%)	1.04	0.66	14.88	05.67
CV	23.5	78.3	28.90	08.70

SED: Standard Errors Differences in Means; LSD: Least Significant Difference; CV: Coefficient of Variation.

4.4. Cooking, taste and fiber content

The cooking score of the roots of cassava clones ranged from 1.11 to 3. The control varieties Bonoua2 and Yacé followed by clones 15 (165) 25, 15 (397) 3 and 15 (295) 6 had the best cooking quality. Several clones including Bocou2 control registered a medium quality of cooking. Four clones, 15 (206) 1, 15 (358) 10, 15 (377) 5 and 15

(431) 29 showed a poor cooking quality. For the taste, the score of cassava clones varied from 1.11 to 2.55. The Bonoua2 control followed by Bocou2 control and clones 15 (435) 36, 15 (25) 11, 15 (295) 6, 15 (313) 20, 15 (338) 12, 15 (397), 15 (402) 23, and 15 (51) 10 recorded a sweet taste (Table 3).

Table 3: Cassava clones with colored flesh having a cooking, a taste and a fiber content superior or similar to those of the three control varieties (Bonoua2, Yacé, and Bocou2)

Clones	Cooking	Taste	Fiber content
Bonoua2 (T1)	1.11	1.11	0.99
Yacé (T2)	1.11	2.33	1.66
Bocou2 (T3)	2.78	1.89	1.71
15 (313) 20	1.89	1.33	1.88
15 (295) 6	1.44	1.56	1.33
15 (336) 20	2.33	1.67	1.66
15 (304) 27	1.67	1.89	1.55
15 (431) 29	3.00	1.89	1.49
15 (397) 3	1.33	1.22	1.49
15 (409) 24	2.33	2.11	1.83
15 (176) 1	1.66	1.89	1.94
15 (263) 15	1.56	2.00	1.88
15 (407) 17	1.56	1.67	1.55
15 (327) 23	2.78	1.89	2.55
15 (324) 32	2.33	2.11	1.88
15 (402) 23	1.89	1.33	2.44
15 (338) 12	2.45	2.33	1.38
15 (377) 5	3.00	2.22	1.99
15 (127) 21	2.22	2.22	2.16
15 (198) 34	1.89	2.00	1.99
15 (456) 5	1.98	2.27	2.51
15 (165) 25	1.45	1.67	1.88
15 (393) 3	2.45	2.33	1.77
15 (197) 32	2.33	2.55	2.33
Overall average	2.17	1.90	1.83
SED	0.51	0.54	0.47
LSD (5%)	1.02	1.06	0.93
CV	28.9	34.4	31.30

SED: Standard Errors Differences in Means; LSD: Least Significant Difference; CV: Coefficient of Variation.

4.5 Starch parenchyma color

Four tuberous root parenchyma color modalities, i.e., cream, light yellow, dark yellow and orange colors were observed in the cassava clones (Table 4). The dark yellow coloration was observed in approximately 44% of the clones. Light yellow and orange colorations were observed in 36% and 12% of clones, respectively. Finally, 5% of the clones have cream-colored tuberous roots.

Table 4: Color of the parenchyma of the tuberous roots of the 41 colored flesh cassava clones

Clones	Scores	Color of the flesh	Proportion (%)
15 (1) 15, and 15 (94) 5	2	Cream	5
15 (397) 3, 15 (409) 24, 15 (176) 9, 15 (263) 15, 15 (407) 17, 15 (327) 23, 15 (432) 30, 15 (196) 31, 15 (127) 21, 15 (415) 19, 15 (291) 9, 15 (31) 12, 15 (206) 1, 15 (148) 10, 15 (193) 3, and 15 (51) 13	3	Light yellow	39
15 (295) 6, 15 (165) 25, 15 (431) 29, 15 (324) 32, 15 (336) 20, 15 (304) 27, 15 (402) 23, 15 (338) 12, 15 (377) 5, 15 (198) 34, 15 (456) 5, 15 (323) 1, 15 (320) 11, 15 (200) 2, 15 (358) 10, 15 (239) 29, 15 (212) 18, and 15 (197) 32	4	Dark yellow	44
15 (313) 20, 15 (51) 10, 15 (391) 2, 15 (435) 36, and 15 (25) 11	5	Orange	12

5. Discussion

The incidence of mites was higher in the flesh-colored cassava clones than in the three controls Bonoua2, Yacé, and Bocou2. Indeed, Ikotun et al. *(*1990) reported that some improved varieties can suffer yield losses of 45% due to mites depending on the age of the plant and the season. It is therefore advisable to cultivate or plant early at the start of the rainy season (Akpingny and Koulou, 2017). However, N'Zué *et al. (*2004) showed that the selection of resistant varieties based on the presence of mites would be ineffective. Biological control programs already exist in certain research institutes such as the International Institute of Tropical Agriculture (IITA), the International Center for Tropical Agriculture (ICTA) and the Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA). Moreover, Ikotun et al. *(*1990) noted that mites belonging to the family of *Phytoseiids* are used as the main control agents against green mites.

Yield of fresh roots revealed cassava clones with colored flesh efficient with yields between 17.69 and 48.26 t/ha. It is higher than those obtained by Adetoro *et al. (*2018) who stated that the yield varies between 10 to 24 t/ha. Clones (15 (431) 29 and 15 (456) 5) yielded more than 40 t/ha. These yields were superior to those of all flesh-colored clones studied by Dixon et al. *(*2010) in which the high-performing got yields less than 40 t/h. However, these yields were lower than those obtained by Ntawuruhunga and Okidi (2010) which were around 60 t/ha. Yields of fresh roots from several clones are similar to those of the control Bocou2 which is an improved variety popularized in Côte d'Ivoire. However, results obtained in our study could be improved by the effective control against pests. According to N'Zué *et al. (*2005), these pests can cause 80% of yield loss. The results analysis also showed that the two controls Bonoua2 and Yacé are less productive than some tested clones. This result is in agreement with the conclusions of several works demonstrating that improved varieties have higher yields than local varieties (N'Zué *et al*., 2004, Bakayoko *et al*., 2012, and Djnadou *et al*., 2018).

Root dry matter content of cassava clones with colored flesh evaluated varied between 27.69 and 43.45%. These percentages are comparable to those obtained by Ntawuruhunga and Okidi (2010), Dixon et al. *(*2010), Cissé (2015), and Coulibaly (2020) which are around 30 to 40%. However, these dry matter contents could be improved insofar as Vimala et al. *(*2008) achieved rates of up to 47%. The values of the dry matter content of the clones relatively low in the present study could be due to the effort of improvement achieved by crossing the flesh-colored varieties introduced from IITA with the local cultivars containing high dry matter. The relatively low dry matter values in the present study could be due to the action of mites. Indeed, Yaninek and Herren (1988) and Bonato et al. (1994) indicated that green mites can cause an 80% drop in dry matter content.

Some clones with colored flesh had bad cooking. These results are consistent with those observed by Moorthly *et al. (*1996) who showed that the poor cooking quality of cassava colored flesh could be due to a high carotenoid content. However, clones 15 (165) 25, 15 (397) 3, and 15 (295) 6, had better cooking quality compared to the Bonoua2 control.

Some flesh-colored clones evaluated had a sweet taste. This result is in agreement with that of Gu et al. *(*2013) who mentioned that most cassava varieties with flesh-colored rich in pro-vitamin A have a sweet taste. These authors also showed that the compounds responsible of bitter taste like tannins and cyanogen's are in low quantity in fleshy tuberous roots colored and this may influence the taste. These cassava clones with colored flesh are very good for making chips and crispy golden-colored fries (Vimala *et al*., 2008).

The tuberous roots of the majority of the clones currently studied were dark yellow. This observation is in agreement with that made at IITA (2007) during an evaluation of flesh-colored cassava clones. According to Ceballos et al. *(*2013) and Bechoff *et al. (*2015), carotenoid content is related strongly to cassava flesh color. These authors also showed that the values of the content of carotenoids corresponding to the different colorations: 1, 4, 6, 8 and over 12 (max.25.8) µg/g of fresh weight of roots for white, cream, light yellow, dark yellow, and orange colorations. Additionally, Nassar et al. *(*2005) showed that the presence of beta-carotene also contributes to the overall color of the colored flesh of cassava.

6.Conclusion

For the selection of new high-yielding varieties, rich in pro-vitamin A and for multiple purposes, 44 flesh-colored cassava clones under selection were evaluated with three control varieties Bonoua2, Yacé, and Bocou2. At the end of the evaluation, eleven (11) clones: 15 (165) 25, 15 (456) 5, 15 (391) 2, 15 (198) 34, 15 (407) 17, 15 (263) 15, 15 (179) 9, 15 (397) 3, 15 (304) 27, 15 (295) 6, and 15 (313) 20 were selected primarily based on their yields and the quality of cooking in water as well as the coloring of the flesh of the tuberous root parenchyma. Clones 15 (397) 3, 15 (165) 25, and 15 (295) 6 especially had better cooking quality. Also, 11 clones exhibited several sought-after characteristics and could be evaluated multi-local in research stations and on-farm in view to future dissemination.

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