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# Seasonal Fruit Quality Profile of Three Orange Varieties in Teso Subregion—Eastern Uganda

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## Abstract

Teso subregion in Eastern Uganda is a leading production hub for citrus in Uganda. However, information on fruit quality profile of the three major varieties (Hamlin, Valencia and Washington navel) grown in this region was limited and/or unreported, partly resulting in their limited use for industrial processing. The current study sought to understand the seasonal quality profile of these varieties during the wet and dry seasons for the years 2019, 2022 and 2023. The study was conducted with farmers in the districts of Kumi, Ngora, Soroti and Kalaki. Mature green oranges were periodically harvested and analysed for physical and chemical properties. The results showed that the quality of oranges varied depending on the season at harvest and the variety with significant differences ($p \leq 0.05$). Mean weight per fruit was highest in wet season Washington navel (277.5 g) and lowest in dry season Hamlin (149.3 g). Similarly, fruit size varied in the wet season where Washington navel (81.2 mm) had the biggest fruits while dry season Hamlin were smallest (66.6 mm). Dry season Washington navel had had the thickest peel (7.9 mm). Valencia from the wet season had the highest juice content (36.9%) compared to Washington navel (26.5%) from the dry season with the lowest. Titratable acidity was higher in the dry season Valencia (0.9%) compared to the wet season Washington navel and Hamlin (0.3%). Similarly, Total soluble solids (TSS) was higher in the dry season (Washington navel, 10.1 ˚Brix) in contrast to the wet season (Hamlin and Valencia, 7.7 ˚Brix). Valencia had the lowest pH (3.1) however, pH did not vary significantly between season for each variety except for Hamlin. Vitamin C content was higher during the dry season led by Valencia (57.6 mg/100g) and Hamlin (57.4 mg/100g). Sugar to acid ratio was highest during the wet season (Washington navel, 41.5) and lowest in the dry season (Valencia, 17.1). Overall, dry season fruits and more especially Valencia showed versatility in meeting most of the quality requirements for both industrial juice processing and the fresh market. However, there is need to improve the available orange varieties with regard to juice content and optimal sugar: acid ratio regardless of season.

## Keywords

Citrus Quality, Kyoga Plains, Valencia, Hamlin, Washington Navel, Physical, Chemical

## 1. Introduction

Citrus fruits are of significant global importance with an estimated annual production of 166 million MT, of which the sweet oranges (*Citrus sinensis* (L.) Osbeck) are the most abundant, constituting more than 45% of global citrus production [1]. Other renown and commercially preferred *Citrus* species include: mandarin (*Citrus reticulata* Blanco), pomelo (*Citrus maxima* (Burm.) Merr.), lemon (*Citrus limon* (L.) Osbeck), lime (*Citrus aurantiifolia* (Christm.) Swingle) and citron (*Citrus medica* L.), grapefruit (*Citrus paradisi* Macfad.) [2]. Citrus is especially cultivated in tropical and subtropical regions as well as the Mediterranean Basin and regions with a Mediterranean climate however, it is productive in a wide range of climates also encompassing; equatorial, cool, hot, humid and semi-arid [3] [4]. Citrus fruits are widely consumed and have nutritional and health benefits as they are an important source of Vitamin C, folate, potassium and carotenoids and other phytonutrients of physiological importance such as polyphenols, flavonoids, coumarins and terpenes [3].

Citrus production in Uganda is dominated by oranges and is mostly concentrated in the Kyoga plains agroecological zone in Eastern Uganda mostly spanning Teso subregion [5]. Orange production in Teso region has been on the increase, rising from 200,000 MT valued at US$ 30 million in the 90's to 360,000 MT valued at US$ 47 million in 2009 to 769,177 MT valued at about US$ 154 million in 2015 [6]-[8]. Oranges in Teso sub region are harvested throughout the year with a peak season in September to December. The main varieties grown in the region are: Washington Navel, sweet Valencia, Hamlin and the local orange [5]. Navel oranges usually have large, seedless fruits and therefore good eating quality while Valencia is known for having high juice and sugar content, good rind firmness, adaptability to different agroecologies and long shelf life [3].

In Uganda, oranges are largely marketed in the fresh form of which the desirable quality attributes by traders are colour, maturity level, size, taste and texture [5]. The pre-harvest quality of oranges is variable depending on many factors such as climate, maturity stage, soil conditions, scion/rootstock combination and agronomic practices among others [3] [9] [10]. More so, a given variety will exhibit significantly different quality in regions of dissimilar climate [11]. Maturity of oranges is complex entailing physiological processes that cause internal and external changes in the fruit flesh and peel respectively [12]. The maturity of oranges is defined by quality indicators namely: juice content, Total soluble solids (TSS), acidity, sugar to acid ratio and colour [13] [14]. Fruit size and weight are also important quality parameters especially for fruit trade [12]. Although external colour is a key indicator of orange fruit maturity, oranges in the tropics tend to retain their green colour at maturity due to partial degradation of chlorophyll associated with high average temperatures [9]. Therefore, it is important to have a holistic consideration of maturity.

As reported by [5], most fruit juice processing firms in Uganda did not use oranges from Teso subregion as raw material as they did not meet consumers' desirable quality in terms of colour and taste of the end-products. Information on the quality of oranges grown in Teso remains limited or unreported. The current study sought to bridge this gap. Therefore, the objective of this study was to investigate the seasonal profile of orange fruit quality in Teso subregion in terms of physical and chemical characteristics during wet and dry seasons in the period 2019, 2022 and 2023.

## 2. Methodology

### 2.1. Study Area and Sampling

The study was conducted in the orange production belt of Teso subregion within the Kyoga plains. More specifically, in the districts of Kumi, Ngora, Soroti and Kalaki. Oranges used in the study were mostly obtained from the orchards of farmers in the KOPIA model village project. The fruits were purposively harvested at a mature green stage based on the maturity colour chart of [15] (**Figure 1**). In addition, all fruits sampled had an equatorial diameter of at least 60 mm.

| Variety | Hamlin | Washington navel | Valencia |
|---|---|---|---|
| External peel colour at harvest |  |  |  |

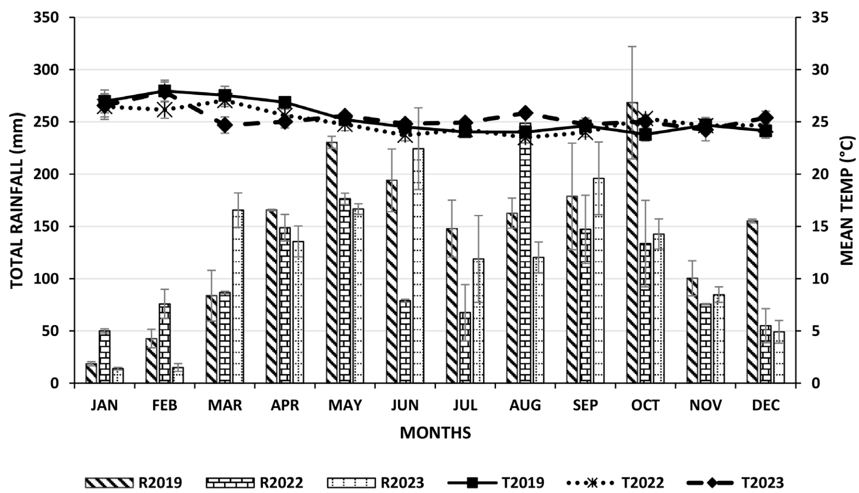
Pictures extracted from [15].

**Figure 1.** Maturity at harvest.

Samples of the three main orange varieties in Teso namely Hamlin, Valencia and Washington navel were collected during the wet and dry seasons for the years 2019, 2022 and 2023. In each of the aforementioned years, samples were collected in February (dry) and October (wet) (**Figure 2**). A completely randomised design was used whereby triplicate samples were obtained from different farmers each time out of a pool of 120 farmers under the KOPIA-Citrus project. During each season, fruit samples were collected from 5 farmers per district. For each farmer, 5 fruits were picked from each tree of a given variety. Samples were collected in breathable bags, labelled and placed in plastic crates then transported to the laboratory within 48 hours after sampling.

### 2.2. Weather Data for Study Period

The aggregated total rainfall (precipitation) and mean temperature data for Soroti and Kumi were extracted from [16]. Rainfall and Temperature datasets were generated using CHIRPS 4.8 km daily and TerraClimate 4 km—monthly respectively. The average Total Rainfall and Mean Temperature data for Soroti and Kumi is shown in **Figure 2**.




R—Total Rainfall; T—Mean Temperature.

**Figure 2.** Total rainfall and mean temperature of Soroti and Kumi.

The highest mean temperature for the study period was 27.9˚C in Feb 2019 and lowest 23.5˚C in August 2022. The highest total rainfall was recorded in October 2019 (268.5 mm) while the lowest was in January 2023 (14.0 mm).

### 2.3. Laboratory Analysis

All chemicals and/or reagents used for laboratory analysis were reagent grade.

Orange samples were analysed in the laboratory for quality indices in triplicate for the three varieties namely Washington navel, Valencia, and Hamlin. Parameters analysed included size, juice content, pH, Total soluble solids content, Titratable acidity and ascorbic acid (Vitamin C) content.

#### 2.3.1. Fruit Weight and Size

A method similar to [17] was used. The individual weight of three randomly selected fruits from each variety was taken on a digital electronic laboratory analytical balance (Mettler Toledo, 520 g capacity Mettler-Toledo International Inc., China). The average weight of the fruits was calculated and expressed in grams. Similarly for size, the individual equatorial diameter of triplicate randomly selected fruits from each variety was measured using Vernier callipers (Qstexpress, range 0 - 150 mm, accuracy 0.01 mm, Model no. sQk4485246, China) with the average calculated and expressed in mm.

#### 2.3.2. Peel Thickness

Peel thickness (mm) was measured from the outside edge to the inner edge of the white albedo tissue with the aforementioned Digital Vernier calipers using a method similar to [17].

#### 2.3.3. Juice Content

Three individual oranges from each variety were cut into half using a kitchen knife and juice extracted using an electric citrus juicer (Aicok GS-403Y, China). Juice weight was measured on a digital electronic laboratory analytical scale. Juice content was measured in triplicate using the formula:

$$\%\text{Juice content} = \left(\frac{\text{Weight of juice}}{\text{Fresh weight of whole fruit}}\right) \times 100$$

#### 2.3.4. Total Soluble Solids (TSS)

The Total soluble solids content (TSS) of the juice was measured using a method similar to [18]. Total soluble solids was measured using a Hand held refractometer (0 - 40 ˚Brix, ATC, Model no. THE01502B, China) after calibration with distilled water. Two drops of the juice sample were transferred to the refractometer prism surface using a Pasteur pipette prior to reading. The TSS was expressed in ˚Brix.

#### 2.3.5. Titratable Acidity (TA) and pH

Titratable acidity and pH were determined using methods similar to [19]. pH was measured using a pH meter (Benchtop pH Meter, 0.01 Resolution, Hanna-HI2211) which was first calibrated with standard buffer solutions of pH 4 and 7.

Titratable Acidity was measured titrimetrically. 2 - 3 drops of 1% Phenolphthalein indicator were added to a mixture containing 5mls of orange juice and 12.5 mls of distilled water in a 250 ml beaker. 0.1 N NaOH in a burette was titrated against this mixture till an endpoint indicated by a faint pink colour. The titre reading for each titration (samples in triplicate) was recorded. The Titratable acidity was expressed as % Citric acid and calculated using the formula:

$$\%\text{Acid} = \frac{(\text{ml base titrant}) \times (\text{ml base titrant}) \times (\text{Eg. Wt. of acid})}{(\text{sample volume in ml}) \times 10}$$

where the Equivalent weight (*Eq. Wt.*) of citric acid = 64.04.

#### 2.3.6. Vitamin C Content

Vitamin C content was determined by Indophenol method [19]. An aliquot containing 5 ml metaphosphoric acid-acetic acid solution and 2 ml orange juice in 50 ml Erlenmeyer flasks was titrated with the indophenol dye solution until a light and distinct rose-pink colour persisted for more than 5 seconds. The titre reading for each titration (samples in triplicate) was recorded.

Ascorbic acid was calculated using the formula:

$$\text{mg ascorbic acid per ml} = (X - B) \times \left(\frac{F}{E}\right) \times \left(\frac{V}{Y}\right)$$

where:

$X$ = average ml for sample titration, $B$ = average ml for sample blank titration, $F$ = titre of dye (= mg ascorbic acid equivalent to 1.0 ml indophenol standard solution), $E$ = ml assayed (= 2 ml), $V$ = volume of initial assay solution and $Y$ = volume of sample aliquot titrated.

Ascorbic acid was expressed as mg ascorbic acid/100ml.

### 2.4. Statistical Analysis

Data on physico-chemical characteristics were analysed using one-way ANOVA to identify significant differences in quality attributes between varieties and seasons. The Tukey's HSD Post-hoc tests was conducted to determine specific differences between seasonal and yearly harvests. The XLSTAT Statistical software (2014) was used for the analysis.

## 3. Results

### 3.1. Variation of Physical Parameters with Season

The physical characteristics of oranges are shown in Table 1. Fruit weight was highest in wet season Washington navel (277.5 g) and significantly different from all the others. Dry season Hamlin (149.3 g) had the lowest weight and this was significantly different from other means, with the exception of dry season Valencia. For each variety, fruit weight in the wet season was significantly higher than the dry season.

**Table 1.** Physical characteristics of oranges.

| Variety/Season/ Physical parameter | Fruit weight (g) | Fruit size (equatorial diameter mm) | Juice content (%) | Peel thickness (mm) |
|---|---|---|---|---|
| Hamlin-D | $149.3 \pm 25.7^{d}$ | $66.6 \pm 3.9^{c}$ | $27.8 \pm 7.4^{c}$ | $5.0 \pm 1.3^{bc}$ |
| Hamlin-W | $178.0 \pm 45.3^{c}$ | $69.4 \pm 6.4^{c}$ | $31.7 \pm 8.3^{b}$ | $4.6 \pm 1.4^{c}$ |
| Valencia-D | $169.1 \pm 39.8^{cd}$ | $68.8 \pm 4.8^{c}$ | $28.3 \pm 7.7^{bc}$ | $5.1 \pm 1.1^{bc}$ |
| Valencia-W | $224.7 \pm 56.0^{b}$ | $75.4 \pm 7.0^{b}$ | $36.9 \pm 7.7^{a}$ | $4.7 \pm 0.7^{bc}$ |
| Washington-D | $228.1 \pm 75.0^{b}$ | $74.9 \pm 6.7^{b}$ | $26.5 \pm 7.9^{c}$ | $7.9 \pm 2.1^{a}$ |
| Washington-W | $277.5 \pm 84.5^{a}$ | $81.2 \pm 10.1^{a}$ | $29.9 \pm 8.6^{bc}$ | $6.3 \pm 2.0^{b}$ |

Different letter denotes significant difference among means in the same column ($p < 0.05$, Tukey's test); D symbolizes dry season while W is wet season.

The fruit size followed a similar pattern as weight, with wet season Washington navel (81.2 mm) being significantly bigger than the rest. Wet season fruits were significantly bigger than dry season for the respective varieties except for Hamlin where the size difference was not significant. In terms of juice content, wet season Valencia (36.9%) had the highest and the difference from the others was significant. Dry season Washington navel (7.9 mm) had a significantly thicker peel than all other varieties.

## 3.2. Variation of Chemical Parameters with Season

### 3.2.1. Titratable Acidity (TA)

There was a seasonal dichotomy in terms of the titratable acidity of the orange varieties as shown in Figure 3. There were significant differences in titratable acidity between the wet and dry season for all the varieties.

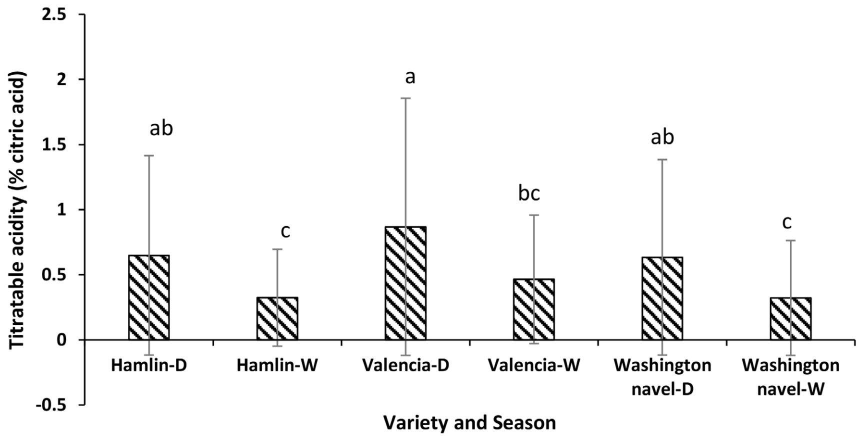



Figure 3. Titratable acidity of different orange varieties by season.

Generally, titratable acidity for each cultivar was significantly higher in the dry season. Dry season Valencia had the highest TA (0.9%) while wet season Washington navel and Hamlin had the lowest (both 0.3%).

### 3.2.2. Total Soluble Solids (TSS)

Total Soluble Solids varied between 7.7 and 10.1 ˚Brix (Figure 4). Wet and dry season TSS were significantly different for all the varieties with dry season TSS being higher than that of the wet season.

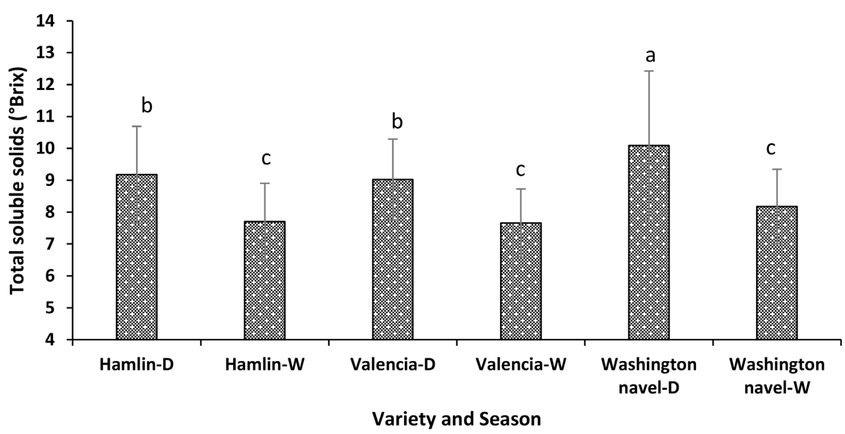



Figure 4. Total soluble solids content of different orange varieties by season.

Dry season Washington had the highest TSS (10.1 ˚Brix), significantly different from the other varieties.

#### 3.2.3. pH

The pH of oranges ranged between 3.1 to 3.6 (**Figure 5**). Valencia had the lowest pH for both dry and wet season while Washington navel had the highest pH. The seasonal differences in pH for each variety were not significant with the exception of Hamlin.

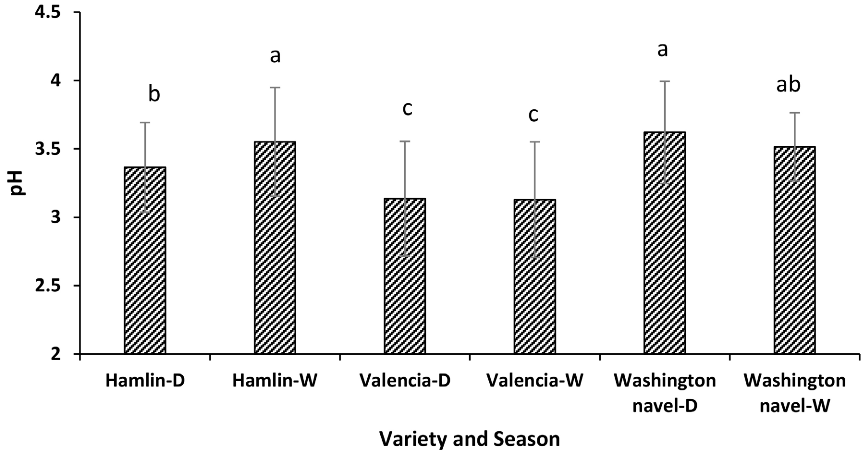



**Figure 5.** pH of different orange varieties by season.

#### 3.2.4. Vitamin C Content

Vitamin C content of the oranges is shown in **Figure 6**. Dry season Vitamin C content was relatively higher than wet season for all the varieties especially for Hamlin and Valencia for which the seasonal differences were significant. In fact, dry season Hamlin (57.4 mg/100g) and Valencia (57.6 mg/100g) had the highest Vitamin C content, significantly higher than the others.

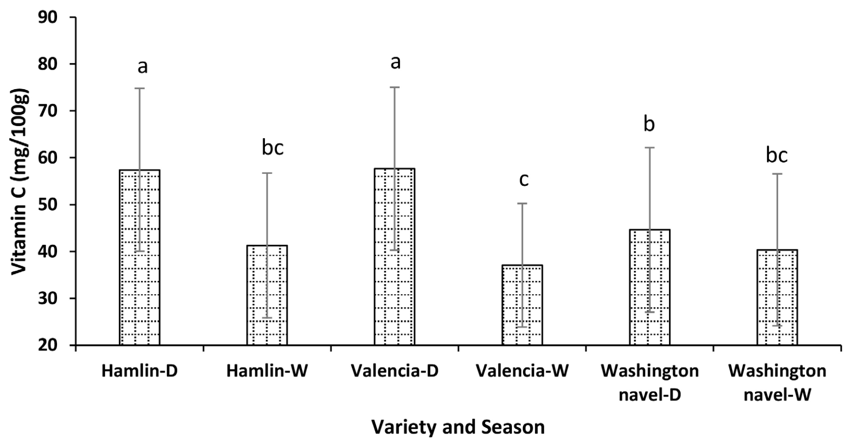



**Figure 6.** Vitamin C content of different orange varieties by season.

Wet season Valencia (37.0 mg/100g) had the lowest Vitamin C content. Vitamin C content of Washington navel did not vary significantly with season.

#### 3.2.5. Sugar to Acid Ratio

The sugar to acid ratio of the oranges is shown in **Figure 7**. The sugar to acid ratio varied between 17.1 for Valencia during dry season and 41.5 for Washington navel during the wet season. It varied significantly between seasons for Washington navel and Hamlin however, this was not the case for Valencia.

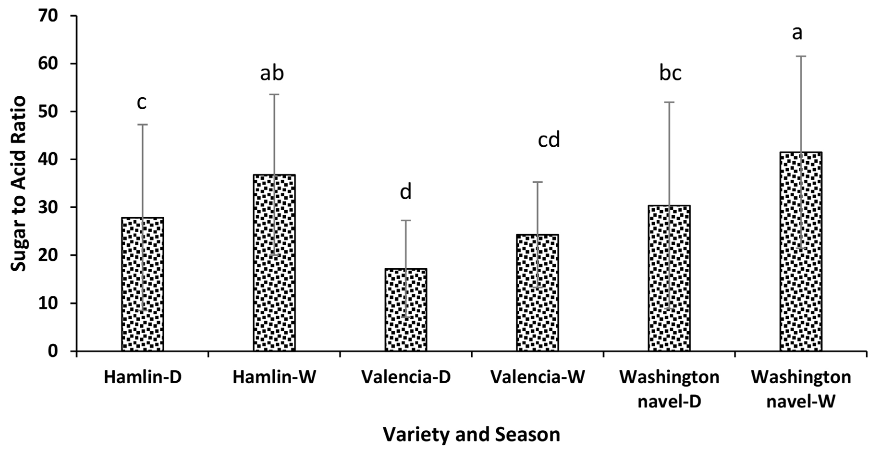



**Figure 7.** Sugar to Acid ratio of different orange varieties by season.

The dry season Valencia had significantly lower sugar to acid ratio compared to the other varieties except wet season Valencia. Generally, Valencia had relatively lower sugar to acid ratio regardless of season.

### 3.3. Mapping of Seasonal Variation of Physico-Chemical Characteristics with Orange Varieties

The Principal Component Analysis (PCA) biplot showing the relationship between seasonal variation of physico-chemical characteristics with orange varieties is shown in **Figure 8**. The physical characteristics such as fruit size and weight were positively associated with the wet season Washington navel. In addition, it was also associated with a high sugar to acid ratio. On the other hand, dry season Washington navel was linked to high total soluble solids and pH.

Wet season Valencia had a strong association with juice content while dry season Valencia and Hamlin had an affiliation with titratable acidity and Vitamin C content.

## 4. Discussion

Citrus fruit weight and size are important towards determining their commercial destination. Large and medium sized fruits with equatorial diameter > 70 mm and average weight 152.5 g are preferred for the fresh fruit market while the smaller ones are channelled to industrial juice processing [20] [21]. The bigger wet season Washington navel oranges span size codes 3, 4 and 5 (73 - 92 mm) while the intermediate dry season Washington and wet season Valencia fall within codes 5, 6 and 7 (67 - 84 mm). The dry season Valencia as well as Hamlin for both seasons were relatively smaller and lie in the category 7 and 8 (64 - 76 mm) [14]. Washington navel is the most widely grown of the navel oranges globally and is characterized by large fruit size and being seedless [22]. The bigger and heavier fruits in the wet season are attributed to excess water available to the trees [9]. Based on size criteria, Washington navel from both seasons as well as wet season Valencia are fit for the fresh market while the Hamlin for both seasons and dry season Valencia are ideal for processing.

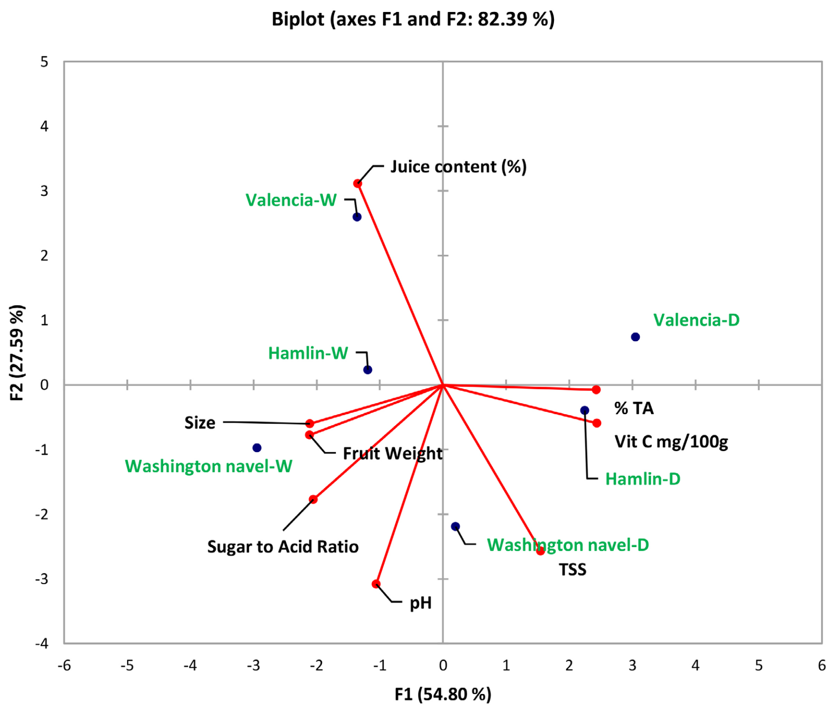



**Figure 8.** Relationship between seasonal variation of physico-chemical characteristics with orange varieties.

Peel thickness is dependent on variety, maturity stage and climate conditions. The peel thickness for Valencia was similar to that reported by [23]. Thin peels are associated with higher juice yield and are thus preferred for processing while the thicker peel goes into the fresh market as they are generally regarded as easier to peel and are more shelf stable [24] [25]. According to [23], smaller peel thickness was considered at ≤3 mm. The peels for all the varieties in our study were at least 4mm regardless of season, therefore they could ostensibly be described as having intermediate thickness, the exception being dry season Washington navel whose peel was significantly thicker. Fruits grown in dry and hot conditions tend to have thicker and harder peels [3]. Thicker peels like those of the dry season Washington navel provide opportunities for oil and pectin extraction.

TSS is a good indicator of the sugar content and thus sweetness of oranges as 80% of it is contributed by sucrose, fructose and glucose [26]. The recommended minimum value of TSS of oranges is 8 - 10 ˚Brix [27] [28]. All the dry season oranges, regardless of variety as well as wet season Washington navel, met this requirement. In addition, the wet season Hamlin and Valencia were borderline. Lower TSS in the wet season can be explained by dilution of sugars by excess water available in the soil [9]. The relatively low TSS content in the fruits generally can be explained by warm temperatures of lowland tropics which accelerate respiration rates and fruit maturity resulting in insufficient time to accumulate maximum TSS while acidity also declines fast thus giving a sharp increase in TSS to acid ratio [3] [9].

Citric acid is the main organic acid in citrus fruits varying from 0.5% to 1.5% in oranges [22]. Variation in acidity depends on the variety, rootstock, level of harvest maturity, geographical location and season [9] [22] [23]. [29] evaluated fruits from orange tree tops on different rootstocks, reporting TA in range 0.36% to 1.47% c.a. In Tanzania, [30] reported TA of 0.60% to 1.65% c.a. from Valencia and Navel oranges at different harvest stages and storage time. The TA for wet and dry season oranges in this study was comparable with the aforementioned studies. However, overall TA was low across the three varieties especially for the wet season fruits. During the wet season, acid levels decrease due to the dilution effect of excess water [9]. The generally low acidity is associated with high temperatures in tropical climates that accelerate physiological processes such as respiration resulting in rapid breakdown of organic acids [3] [9]. A minimum TA of 0.5 and 0.75% is recommended for industrial processing and fresh consumption respectively [23] [24] [31]. The dry season oranges particularly Valencia met this criterion.

Citrus fruits are one of the main sources of vitamin C for human nutrition of which oranges and lemons are richer in vitamin C than other citrus fruit [3]. Vitamin C content of fresh oranges (*C. sinensis*) varies between 23 and 83 mg per 100 g. This is influenced by several factors such as maturity stage, variety, climate, handling and storage conditions; tending to decrease after harvest [22] [32]. The vitamin C content was within this reported range for all varieties across seasons. In addition, it was similar to that reported for Valencia and Navel oranges (31.3 - 50.4 mg/100g) in Tanzania [30]. Seasonal variation of vitamin C mirrored that of TA and can be explained similarly.

The pH of the oranges (3.1 - 3.6) is similar to that reported for sweet oranges [33] [34]. The organic acids in oranges especially citric acid together with malic and succinic acid are responsible for the acidic pH [33].

Juice content is an important citrus fruit quality parameter. The required minimum juice content for navel and other oranges (includes Valencia and Hamlin) is 33% and 35% respectively [14]. Only wet season Valencia met this minimum threshold. More so, a juice content of at least 50% is recommended for orange fruits to be considered for industrial juice production [28], of which none of the cultivars matched this. Oranges with thick peels have relatively low juice content and extraction levels [35]. Lower juice content in the dry season could be linked to reduced water available to the trees. [36] reported a decrease in juice content of limes due to soil water deficit.

Sugar to acid ratio is a good indicator of citrus fruit maturity. According to East

African Standards, the minimum ratio should be 6.5 [14]. Furthermore, for juice processing a ratio of 14 - 16 is recommended [28]. All the oranges had high sugar to acid ratio with a minimum of 17 in the dry season Valencia. The high sugar to acid ratio is mostly due to the low acidity associated with fruits grown in a hot climate [3]. However, a very high sugar: acid ratio results in an insipid taste [37].

As reported by [10] the area of origin and inherent unique characteristics of some citrus cultivars contribute to their suitability to certain climates. Valencia is a late cultivar which develops and matures over a longer period compared to Washington and Hamlin (mid-season cultivars) [3] [10]. This could explain its better overall characteristics. Moreover, Valencia is the most widely grown cultivar globally and is associated with a high juice and sugar content with good rind firmness, giving it a longer shelf life [3].

## 5. Conclusion

The study showed that fruit quality of oranges in Teso was dependent on the prevailing season at harvest and the variety with significant differences. Based on fruit size, Washington navel is suited for the fresh market and Hamlin for processing. Valencia was intermediate and thus serves a dual purpose. The dry season fruits across cultivars met the minimum TSS content requirements and optimum levels of acidity for both industrial juice processing and the fresh market. Both wet and especially dry season Valencia provide sugar: acid ratio within the optimum range for industrial juice processing. Therefore, we recommend that Valencia be prioritized for scaled production due to its versatility in meeting the requirements of both the fresh market and industrial juice processing. Breeding, propagation and cultural practices should be geared towards increasing juice content while maintaining optimal sugar: acid ratio of the available cultivars regardless of season. The current study did not consider consumer preferences of the different orange varieties across seasons and therefore this aspect is recommended for subsequent research.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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