Nutritional Values of Onion Bulbs with Some Essential Structural Parameters for Packaging Process

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Abstract: Onions belong to the Allium genus that has been frequently used for human diet and the traditional medication due to the bioactive compounds. The main nutritional values, vitamins, and amino acid compositions of onion bulbs (Yellow, Red, Green, Leek, and Baby onions) with some essential structural parameters for the packaging process were investigated. Physical and structural parameters with frictions were applied for the packaging process. The results reported that moisture content was the main component of onion bulbs (88.65%). Besides, they were rich in proteins (9.22–13.21 g/100 g infresh weight) (FW). Results reported that Red and Yellow varieties established the largest vitamin C and carotenoids contents (45.07 mg/100 g−1 FW) and (1.44 µg/mL FW), respectively. The major amino acid was arginine which was highly found in Green variety (17.62 mg/g FW) and a relatively high amount of glutamic and aspartic acids as (9.88–14.89 mg/g FW) and (4.93–10.55 mg/g FW), respectively. Yellow variety established the largest width, thickness, surface area, aspect ratio, and sphericity. The highest static and kinetic frictions were established on steel (0.14–0.52) and (0.75–0.96), respectively. This study presents the nutritional evidence of onion varieties for the human diet besides the horticultural processing for packaging quality improvement.

Keywords: onions; nutritional values; vitamins; amino acids; physical; friction

1. Introduction

Onion (Allium cepa L.) belongs to the Alliaceae family which is mostly used as a staple food due to the presence of essential oils that gain strong flavor and taste in diet [1]. It has various forms as a whole, raw, flakes, ground, liquid, dried, or even fermented for culinary uses [2]. It has high effective nutrients as proteins, carbohydrates, sugars (glucose, fructose, galactose, arabinose), vitamins (C, β-carotenes), minerals (calcium, iron, sulfur) with some flavonoids and polyphenols components. Onion is commonly used in many medicinal purposes as a traditional medicine for the treatment of skin diseases, microbial growth, gastrointestinal problems, worms, and injuries [3,4]. Several epidemiological studies established that onion consumption can decrease the development risks for many diseases, such as inflammatory, coronary heart, cancer, respiratory problems due to their bioactive components [5–7]. Besides, the onion amino acids link with the sensory response of the “umami” taste [8]. Onions contain huge amounts of arginine that acts as a nitrogen reservoir and a quantity amounts of lysine and glutamic acids [9]. Therefore, onion plays an essential role in the human diet. Physical and structural parameters of food stuff participate in a significant role in processing and packaging operations. Besides, foods
are highly complex systems that demand much ingenuity due to the data scantiness in scientific researches. Physical structural parameters of various onion varieties vary with several factors such as their proximate chemical compositions [10]. Among these structural parameters, mass, weight, volume, densities, projected area, and friction forces are the most essential in the sizing, grading, sorting, conveying, and packaging systems [11]. Therefore, the relationship between weight and both intermediate diameters and geometric attributes is needed to determine the best time for harvesting [12].

This research established the main nutritional values, vitamins, and amino acid compositions of several onion bulbs with some essential structural parameters for providing authentic information about onion the packaging process to design and fabrication of sorting and separation equipments for the onions.

2. Materials and Methods

2.1. Chemical and Reagents

All the solvents and reagents used in this research work were without any further purification. All standards for vitamins and amino acids were from (Sigma, St. Louis, MI, USA).

2.2. Plant Material

Onion bulbs of five different varieties, namely Yellow, Red, Green, Leek, and Baby were used in this research work. Onion pulp types were (Red, Yellow, and Baby), while leek was pale green (Approximately 607.44 mm) and green onion was larger than the leek (approximately 1055.63 mm) in length. The bulbs were purchased from commercial stores in Taif City, Saudi Arabia. The 20 bulbs of each variety were examined in the department of food science and nutrition, College of Science, Taif University.

2.3. Sample Preparation for Nutritional Values

The selected onion bulbs were cleaned, socked into salty water for 20 min to inhibit the microbial activity, and cut into slices as $10 \times 20 \text{mm}^2$ to maintain uniform drying. Freeze-dried was achieved (ALPHA 1-4 LSC, Osterode am Harz, Germany) at 0.04 amber and $-50^\circ\text{C}$ for 2 days. After drying, the onion slices were grounded to powder, packaged, and stored at $-80^\circ\text{C}$ until extract.

2.4. Determination of Protein, Ash, Fiber, Crude Fat, Carbohydrate, and pH Contents of Onion Bulbs

Standard recommended methods were done to determine the chemical analysis levels of protein, ash, fiber, crude fat, carbohydrate, and pH contents according to the method elaborated in the Association of Official Analytical Chemists AOAC [13].

2.5. Vitamin C Analysis (HPLC)

The vitamin C determination was achieved according to the modified method of Rokayya et al. [14]. Chromatographic analyses were detected by an Agilent HPLC system (2000 ECOM, Chrastany u Prahy, CZ 252 19, Czech) at (254 nm) with UV detection. Analytical column YMC-Triart C18 (150 $\times$ 4.6 mm) was used as the mobile phase of A/B 33/67; A: 0.1 M potassium acetate, distilled water 50:50, pH (4.9) and 1 mL/min for the flow rate at the ambient temperature.

2.6. Carotenoids Determination

The carotenoids determination was achieved according to the HOLM methodology [15]. The microwave extraction assay (Start E, Osterode am Harz, Germany) was detected by a Spectrum spectrophotometer at a wavelength of 440 nm (754 PC, Shanghai, China).
2.7. Amino Acid Measurement

Onion aliquots of about 10 mg of proteins were mixed with 9 mL of 6 M HCl [8]. After the sealing process, the onion extracts were hydrolyzed at 110 °C for 24 h after influencing by nitrogen gas. Extracts were diluted with (0.02 N) HCl, filtered and examined by an amino acid analyzer (Hitachi L-8800, Tokyo, Japan).

2.8. Physical Properties

Moisture content \((M_c)\) was detected by using the standard methods of AOAC [13]. The average size of the 20 bulbs of each variety, the three linear dimensions namely, length \((L)\), width \((W)\), and thickness \((T)\) were evaluated by a digital caliper with an accuracy of 0.01 mm [16]. Mass \((M)\) of individual onions was determined through a digitalized sensitive balance with a capacity of 0–1200 g and an accuracy of ±0.01 g. The aspect ratio \((S_p)\) was calculated according to Rokayya and Ebtihal [17]. Geometric mean diameter \((D_g)\), arithmetic mean diameter \((D_a)\), square mean diameter \((D_s)\), and equivalent diameter \((D_e)\) were calculated based on the mathematical expression of the ellipsoidal bodies [18].

\[
S_p = \frac{W}{L} \tag{1}
\]
\[
D_a = \frac{L + W + T}{3} \tag{2}
\]
\[
D_g = (LWT)^{0.333} \tag{3}
\]
\[
D_s = \left(\frac{LW + WT + TL}{3}\right)^{0.333} \tag{4}
\]
\[
D_e = \frac{D_a + D_s}{3} \tag{5}
\]

The actual volume \((V_m)\) was evaluated from the relationship given by Amin et al. [19] then the shape was assumed as a regularly geometrical shape, i.e., prolate spheroid \((V_{psp})\) and ellipsoid \((V_{ell})\) shapes, and thus their volumes were evaluated by the relationships:

\[
V_m = \frac{w}{\gamma} \tag{6}
\]
\[
V_{psp} = \frac{4\pi}{3} \left(\frac{L}{2}\right) \left(\frac{W}{2}\right)^2 \tag{7}
\]
\[
V_{ell} = \frac{4\pi}{3} \left(\frac{L}{2}\right) \left(\frac{W}{2}\right) \left(\frac{T}{2}\right) \tag{8}
\]

where \(w\) is the weight of the displaced water and \(\gamma\) is the weight density of water. Surface area \((S)\) and sphericity \((\phi)\) have been calculated by the equations [20]:

\[
S = \pi D_g^2 \tag{9}
\]
\[
\phi = \frac{D_g}{L} \tag{10}
\]

where \(D_g\) is the geometric mean diameter.

The packing coefficient was evaluated according to the formula [21]:

\[
\lambda = \frac{V}{V_o} \tag{11}
\]

where \(V\) is the true bulk of bulbs and \(V_o\) is the bulk of the box.
2.9. Structural Parameters

The true density ($\rho_t$) and bulk density ($\rho_b$) of onions were measured by using the standard liquid displacement method, while the density ratio ($\rho_r$) and percentage of porosity ($P$) were described by Rokayya and Ebtihal [17].

The projected area of onions to length, width, and thickness ($PAL$, $PAW$, and $PAT$) was determined by using a digital camera (Canon SX 210-IS, 14 Mpxels) and the Image Tool for Windows (version 7.00) program as follows [11]:

$$CPA = \frac{PAL + PAW + PAT}{3} \tag{12}$$

where $PAL$, $PAW$, and $PAT$ are the projected areas at right angles to length, width, and thickness, respectively.

The static and kinetic coefficients of friction were established on several structural materials, such as steel, iron, glass, and plastic, by using friction equipment, while the angle tilt was read from a graduated scale as follows [16]:

$$\mu_s = \tan(\theta) \tag{13}$$

$$\mu_k = \frac{F_d}{N} \tag{14}$$

where $\mu_s$ is static, $\mu_k$ is kinetic, $\theta$ is the tilt angle, $F_d$ is the measured friction and $N$ is the normal force.

2.10. Data Analysis

The data were expressed as mean (+/−) standard deviation, subjected to analysis of variance (ANOVA) with three replications, and statistical analysis was applied by using SPSS 16.00 for Windows. Duncan’s test as a posthoc test was used at a $p < 0.05$ significance level.

3. Results and Discussion

3.1. Nutritional Values

Figure 1 represents the results of the nutritional values carried out on some onion bulb varieties. Protein content varied overall from 9.22 g/100 g FW (Green) to 13.21 g/100 g FW (Leek), Figure 1a. It was found that protein content agreed with that of onion bulbs investigated by Abdou et al. [22] that ranged from 9.84 to 12.09 g/100 g. The protein daily allowance is 50 to 63 g protein/day as per USDA recommendations (2000) [23]. About 80% of protein intake can be of vegetable origin, especially in developing countries, as it is more economic than animal protein. Therefore, onion consumption might supply a considerable amount for human needs.

However, ash contents varied from 3.02 g/100 g FW (Leek) to 4.92 g/100 g FW (Baby), Figure 1b. These results were similar to the other onion varieties [1].

As shown in Figure 1c, the fiber content values vary between 1.69 g/100 g FW in the Baby variety and 1.81 g/100 g FW in Green samples. Higher fiber content can be related to several factors, including the type and age [24].

Abhayawick et al. [10] established similar results of crude fat in onion bulbs to our contents, varying from 2.01 to 3.72 g/100 g FW. All onion bulbs have high crude fat, especially the Red variety, Figure 1d.

The carbohydrate content of different bulbs was varied; the Green variety had the highest at 83.04 g/100 g FW, followed by Leek at 79.88 g/100 g FW, Figure 1e. On the other hand, the Red variety had the lowest carbohydrate content at 77.20 g/100 g FW compared with other onion bulbs. All bulbs had a slightly higher carbohydrate content than the varieties reported by Elizabeth et al. [1].

The results for acidity were 6.24 (Baby) to 6.61 (Leek), Figure 1f. The low acidity might be a limitation for onion preservation [25].
Figure 1. Nutritional values: protein (a), ash (b), fiber (c), crude fat (d), carbohydrate (e), and pH (f) contents of onion bulbs.
3.2. Vitamin C and Carotenoid Values

In this research, the extraction of vitamin C using HPLC with fluorometric detectors was carried out. Though the use of UV detection coupled with HPLC for water-soluble vitamins is a sophisticated and expensive procedure, at the same time, it has been established to be a reliable, fast, and simple method [14]. Figure 2a shows the vitamin C contents for different onion bulbs, which is considered as a water-soluble antioxidant. The daily vitamin C intake should be 45–50 mg according to the World Health Organization [26]. The results reported that the largest vitamin C value was detected in the Red variety (45.07 mg/100 g FW) followed by the Baby variety (38.12 mg/100 g FW), while Green and Leek varieties showed the lowest (10.10 and 12.03 mg/100 g FW, respectively). These values were nonetheless higher than those reported for other onion bulbs [22].

![Graphs showing vitamin C and carotenoid values](image)

**Figure 2.** Vitamin C (a) and carotenoid values (b).

Carotenoid content can be influenced by several factors, such as variety, climate, genetic variability, and fertilizers [27]. In this study, Figure 2b reports that the highest carotenoid content was found in the Yellow variety (1.44 µg/mL FW), compared to the Baby variety (0.57 µg/mL FW). Green and Leek varieties reported similar values (0.80–0.85 µg/mL FW). A similar finding was reported for carotenoids that explained that the increased values could be related to sufficient nitrogen uptake which can cause onion bulbs to absorb more nitrogen and to build more chlorophyll structures [28].

3.3. Amino Acid Profile

The amino acid profile of the onion bulbs is shown in Figure 3, listing a total of 17 amino acid concentrations in mg/g FW. The major amino acid was arginine which was found to have the highest level in the Green variety (17.02 mg/g FW), followed by the Leek variety (12.30 mg/g FW). These results were in agreement with those of Lee et al. [29], who established arginine as the major amino acid in various onion bulbs. Methionine and cysteine were the minor amino acids in onion bulbs, varying from 0.007–0.013 mg/g FW and 0.015–0.023 mg/g FW, respectively. The results showed a relatively large amount of glutamic and aspartic acids from 9.88–14.89 mg/g FW and 4.93–10.55 mg/g FW, respectively. These two amino acids have a crucial role as a nitrogen source during the maturation period and are responsible for the “umami” taste of onions [30,31].
3.3. Amino Acid Profile

The amino acid profile of the onion bulbs is shown in Figure 3. Aspartic acid, serine, glycine, histidine, arginine, threonine, alanine, proline, cysteine, tyrosine, valine, methionine, lysine, isoleucine, leucine, and phenylalanine were present in the onion bulbs.

3.4. Physical and Structural Parameters

Table 1 shows the physical and structural parameters of five onion bulbs. The average moisture content ($M_w$) of the fresh onion bulbs was high for all varieties (88.65%). The Yellow variety had the highest value (92.59%). Abdou et al. [22] reported similar moisture contents for onion varieties cultivated in Cameroon. As a result, rotting and sprouting are influenced by high moisture content [10,11]. Green onion produced the longest length of 106.98 cm; the Yellow bulb had the largest thickness and width. From Ghabel et al. [32], who studied Iranian onions, the values of length, width, and thickness were in agreement with the onion variety bulbs. Green onion gave the highest mean weight (236.67 g), followed by Yellow, Red, Green, Leek, and Baby onion, respectively.

The highest and the lowest diameters were observed for Yellow and Leek, respectively. Against Ghabel et al. [32], geometric mean diameter results were recorded (69.23–73.14 mm). The highest and the lowest values of actual volume were for Green and Leek varieties, respectively. The results were in agreement with Bahnasawyet al. [33]. The ellipsoid and prolate spheroid volumes were (245.23, 250.26 cm$^3$), (201.42, 202.78 cm$^3$), (304.27, 302.04 cm$^3$), (20.53, 20.28 cm$^3$), and (22.45, 31.54 cm$^3$) for onion varieties Yellow, Red, Green, Leek, and Baby, respectively. The mean surface area was 187.08, 163.56, 53.74, 165.33, and 38.70 cm$^2$, respectively. Sphericity of onion varieties was 0.99, 0.93, 0.08, 0.05, and 0.82 for Yellow, Red, Green, Leek, and Baby onion, respectively.

The relationships between the main dimensions and mass are as follows:

- For Yellow bulb: $L = 1.00X W = 1.02X T = 0.35X M$
- For Red bulb: $L = 1.12X W = 1.13X T = 0.54X M$
- For Green onion: $L = 46.31X W = 45.90X T = 4.58X M$
- For Leek onion: $L = 80.32X W = 78.12X T = 63.67X M$
- For Baby bulb: $L = 1.14X W = 1.59X T = 2.16X M$

Figure 3. Amino acid profile.
Table 1. Some structural parameters of onion bulbs.

| Varieties | Yellow | Red | Green | Leek | Baby |
|-----------|--------|-----|-------|------|------|
| $M_c$     | 92.59 ± 0.21 b | 92.17 ± 0.07 a | 85.60 ± 0.57 c | 91.05 ± 0.21 b | 81.84 ± 0.52 d |
| $L$       | 77.82 ± 6.46 b | 77.93 ± 6.34 b | 1069.78 ± 82.03 a | 618.55 ± 69.41 c | 42.37 ± 2.97 d |
| $W$       | 78.00 ± 7.07 a | 69.94 ± 8.00 b | 23.10 ± 1.51 d | 7.77 ± 1.14 e | 37.46 ± 3.44 c |
| $T$       | 76.55 ± 5.72 a | 69.40 ± 8.64 b | 23.30 ± 1.37 c | 7.93 ± 0.86 d | 26.79 ± 2.04 c |
| $M$       | 227.63 ± 50.74 a | 155.41 ± 53.51 b | 236.67 ± 36.98 a | 11.70 ± 5.69 c | 19.70 ± 2.28 c |
| $D_S$     | 77.04 ± 5.22 a | 71.91 ± 6.69 b | 82.81 ± 5.30 c | 33.50 ± 3.80 d | 34.75 ± 2.30 c |
| $D_D$     | 77.46 ± 5.19 a | 72.42 ± 6.59 a | 372.06 ± 28.18 b | 211.42 ± 23.63 d | 35.54 ± 2.36 b |
| $D_S$     | 18.10 ± 0.81 a | 17.29 ± 1.06 a | 25.48 ± 1.23 b | 14.76 ± 1.08 d | 10.72 ± 0.47 c |
| $D_D$     | 57.53 ± 3.74 a | 53.88 ± 4.78 a | 160.12 ± 11.48 b | 86.56 ± 9.37 d | 27.00 ± 1.71 c |
| $V_m$     | 245.56 ± 53.14 a | 168.73 ± 69.00 b | 248.99 ± 131.05 c | 21.09 ± 9.34 c | 22.60 ± 20.41 c |
| $V_{el}$  | 245.23 ± 50.16 a | 201.42 ± 55.16 b | 304.27 ± 59.17 c | 20.53 ± 7.23 c | 22.45 ± 4.71 c |
| $V_{pp}$  | 250.26 ± 55.37 a | 202.78 ± 53.88 b | 302.04 ± 61.27 c | 20.28 ± 7.87 c | 31.54 ± 7.74 c |
| $S_p$     | 1.01 ± 0.11 a | 0.90 ± 0.10 b | 0.02 ± 0.00 c | 0.01 ± 0.00 d | 0.08 ± 0.07 b |
| $S$       | 187.08 ± 25.44 a | 163.56 ± 30.17 c | 53.74 ± 6.67 c | 165.33 ± 16.93 a | 38.70 ± 5.18 b |
| $q$       | 0.99 ± 0.06 a | 0.93 ± 0.07 b | 0.08 ± 0.00 d | 0.05 ± 0.00 c | 0.82 ± 0.04 c |
| $\lambda$ | 0.47 ± 0.02 b | 0.35 ± 0.03 c | 0.65 ± 0.10 a | 0.68 ± 0.04 a | 0.40 ± 0.10 b,c |
| $L/W$     | 1.00 ± 0.12 c | 1.12 ± 0.13 c | 46.31 ± 1.77 b | 80.32 ± 9.07 a | 1.14 ± 0.09 c |
| $L/T$     | 1.02 ± 0.10 d | 1.13 ± 0.14 d | 45.90 ± 1.73 b | 78.12 ± 5.96 a | 1.59 ± 0.13 c |
| $L/M$     | 0.35 ± 0.07 b | 0.54 ± 0.14 b | 4.58 ± 0.50 b | 63.67 ± 32.31 a | 2.16 ± 0.13 b |
| $L/D_g$   | 1.01 ± 0.07 d | 1.09 ± 0.09 cd | 12.91 ± 0.29 b | 18.49 ± 1.03 a | 1.22 ± 0.05 c |
| $L/p$     | 78.93 ± 10.90 c | 84.90 ± 11.45 c | 13825.81 ± 1292.70 a | 11451.19 ± 1559.47 b | 51.74 ± 4.96 d |

Each value is presented as (SD±). Data with various uppercase superscript letters indicate significantly using the test of Duncan’s multiple ranges.

The highest true and bulk densities were 1299.59 and 400.22 kg/m$^3$ for the Baby onion variety, respectively, shown in Table 2. The corresponding values for Yellow were 926.44, 365.61 kg/m$^3$, Red 986.24, 323.78 kg/m$^3$, Green 1062.11, 224.47 kg/m$^3$, and Leek 579.79, 188.18 kg/m$^3$. A true density of 1025–1063 kg/m$^3$ was found in a previous study [10]. Bulk density results in Ghabel et al. [32] showed an agreement with our study. Density information is needed in the separation processes of onion bulbs [17]. The highest value of the density ratio was for the Baby onion variety and the lowest was for the Green onion variety. The porosity of Green onion had the highest value of 76.66%; on the other hand, Baby onion recorded the lowest value of 55.08%.

Table 2. Volume and density characteristics.

| Varieties | Yellow | Red | Green | Leek | Baby |
|-----------|--------|-----|-------|------|------|
| $\rho_t$  | 926.44 ± 45.81 a | 986.24 ± 289.53 a | 1062.11 ± 274.31 a | 579.79 ± 199.26 b | 1299.59 ± 737.06 a |
| $\rho_b$  | 365.61 ± 17.74 b | 323.78 ± 19.48 c | 224.47 ± 21.54 d | 188.18 ± 32.55 e | 400.22 ± 26.65 a |
| $\rho_b/\rho_t$ | 39.54 ± 2.57 b | 35.53 ± 11.74 b | 23.34 ± 10.53 b | 36.44 ± 17.47 a | 44.92 ± 36.00 b |
| $P$       | 60.46 ± 2.57 a | 64.47 ± 11.74 a | 76.66 ± 10.53 a | 63.56 ± 17.47 b | 55.08 ± 36.00 a |

Each value is presented as (SD±). Data with various uppercase superscript letters indicate significantly using the test of Duncan’s multiple ranges.

3.5. Projected Area and Frictions

The projected area and coefficients of friction are given in Table 3. The mean projected areas perpendicular to the main dimensions were 68.24, 65.78, and 63.90 cm$^2$ for Yellow, 51.36, 50.36, 55.19 cm$^2$ for Red, 4.33, 114.53, 119.57 cm$^2$ for Green, 4.33, 33.71, 25.91 cm$^2$ for Leek, and 9.75, 10.85, 12.34 cm$^2$ for Baby onion varieties for $L$, $W$, and $T$, respectively. It was established that the projected areas for the Green variety were the highest (79.47 cm$^2$) and the Baby onion variety had the lowest (10.98 cm$^2$).
Table 3. Projected area and friction characteristics.

| Varieties | Yellow     | Red        | Green       | Leek        | Baby        |
|-----------|------------|------------|-------------|-------------|-------------|
| PAL       | 68.24 ± 9.26 \textsuperscript{a} | 51.36 ± 16.72 \textsuperscript{b} | 4.33 ± 3.19 \textsuperscript{c} | 4.33 ± 3.19 \textsuperscript{c} | 9.75 ± 0.84 \textsuperscript{c} |
| PAW       | 65.78 ± 11.17 \textsuperscript{b} | 50.36 ± 14.76 \textsuperscript{c} | 114.53 ± 13.53 \textsuperscript{a} | 33.71 ± 3.17 \textsuperscript{d} | 10.85 ± 1.99 \textsuperscript{e} |
| PAI       | 63.90 ± 11.93 \textsuperscript{b} | 55.19 ± 13.48 \textsuperscript{b} | 119.57 ± 7.30 \textsuperscript{a} | 25.91 ± 6.03 \textsuperscript{c} | 12.34 ± 1.47 \textsuperscript{d} |
| CAP       | 65.97 ± 10.68 \textsuperscript{b} | 52.30 ± 14.30 \textsuperscript{c} | 79.47 ± 5.90 \textsuperscript{a} | 21.32 ± 3.37 \textsuperscript{d} | 10.98 ± 1.09 \textsuperscript{e} |

| Static coefficient of friction, $\mu_s$ |
|----------------------------------------|
| Steel                                 | 0.15 ± 0.07 \textsuperscript{c} | 0.14 ± 0.02 \textsuperscript{c} | 0.29 ± 0.09 \textsuperscript{b} | 0.52 ± 0.06 \textsuperscript{a} | 0.31 ± 0.09 \textsuperscript{b} |
| Iron                                  | 0.19 ± 0.07 \textsuperscript{c} | 0.07 ± 0.03 \textsuperscript{d} | 0.24 ± 0.05 \textsuperscript{b, c} | 0.34 ± 0.07 \textsuperscript{a} | 0.28 ± 0.06 \textsuperscript{a, b} |
| Glass                                 | 0.19 ± 0.08 \textsuperscript{b, c} | 0.11 ± 0.02 \textsuperscript{c} | 0.30 ± 0.10 \textsuperscript{a, b} | 0.38 ± 0.13 \textsuperscript{b} | 0.32 ± 0.12 \textsuperscript{a} |
| Plastic                               | 0.24 ± 0.06 \textsuperscript{a} | 0.09 ± 0.02 \textsuperscript{a} | 0.20 ± 0.08 \textsuperscript{a} | 0.26 ± 0.11 \textsuperscript{b} | 0.25 ± 0.06 \textsuperscript{a} |

| Kinetic coefficient of friction, $\mu_k$ |
|-----------------------------------------|
| Steel                                   | 0.79 ± 0.12 \textsuperscript{a, b} | 0.94 ± 0.23 \textsuperscript{a, b} | 0.83 ± 0.11 \textsuperscript{a, b} | 0.75 ± 0.11 \textsuperscript{b} | 0.96 ± 0.14 \textsuperscript{a} |
| Iron                                    | 0.54 ± 0.13 \textsuperscript{b} | 0.95 ± 0.21 \textsuperscript{a} | 0.94 ± 0.17 \textsuperscript{a} | 0.62 ± 0.13 \textsuperscript{b} | 0.96 ± 0.08 \textsuperscript{a} |
| Glass                                   | 0.65 ± 0.18 \textsuperscript{a} | 0.59 ± 0.21 \textsuperscript{a, b} | 0.73 ± 0.12 \textsuperscript{a} | 0.46 ± 0.13 \textsuperscript{b} | 0.73 ± 0.08 \textsuperscript{a} |
| Plastic                                 | 0.65 ± 0.19 \textsuperscript{a} | 0.75 ± 0.22 \textsuperscript{a} | 0.82 ± 0.13 \textsuperscript{a} | 0.62 ± 0.13 \textsuperscript{a} | 0.76 ± 0.07 \textsuperscript{a} |

Each value is presented as (SD±). Data with various uppercase superscript letters indicate significantly using the test of Duncan’s multiple ranges.

The highest static friction was established on steel (0.14–0.52), followed by glass (0.11–0.38), iron (0.07–0.34), and plastic (0.09–0.26) due to the frictional properties of surface materials. The kinetic friction was established on steel (0.75–0.96), followed by iron (0.54–0.96), plastic (0.62–0.82), and glass (0.46–0.73).

4. Conclusions

This research work aimed to study the comparative analysis of the main nutritional values, vitamins, and amino acid compositions of five varieties of onion bulbs with some essential structural parameters for the packaging process. Onion bulbs had high protein content, fat, and ash and low fiber and carbohydrates contents. Additionally, they gave an acceptable impression in terms of vitamins and amino acids, with a predominance of arginine. Results for nutritional values help in gaining better views on onion benefits, while the structural parameters help in designing equipment for the packaging process and sorting.

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Abbreviations

**CAP** Criteria projected area, cm$^2$

**$D_a$** Arithmetic mean diameter, mm

**$D_e$** Equivalent mean diameter, mm

**$D_g$** Geometrical mean diameter, mm

**$D_s$** Square mean diameter, mm

**$F_d$** Measured friction force, N

**$L$** Length, mm

**$M$** Mass, g

**$W$** Width, mm

**$M_c$** Moisture content, %

**$N$** Normal force, N

**$P$** Porosity, %

**$PAL$** First projected area, cm$^2$

**$PAT$** Third projected area, cm$^2$

**$PAW$** Second projected area, cm$^2$

**$\rho_b$** Bulk density, Kg/cm$^3$

**$\rho_t$** Density ratio

**$\rho_t$** True density, Kg/cm$^3$

**$S_p$** Aspect ratio

**$S$** Surface area, cm$^2$

**$T$** Thickness, mm

**$V$** True bulk of onions, cm$^3$

**$V_{ell}$** Ellipsoid volume, cm$^3$

**$V_m$** Onion actual volume, cm$^3$

**$V_o$** Bulk of the box, cm$^3$

**$V_{psp}$** Prolate spheroid volume, cm$^3$

**$w$** Weight of the displaced water, Kg

**$\gamma$** Weight density of water, Kg/cm$^3$

**$\theta$** Tilt angle of the friction device, deg

**$\lambda$** Packing factor

**$\mu_k$** Kinetic coefficient of friction

**$\mu_s$** Static coefficient of friction

**$\phi$** Sphericity

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