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Characterization of a tomato collection from different regions of Morocco

Fanedoul Jawhara [1,2], Belghazi Fatima [3], Sahri Ali [4], Zouine Mohamed [5], Harrak Hasnaâ [6], El Ghadraoui Lahsen [2] and Bekkaoui Faouzi [1]

faouzi.bekkaoui@inra.ma

1: National Institute of Agricultural Research, Avenue Ennasr, BP 415 Rabat Principale, 10090 Rabat, Morocco.

2: Faculty of Science and Technology, BP 2202, Route d'Imouzzer, Fes, Morocco.

3: Regional Center of Agricultural Research of Agadir, National Institute of Agricultural Research, Avenue Ennasr, BP 415 Rabat Principale, 10090 Rabat, Morocco.

4: Environment and Sustainable Management of Natural Resources Research Unit, Regional Center of Agricultural Research of Settat, National Institute of Agricultural Research, Avenue Ennasr, BP 415 Rabat Principale, 10090 Rabat, Morocco.

5: Fruit Genomics and Biotechnology Laboratory, UMR990 INRA/INP-ENSAT, Avenue de l'Agrobiopole, BP 32607, 31326 Castanet-Tolosan Cedex, France.

6: Agro-Food Technology and Quality Laboratory, Plant improvement and Quality Research Unit, Regional Center of Agricultural Research of Marrakesh, National Institute of Agricultural Research, Avenue Ennasr, BP 415 Rabat Principale, 10090 Rabat, Morocco.

Abstract

Tomatoes are one of the most important crops in Morocco. National tomato production reached 1 231 250 tons in 2019. The sector generates thousands of jobs and is one of the pillars of the country's economy through exports. Hence, it is judicious to search for new varieties with high commercial potential. This study aimed to characterize a collection of four local tomato genotypes (‘Taliouine’, ‘Zagora’, ‘Oufella’ and ‘Cerise or Cherry tomato’) from accessions collected in different regions of Morocco, compared to two commercial genotypes (‘Campbell 33’ and ‘Rio Grande’). The analyses concerned agronomic and growth criteria, sensory criteria and physical and physicochemical criteria (humidity, pH, Brix and color). The obtained results showed a great variability between the studied genotypes. Some genotypes showed interesting performances like ‘Campbell 33’ (number of leaves per branch), ‘Rio Grande’ (number of fruits per plant), ‘Cerise tomato’ (number of fruiting branches per plant) and ‘Taliouine’ (plant height). The three genotypes with the best taste are ‘Campbell 33’, ‘Cerise tomato’ and ‘Oufella’. They also show a high intensity of red color, high skin firmness and high aroma content. Significant variations were also observed for the different physicochemical criteria. Such results will help to identify relevant criteria that can be used for varietal improvement and can also constitute basic criteria to differentiate between tomato accessions.

Keywords. *Solanum lycopersicum* L., genotype, variability, varietal characterization, quality.

Caractérisation d'une collection de tomates issues de différentes régions du Maroc

Résumé

Les tomates sont l'une des cultures les plus importantes au Maroc. La production nationale de tomates a atteint 1 231 250 tons en 2019. Le secteur génère des milliers d'emplois et constitue l'un des piliers de l'économie du pays grâce aux exportations. Il est donc judicieux de rechercher de nouvelles variétés à fort potentiel commercial. Cette étude avait comme objectif la caractérisation d'une collection de quatre génotypes de tomates locales issues d'accessions collectées dans différentes régions du Maroc ('Taliouine', 'Zagora', 'Oufella' et 'Tomate cerise'), comparée à deux génotypes commerciaux ('Campbell 33' et 'Rio Grande'). Les analyses ont concerné des critères agronomiques et de croissance, des critères sensoriels et des critères physiques et physicochimiques (humidité, pH, Brix et couleur). Les résultats obtenus ont montré une assez grande variabilité entre les différents génotypes étudiés. Certains génotypes ont présenté des performances importantes comme 'Campbell 33' (nombre de feuilles par branche), 'Rio Grande' (nombre de fruits par plante), 'Tomate cerise' (nombre de branches fructifères par plante) et 'Taliouine' (hauteur de la plante). Les trois génotypes les mieux appréciés pour leur goût sont 'Campbell 33', 'Tomate cerise' et 'Oufella'. Ces derniers montrent une forte intensité au niveau de leur couleur rouge, une peau très ferme et des teneurs élevés en arômes. Des variations significatives ont été également observées pour les différents critères physicochimiques étudiés. De tels résultats aideront à identifier les critères importants qui peuvent être utilisées pour l'amélioration variétale et qui peuvent aussi constituer des critères de base pour différencier entre les accessions de tomates.

Mots-clés : *Solanum lycopersicum* L., génotype, variabilité, caractérisation variétale, qualité.

تصنيف مجموعة طماطم منحدرة من مناطق مختلفة من المغرب

فندول جوهرة، بلغازي فاطمة، سهري علي، زوين محمد، الحراق حسناء، الغدراوي لحسن وبكاوي فوزي

ملخص

تعتبر الطماطم من أهم المحاصيل في المغرب. ولقد بلغ الإنتاج الوطني من الطماطم 1.231.250 طنًا سنة 2019. يوفر القطاع آلاف الوظائف وهو أحد دعائم اقتصاد البلاد من خلال الصادرات. ومن هنا يأتي الاهتمام بالبحث عن أصناف جديدة ذات مقومات تجارية عالية. كان الهدف من هذه الدراسة هو توصيف مجموعة من أربعة أنماط وراثية من الطماطم المحلية 'تالوين' و'زاكورة' و'أوفيلا' و'الطماطم الكرزية' من المدخلات التي تم جمعها في مناطق مختلفة من المغرب مقارنة بنوعين وراثيين تجاريين 'كامبل 33' و'ريو غراندي'. شملت التحليلات الخصائص الزراعية وخصائص النمو والخصائص الحسية وكذا الخصائص الفيزيائية والفيزيوكيميائية (الرطوبة، والرقم الهيدروجيني، والبريكس، واللون). أظهرت النتائج التي تم الحصول عليها تباينًا كبيرًا نسبيًا بين الأنماط الجينية المختلفة التي تمت دراستها. أظهرت بعض الأنماط الجينية مقومات مهمة مثل 'كامبل 33' (عدد الأوراق لكل فرع)، 'ريو غراندي' (عدد الثمار لكل نبتة)، و'الطماطم الكرزية' (عدد الأفرع المثمرة لكل نبتة) و'تالوين' (ارتفاع النبتة). الأنواع الثلاثة التي حظيت باستحسان كبير فيما يخص ذوقها هي 'كامبل 33' و'الطماطم الكرزية' وأوفيلا. ولقد أظهرت كذلك هذه الأنماط الجينية كثافة قوية على مستوى لونها الأحمر، وصلابة عالية للجلد ومحتويات كثيرة لمكونات الرائحة. كما لوحظت اختلافات كبيرة لمختلف الخصائص الفيزيوكيميائية. ستساعد هذه النتائج في تحديد الخصائص المهمة التي يمكن استخدامها لتحسين الأصناف والتي يمكن أن تشكل أيضًا خصائص أساسية للتمييز بين مختلف الأنماط الجينية للطماطم.

الكلمات المفتاحية: *Solanum lycopersicum* L.، النمط الجيني، التنوع، التصنيف، الجودة.

Introduction

The cultivated tomato, *Solanum lycopersicum* L., belongs to the *Solanaceae family*, which also includes potatoes, eggplant, pepper, and tobacco (Mueller *et al.*, 2005; Fernandez-Pozo *et al.*, 2015). It was domesticated in Mexico or Peru from *Solanum lycopersicum var*. cerasiforme, stemming from interspecific crosses between *Solanum lycopersicum* and *Solanum pimpinellifolium* (Nesbitt and Tanksley, 2002; Bergougnoux, 2014). Tomato was brought to Europe during the XVIth century, and later, the crop was diffused to the rest of the world through commercial routes and colonies (Blanca *et al.*, 2012; Razifard *et al.*, 2020).

Tomato is an autogamous and annual crop under a temperate climate. Its biological cycle from seed to seed is around 4 months. The berry-like fruits make 60 to 80% of total plant weight. When they are ripened, approximately 50 days after flower fecundation, fruits contain between 93 and 95% of water (Ceballos and Vallejo 2012; Kaur *et al.*, 2017). The dry matter contains 50% of sugars, especially fructose and glucose, 20% of acids, mainly citric acid and malic acid, and 10% of fibers, including cellulose and hemicellulose (Causse *et al.*, 2004; Bauchet and Causse, 2012; Barrantes *et al.*, 2016).

According to FAO (2019), the global area cultivated with tomato was 5 million hectares with a production of 180 million tonnes in 2019. In Morocco, tomato is one of the most important crops and the sector generates thousands of jobs and is one of the pillars of the country's economy through exports. The tomato accounts for 61% of total exports of vegetables and fruits products, followed by various products such as green beans, zucchini, peppers, strawberries and melons (Cordon et *al.*, 2016; Hou et *al.*, 2015).

For a long time, the tomato breeding programs have been focused on yield, long shelf life, firmness, resistance to diseases, and fruit size to the detriment of taste and fruit quality (Bhattarai *et al.*, 2018; Ronga *et al.*, 2019). Organoleptic fruit quality can be divided into three significant aspects, the visual aspect, especially the color, the texture, and the taste (Domis *et al.*, 2002; Mihr *et al.*, 2005; Aoun *et al.*, 2013; Wang and Seymour, 2017). Today, the current breeding efforts aim to increase the tomato fruit quality in its whole, which potentially includes organoleptic properties and health benefits.

However, due to reduced genetic variation in the cultivated tomato (Bai and Lindhout, 2007; Aflitos *et al.*, 2014), it has become necessary to look for novel genes in genetic resources (old cultivars and local landraces) to increase the potential of the organoleptic quality in fresh tomato (Tanksley and McCouch, 1997; Schauer *et al.*, 2006; Barrantes *et al.*, 2016; Roohanitaziani *et al.*, 2020). Indeed, the genetic resources constitute an important reservoir of variability, exploited since the beginning of tomato breeding (Kulus, 2018). Moreover, the development of genetic engineering techniques has led to a renewed interest in these genetic resources and made it possible to increase the efficiency of their use (Causse *et al.*, 2000; Tam *et al.*, 2006; Chaudhary *et al.*, 2019).

Several studies have focused on describing and analyzing the variability of morphological and fruit quality traits of tomato landraces (Parisi *et al.*, 2005; Ercolano *et al.*, 2008; Terzopoulos and Bebeli, 2010; Cebolla-Cornejo *et al.*, 2013; Figàs *et al.*, 2015; Rai *et al.*, 2017; Renna *et al.*, 2019). These studies have revealed new genotypes with desirable characters that can be used as the primary material to select specific cultivars suitable for different tomato-growing regions.

The main objective of this study is to assess the variability of a collection made up of local tomato. It is imperative to carry out an analytic study of these local populations regarding their morphological, agronomical, and quality characteristics. The information gathered will allow us to exploit the studied material and identify optimal conservation and sustainable use strategies.

Materials and methods

Vegetal material

The vegetal material used in this research is composed of 6 tomato genotypes, Two commercial genotypes (V1: 'Campbell 33' and V2: 'Rio Grande') and four local genotypes (V3: 'Taliouine', V4: 'Zagora', V5: 'Oufella' and V9: 'Cerise (or Cherry) tomato'. The local genotypes were obtained from farmers in the Agadir region and provided by the Regional Agricultural Research Center of Agadir.

Experimental plan

The experiment was set up in a block design with two replications. The studied factor was the genotypes. The plants were planted in soil at a depth of 40 cm, spaced 50 cm apart on the line and 70 cm between the lines, and ten plants per line. The two blocks are separated by 2 m. The replication consists of 6 lines, each representing a genotype.

Agronomic and growth parameters

Germination rate, plant height, number of branches per plant, number of leaves, number of fruiting branches, number of fruits and growth type were determined according to IPGRl (1996) on five plants per genotype taken randomly. The predominant form of the ripe fruit was also compared to the different forms described by IPGRl (1996).

Sensory parameters

The color of immature fruit was determined by visual observation of fruits at the beginning of the turning stage (IPGRl, 1996).

The type of growth was determined by visual observation of plant for each genotype at the final stage (IPGRI, 1996).

The sensory attributes evaluated of the ripe fruit are the color of skin and pulp, the thickness of skin, the firmness of pulp, the texture, the odor and the flavor. The odor and flavor neutralization was provided with water. Samples were evaluated on a linear intensity scale going from 0 (zero) to 5 (very high) by calculating the median, and a scale from 0 (zero) to 10 (very high) for the average of overall appreciation scores calculated for each genotype. The analyses were carried out by a panel of nine experts from the Regional Center of Agricultural Research of Marrakech (INRA) in the sensory analysis room belonging to the Agro-Food Technology and Quality Laboratory established in accordance with the general guidelines for sensory evaluation rooms: ISO 8589-2007.

Physical and physicochemical parameters

pH

pH determined with a pH meter at a temperature of 25 °C using 20 g of tomato juice for each genotype.

Humidity

Humidity determined according to AOAC method n° 920.151 (AOAC, 1990) by drying a 20 g test portion of the tomato juice in an oven at atmospheric pressure and a temperature of 103 ± 2 °C for 48 hours. Humidity, expressed as g of water per 100 g of fresh matter, is determined by the difference in weight before and after drying.

Brix

The total soluble solids or Brix (expressed in °Bx) giving information on the percentage of sugars present in the tomato juice was measured by refractometry at 20 °C.

Skin and juice color

Skin color was measured with a solid colorimeter on 5 tomatoes. Five parameters of color L*, a*, b*, chroma C* and angle *h* were operated at the level of each of the three parts of the fruit (peduncle, central and basal). In total, 15 measurements were made on each fruit. The color of the homogenized and filtered tomato juice was also measured by determining the color parameters L*, a*, b*, chroma C* and angle *h*, using a liquid colorimeter and performing five repetitions.

Ash and minerals

Tomato juice was incinerated at 600 °C for 7 hours (Thermolyne oven type 1400, USA) and the ash content (g/100 g dry matter (DM)) was determined in triplicate for each genotype (AOAC, 1990). For minerals determination, the ash was digested with nitric acid and diluted with demineralized water. The determination of potassium (K), calcium (Ca) and sodium (Na) concentration was performed using a flame spectrophotometer (BMB Technologie XP 2011, Germany) calibrated with different concentrations of K, Ca and Na standards. Measurements were performed in triplicate for each cultivar. Results were expressed as mg/100 g DM.

Statistical analysis

The collected raw data were entered in EXCEL 2016 and analyzed using the statistical processing software XLSTAT 2021. Descriptive statistics (medians, means and standard deviations) and multifactor analysis: Principal Component Analysis (PCA) and Hierarchical Ascending Classification (HAC) were performed to study the variability between the different tomato genotypes.

Results

Variation in agronomic and growth parameters

The most significant variation for the tomato genotypes was observed for the number of fruits per plant, followed by the number of leaves per branch and the number of branches per plant. The standard deviations for these three variables were 10.82, 7.74 and 4.09, respectively. A relatively low standard deviation was observed for the other variables. The average number of fruiting branches varied from 3.00 to 8.67 with a standard deviation of 2.17. Fruit height ranged from 1.20 to 1.70 m with a standard deviation of 0.18 (Tab. 1).

Table 1: Statistics of variation of gronomic and growth parameters of the studied tomato genotypes.

Variable	Minimum	Maximum	Mean	Standard deviation
Height (m)	1.20	1.70	1.49	0.18
Number of branches	10.00	21.67	16.17	4.09
Number of fruiting branches	3.00	8.67	5.44	2.17
Number of fruits per plant	8.33	33.00	16.65	10.82
Number of leaves per branch	11.33	32.33	20.17	7.74

The descriptive analyses on the morphology of the genotypes according to the qualitative variables are given in Table 2. It is observed that 66% of the genotypes have an indeterminate type of growth. Regarding fruit shape, the genotypes have more rounded fruits. At the immature fruit stage, most genotypes have a green color.

Table 2: Frequency distribution of tomato genotypes according to the modality of agronomic and growth parameters.

Variables	Modality	Frequency (%)
Type of growth	Determined	33.34
	Undetermined	66.66
Immature fruit color	Whitish green	16.66
	Light green	33.34
	Green	50.00
Predominant fruit shape	Slightly flattened	16.67
	Rounded	50.00
	Elongated-rounded	16.67
	Cordiform	16.60

Variation in sensory parameters

According to the results of the sensory quality performed on ripe tomatoes, the main observations obtained are as follows:

Visual and touch criteria

Figure 1 shows the medians of the scores for visual and touch criteria of tomatoes of the six studied genotypes. These latter show a fairly bright red color for skin with a median of the sensory panel scores of 4 (on the scale of 5). The genotypes also present a red pulp color with a median of 3, except for the 'Oufella' genotype which obtained a median of 4. For the criterion of the skin thickness, the studied genotypes present a median ranging between 2 and 3. Concerning the firmness of the pulp, the 'Campbell 33' genotype was judged as very firm with a median of 4. Furthermore, the 'Rio Grande', 'Taliouine', 'Zagora' and 'Cerise tomato' genotypes were evaluated as medium firm (with a median of 3).

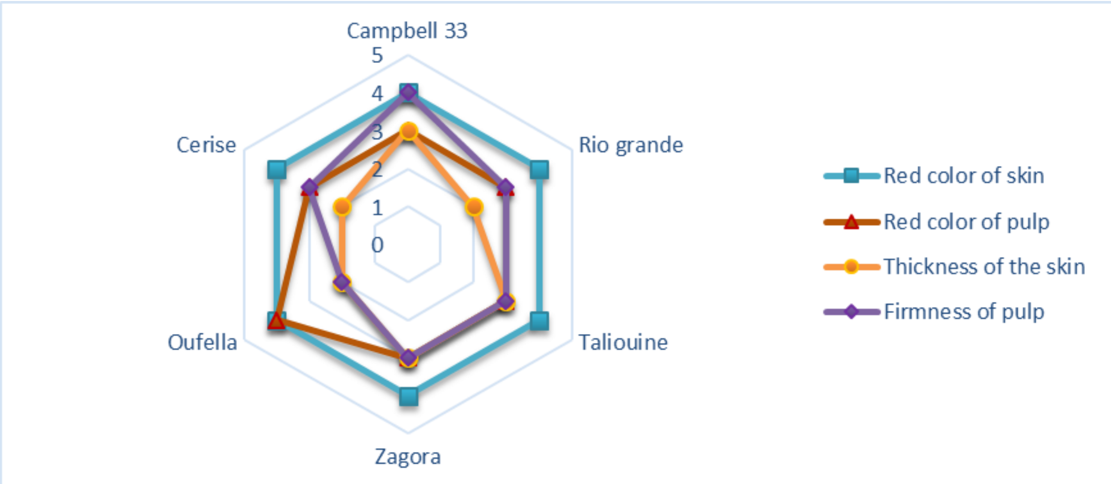

Figure 1: Medians of the scores given by the sensory panel to the visual and touch criteria of tomatoes of the six genotypes.

Types of texture

The medians of the texture scores are presented in Figure 2. The local genotypes 'Zagora' and 'Cerise tomato' have the highest juiciness with a median of 4. The genotypes 'Campbell 33', 'Rio Grande', 'Taliouine' and 'Oufella' have a medium juiciness with a median of 3.

The 'Oufella' genotype is evaluated as very melting with a median of 4 compared to the genotypes 'Cerise tomato', 'Rio Grande', 'Zagora' and 'Taliouine' which are moderately melting with a median ranging from 2 to 3. Furthermore, the commercial genotype 'Campbell 33' represents the weakest melting character with a median of 2.

All genotypes are moderately fleshy and moderately crunchy, except for 'Cerise tomato' and 'Oufella' genotypes which are less crunchy (with a median of 2).

The commercial genotypes 'Campbell 33' and 'Rio Grande' are very firm while the 'Cerise tomato' genotype is not very firm and the other genotypes are moderately firm.

Figure 2: Medians of sensory panel scores for tomato textures of the six genotypes.

Odor and flavor characteristics

The medians of the scores attributed to the odor and flavor characteristics are presented in Figure 3. All the genotypes have a moderately frank and fruity odor, as well as a moderately fruity, moderately persistent flavor, except for the ‘Oufella’ genotype which has a very little persistent flavor. ‘Campbell 33’, ‘Taliouine’ and ‘Oufella’ genotypes have a very frank flavor, and ‘Cerise tomato’, ‘Rio Grande’ and ‘Zagora’ genotypes have a medium frank flavor.

Figure 3: Medians of the scores assigned by the sensory panel to odor and flavor of the six tomato genotypes perceived by nasal and retro-nasal pathways, respectively.

Types of flavors

The medians of the flavor type scores are presented in Figure 4. The genotypes exhibited a moderately sweet flavor (with a median of 3), but the 'Cerise tomato' genotype has a very low sweetness of a median of 1.

We note that the acidity is average for 'Campbell 33', 'Rio Grande' and 'Cerise tomato' genotypes with a median of 3, the other genotypes 'Taliouine', 'Zagora' and 'Oufella' are not very acidic with a median of 2. All the genotypes are not very astringent, except for the 'Cerise tomato' genotype which is the most astringent with a median of 3. We have also noted that the genotypes are not very salty, except for the 'Rio Grande' and 'Oufella' genotypes which they are medium salty.

Figure 4: Medians of flavor scores for tomatoes of the six genotypes.

Overall appreciation

The averages of the overall appreciation score out of 10 were all high for the tomatoes of the six studied genotypes. They ranged from 8.5 to 7.3 (Tab. 3). According to the sensory panel, the most appreciated genotype is the commercial genotype 'Campbell 33' with an average appreciation score of 8.5. This genotype was characterized by its strong firmness, its red color and its very frank and fruity smell.

The local genotypes 'Cerise tomato' and 'Oufella' were also well evaluated with similar overall average scores (8.13 and 8.06, respectively). These two genotypes are similar for color intensity, pulp thickness and juicy texture. They also have a medium profile of flavor.

The relatively less appreciated genotypes with a medium profile for all sensory criteria are 'Rio Grande', 'Taliouine' and 'Zagora' with overall average scores of 8.00, 7.38 and 7.31, respectively.

Table 3: Overall appreciation scores of the studied tomato genotypes.

Genotype	Campbell 33	Cerise tomato	Oufella	Rio Grande	Taliouine	Zagora
Overall score	8.56	8.13	8.06	8.00	7.38	7.31

Variation in physicochemical parameters

Principal component analysis (PCA)

PCA was used to better understand the existing relationships between the studied physical and physicochemical variables of the six tomato genotypes. The first two principal components F1 and F2 explain 89.5% of the total variation between genotypes (the percentage of explanatory information exceeds 50%, so it is a good statistical representation). The first two components (axis 1 and axis 2) were selected to explain the variability within all genotypes. The first principal component (axis 1) represents 63.8% of the total variation, while the second component (axis 2) represents 25.6%.

This representation shows that the 'Cerise tomato' genotype is clearly distinguished from all the genotypes by the studied physicochemical variables. This genotype presents very high variables such as: humidity (97.13%), Brix (8.02 °Bx) and tomato juice color parameters a* (6.98), b* (22.06), chroma C* (23.13) and the angle *h* (72.44) (Tab. 4).

Compared to the other genotypes, the 'Rio Grande' genotype has a high pH and L* color parameter (peduncular, basal and central). This genotype shares with the 'Taliouine' genotype some color variables within the a* parameter (peduncular, basal and central).

The group of 'Oufella', 'Zagora', 'Campbell 33' and 'Taliouine' are clearly similar in the C* and b* color variables (peduncular, basal and central). This shows an important physicochemical variability in this collection of tomatoes (Fig. 5).

Thus, three main groups can be distinguished. The first group comprising the 4 genotypes 'Oufella', 'Zagora', 'Campbell 33' and 'Taliouine' sharing some characters in common, such as color parameters (b*, a* and C* of the skin and L* of the juice). The second group ('Rio Grande') contains the most important color parameters of which a* and L* of the skin and the pH, and the third group constituted by the 'Cerise tomato' with its specific characters which are the humidity, the Brix and the juice color parameters (a*, b*, C* and *h*).

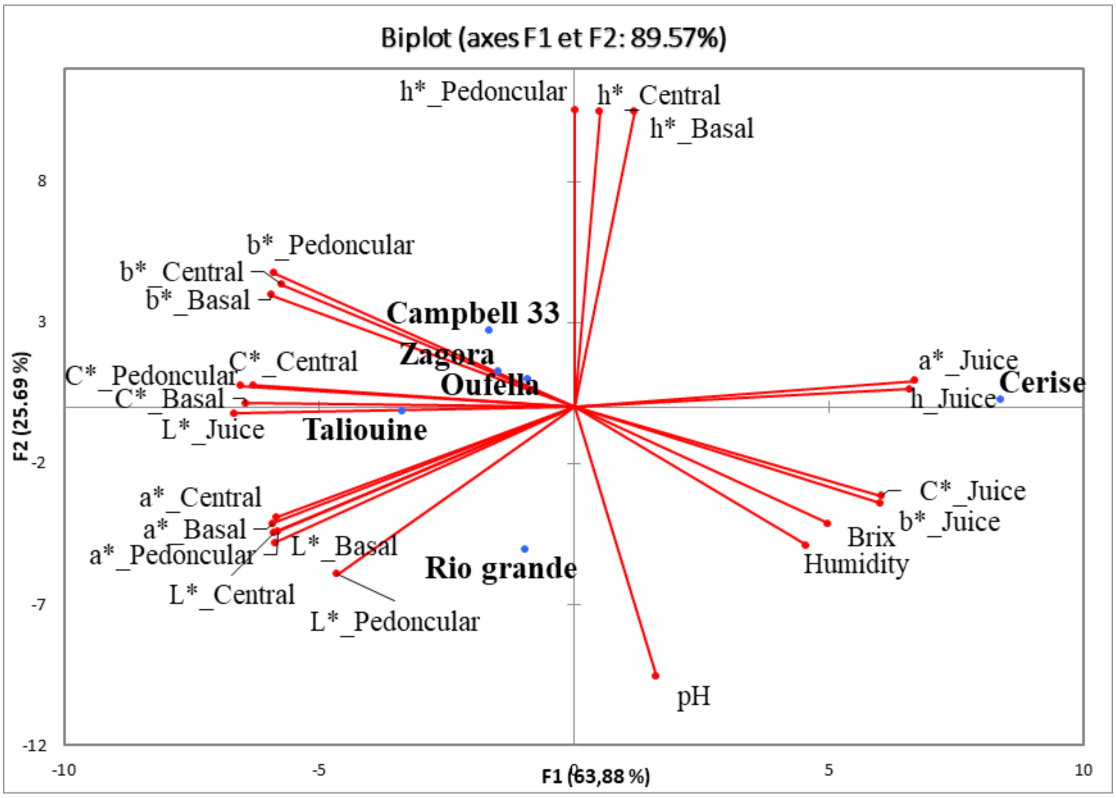

Figure 5: Principal component analysis (PCA) of the first two components (F1 and F2): Separation of the six tomato genotypes according to physical and physicochemical criteria.

Table 4: Averages of physicochemical parameters of the six studied tomato genotypes.

Genotype / Variable	Campbell 33	Rio Grande	Taliouine	Zagora	Oufella	Cerise tomato	Means	Standard deviations
Humidity	94.18	95.90	95.62	93.5	95.34	97.13	95.28	1.29
pH	4.13	4.30	4.13	4.13	4.10	4.19	4.16	0.07
Brix	5.70	6.82	6.82	6.28	5.60	8.02	6.54	0.89
L*_Juice	95.01	91.70	94.71	90.19	92.38	30.94	82.49	25.32
a*_Juice	-2.80	-3.09	-3.47	-2.61	-2.29	6.98	-1.21	4.03
b*_Juice	10.59	14.75	12.82	10.17	10.15	22.06	13.42	4.61
C*_Juice	10.95	15.07	13.29	10.50	10.41	23.13	13.89	4.89
***h*_Juice**	-75.21	-78.16	-74.84	-75.58	-77.31	72.44	-51.44	60.70
L*_Peduncular	24.75	34.97	26.45	31.09	28.22	18.32	27.30	5.69
a*_Peduncular	22.81	29.62	32.54	21.56	23.62	12.08	23.71	7.12
b*_Peduncular	33.79	21.76	37.51	32.00	29.89	14.93	28.31	8.40
C*_Peduncular	40.95	36.83	49.70	38.92	38.16	19.36	37.32	9.92
***h*_Peduncular**	56.13	36.06	49.05	55.56	51.45	50.46	49.79	7.29
L*_Central	25.32	30.27	26.41	26.71	26.48	17.17	25.39	4.37
a*_Central	22.88	28.85	33.28	24.01	21.85	13.04	23.99	6.86
b*_Central	35.79	23.11	37.65	29.73	27.47	16.14	28.32	8.01
C*_Central	42.74	37.08	50.28	38.30	35.24	20.90	37.42	9.72
***h*_Central**	57.61	38.14	48.56	51.04	51.13	51.11	49.60	6.38
L*_Basal	25.65	30.63	27.19	27.13	26.20	18.21	25.84	4.12
a*_Basal	23.03	29.61	33.15	23.65	23.38	12.71	24.26	6.98
b*_Basal	33.27	23.33	37.00	29.89	28.19	16.34	28.00	7.35
C*_Basal	40.57	37.79	49.74	38.31	36.67	20.85	37.32	9.36
***h*_Basal**	55.13	38.24	48.27	51.45	50.27	51.84	49.20	5.82

Hierarchical ascending classification (HAC)

The dendrogram of the hierarchical ascending classification of the six studied tomato genotypes is presented in Figure 6. Two main groups of genotypes can be distinguished according to the physicochemical parameters studied: The ‘Cerise tomato’ genotype (V9) in one group and the other five genotypes in the second group. This latter can be divided in two subgroups: the first subgroup is comprised of V2 and the second one is comprised of V3, V1, V4 and V5 and shows that V4 and V5 are similar and are the nearest ones to V1.

The distribution of the studied genotypes in these different groups explains the existing relationship between the various physical and physicochemical parameters studied. The genotypes that present similar or almost similar characteristics are very close to each other in this dendrogram.

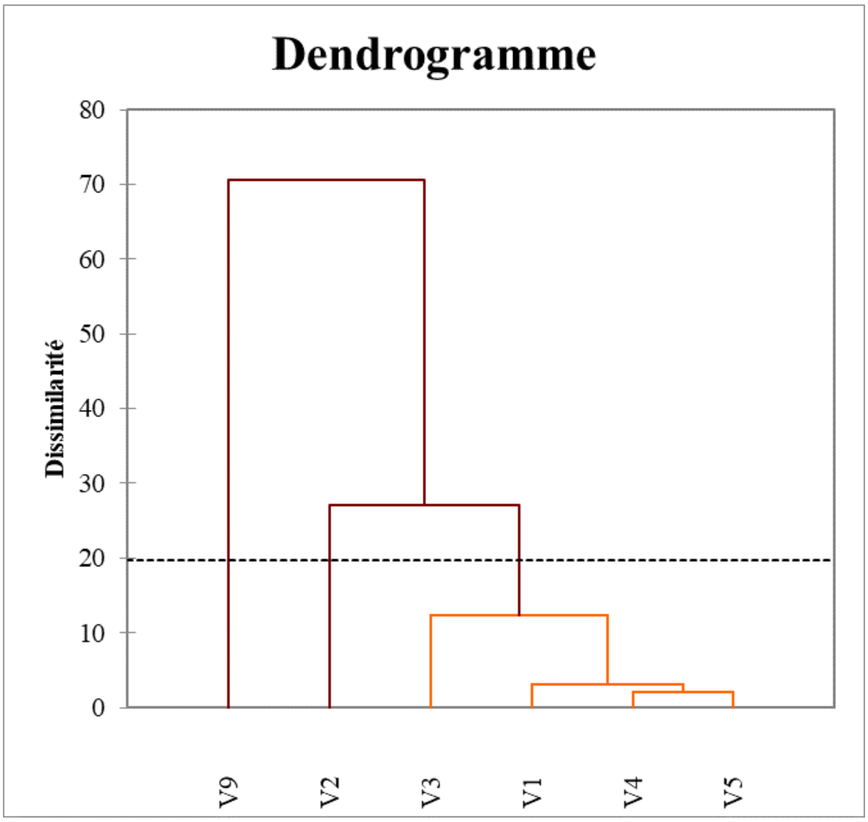

Figure 6: Dendrogram of the six tomato genotypes according to the physical and physicochemical criteria studied (V1: Campbell 33; V2: Rio Grande; V3: Taliouine; V4: Zagora; V5: Oufella; V9: Cerise tomato).

Nutritional quality

Tables 5 and 6 present the average contents of ash and minerals expressed in relation to the fresh and dry matters of the six studied genotypes. The K content averages 6.7 times the Ca content. The Na content is very low or absent (not detected) for the 6 cultivars. The local genotype 'Cerise tomato' was distinguished by very high ash, K, and Ca contents compared to the other genotypes. The local genotype 'Zagora' is the least rich in ash, K and Ca (contents expressed in relation to dry matter). The K and Ca contents of the local genotypes 'Taliouine' and 'Oufella' are very close and they are intermediate between the 2 commercial genotypes. For total ash content, 'Taliouine' far exceeds 'Oufella' and remains intermediate between the two commercial genotypes. For commercial genotypes, 'Rio Grande' had higher ash, K and Ca contents than 'Campbell 33'.

Table 5: Ash contents of the studied tomato genotypes.

Genotype	Ash content (% Fresh matter)	Ash content (% Dry matter)
Campbell 33	0.80	13.67
Rio Grande	0.78	19.09
Taliouine	0.78	17.84
Zagora	0.63	9.74
Oufella	0.58	12.51
Cerise tomato	1.15	40.06
Means	0.79	18.82
Standard deviations	0.20	10.96

Table 6: Mineral contents of the studied tomato genotypes.

Genotype	Potassium (mg/100 g DM)	Calcium (mg/100 g DM)	Sodium (mg/100 g DM)	Potassium (mg/100 g FM)	Calcium (mg/100 g FM)	Sodium (mg/100 g FM)
Campbell 33	4256.50	588.18	n.d.	247.58	34.21	n.d.
Rio grande	6493.20	860.69	n.d.	266.41	35.31	n.d.
Taliouine	5479.50	807.24	n.d.	240.22	35.39	n.d.
Zagora	3662.70	539.34	n.d.	238.23	35.08	n.d.
Oufella	5433.50	761.29	n.d.	253.23	35.48	n.d.
Cerise tomato	11290.00	2299.41	n.d.	323.61	65.91	n.d.
Means	6102.50	976.03	-	261.55	40.23	-
Standard deviations	2729.60	660.36	-	32.06	12.59	-

**DM: Dry matter; FM: Fresh matter; n.d.: Not detected (very low or no content).*

Discussion

The ultimate objective of a plant breeding program is to improve the agronomic and economic characteristics of the plant (Allard, 1960; Zahid *et al.*, 2006; Smith *et al.*, 2015). Knowing the nature and extent of variation and diversity available in genetic resources helps researchers and breeders to design efficient breeding strategies (Rao and Hodgkin, 2002; Ceccarelli *et al.*, 2010; Fu, 2015; Macher *et al.*, 2019). In this study, the variability present in a set of tomatoes, consisting of cultivars and landraces, has been analyzed using agro-morphological and fruit quality related-traits.

Variation in agronomic and growth parameters

Analysis of agronomic and growth parameters showed a wide range of variability among the genotypes according to standard applies to commercial varieties of tomatoes grown from *Lycopersicon esculentum* Mill. (Codex Alimentarius, 2008). This variability offers large flexibility for developing well-adapted tomato varieties to different agro-ecological regions and meets farmers' and consumers' needs.

Our results are in agreement with those of Mohanty (2003) who reported significant differences in number of fruits per plant, plant height and average fruit weight among tomato accessions. This difference in variables among genotypes implies the existence of high variability within the collected tomato accessions and their potential for use in crop improvement.

Variation in sensory parameters

The descriptive statistics showed that most morphotypes (66.66%) had indeterminate growth, while 33.34% had determinate growth. This result confirms that most of the tomato genotypes are local species. Kenneth (2016) conducted a similar study on an agro-morphological characterization of 69 tomato accessions, and reported that 68.1% of the studied accessions were undetermined. Indeterminate tomatoes are important for breeding programs (Meena and Bahadur, 2015; Ganeva *et al.*, 2019).

Lerner (2009) had pointed out that tomatoes with indeterminate growth type grow in height throughout the season, and the stem continues to produce leaf growth. However, these tomatoes could be used in varietal breeding programs to result in genotypes with high leaf density. In a sunny tropical climate, these genotypes may prevent fruit cracking due to solar radiation, increasing the quantity and quality of marketable fruit. Regarding fruit shape, Kenneth (2016) proved that it is a quality parameter for fruits.

The sensory analysis results showed that the genotypes ‘Campbell 33’, ‘Cerise tomato’ and ‘Oufella’ were the best rated for taste, and are among the best rated for red skin and pulp color. According to Helyes and Pek (2006), carbohydrates account for 50-55% of soluble solids in tomatoes, and carbohydrate content is higher in the ripe red fruit. These genotypes are also the best ranked by flavor, specifically acidity. Organic acids are important compounds in determining flavor as they are responsible for the acidic flavor of the fruit (Petit, 2013), and form over 10% of the dry matter (Duffe, 2003). Fruit acidity, mainly due to the presence of citric and malic acid, is highest at the yellow stage (turning stage) and then decreases with maturation (Chanforan, 2010).

Variation in physicochemical parameters

The studied genotypes ‘Campbell 33’, ‘Zagora’ and ‘Oufella’ can be recognized by their dark red fruits and are comparable to the ‘Akikon’ variety, described by Dossou *et al.* (2007). As for the other parameters, they all differ and depend on the genotype concerned. Regardless of their acidity, pH ranged from 4.10 to 4.30 for these genotypes. These results are comparable to those obtained by Dossou *et al.* (2007) and similar to those indicated by Amoussou (1988). At these pH levels, only acidophilic microorganisms, including yeasts, molds, acetobacters and lactobacillus, can grow; but not coliforms such as *Escherichia coli*, since the minimum pH required for the development of such microorganisms is 4.3 according to Rozier *et al.* (1985). The high values of Brix, humidity and pH of the local genotype ‘Cerise tomato’ are in agreement with those reported by Génard *et al.* (2010). The ash content represents the total amount of mineral elements present in a sample (Hireche, 2013). According to Dossou *et al.* (2007), the ash content of tomato purees depends on the variety.

Conclusion

As conclusion for the present study, and based on the agronomic and growth variables studied, we revealed the existence of an important variation within the collected tomato accessions. Moreover, it appears from these results that some genotypes present interesting performances such as ‘Campbell 33’ for number of leaves per branch, ‘Rio Grande’ for number of fruits per plant, ‘Cerise tomato’ for number of fruiting branches per plant and ‘Taliouine’ for plant height. The three genotypes with the best taste are ‘Campbell 33’, ‘Cerise tomato’ and ‘Oufella’. They also show strong intensity of their red color, high skin firmness and high aroma contents. The other genotypes were relatively less appreciated. This sensory evaluation of these genotypes allows a more efficient exploitation of the fruit quality.

Significant variations were also observed between the different physicochemical traits but also between genotypes, such as ‘Cerise tomato’ genotype that present specific characteristics especially humidity, Brix and juice color parameters (a*, b*, C* and *h*). These results will help to identify valuable traits that could be used for varietal improvement such as pH, humidity, Brix and color parameters of skin and juice that can constitute basic criteria to differentiate tomato accessions. Due to the genetic variability within the genotypes, breeders can use them to create and improve varieties performance. Finally, it would be interesting to explore the diversity of this tomato collection for fruit-related traits by the aid of high-throughput genetic and genomic markers.

Conflits of Interest

The authors declare no conflicts of interest.

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