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Research Article
DPPH, FRAP and TAEC Assays with Postharvest Cabbage (*Brassica oleracea*) Parameters During the Packaging Process

[1]Abeer H. Elhakem, [2]Nada Benajiba, [3]Marwa Y. Koko, [4]Ebtihal Khojah and [4]Ahmed Rok

[1]Department of Biology, College of Sciences and Humanities, Prince Sattam Bin Abdulaziz University, Al-Kharj 11942, Saudi Arabia
[2]Department of Basic Health Sciences, Deanship of Preparatory Year, Princess Nourah Bint Abdulrahman University, P.O. Box 84428, Riyadh 11671, Saudi Arabia
[3]National Food Research Centre, P.O. Box 213, Shambat, Khartoum North, Sudan
[4]Department of Food Science and Nutrition, College of Sciences, Taif University, P.O. Box 11099, Taif 21944, Saudi Arabia

Abstract
Background and Objective: Cabbage head is one of the main essential vegetables grown worldwide and contains high antioxidants compounds that fight the inflammation of many diseases. In this study, antioxidant activities and several characteristics of four different cabbage heads (Red, Savoy, Green and Napa) have been investigated. **Materials and Methods:** Characteristics included: Head dimensions, sphericity, aspect ratio, mass, moisture content, project and surface areas. The (static and dynamic) frictions were detected on different surfaces. **Results:** Napa cultivar had the highest TEAC assay (5.69 μmol TE g^{-1} fw). Green head had the highest DPPH assay (91.22 μmol TE g^{-1} fw), while the red head had the highest FRAP assay (79.77 μmol TE g^{-1} fw). The highest moisture content was in the Napa heads (94.91%). Savoy heads recorded the highest width, thickness, aspect ratio, mass and sphericity. The highest static and dynamic frictions were found on galvanic iron (0.29-0.51) and stainless steel (0.36-0.66), respectively. **Conclusion:** The measured data will be used in the cabbage horticultural processing for quality improvement and diet planers due to the high antioxidant activities.

Key words: Oxidation activities, cabbage, physical properties, projected area, density, friction, postharvest

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Corresponding Author: Abeer H. Elhakem, Department of Biology, College of Sciences and Humanities, Prince Sattam Bin Abdulaziz University, Al-Kharj 11942, Saudi Arabia Tel: 00966544232121

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Vegetables are well known as an essential item of trade due to the enormous market potential[1]. Cabbage heads are made up of numerously thick, overlapped smooth leave that covered smooth terminals buds. It contains about 94% water, protein(1.61 g), fat (0.21 g) and carbohydrate per (100 g) (4.21 g), respectively[2,3]. Red cabbage is rich in bioactive and antioxidant phytochemicals such as polyphenols, glucosinolates, carotene, tocopherol, ascorbate and minerals such as potassium, manganese, iron and magnesium. Therefore, cabbage can be usually used for treating different diseases in Chinese medicine as peptic ulcers and gastritis[4].

Physico-mechanical characteristics of agricultural products are very essential for packaging and processing system determinations[5]. Several parameters as surface area, volume, static and dynamic coefficient of frictions could be beneficial during the packaging process. Several reports were conducted on cabbage cultivars within different production countries such as USA[6], Uganda[7], Korea[8] and Tanzania[9].

Consequently, in the recent study, researchers need to investigate the mentioned physical and mechanical estimations of cabbage heads by comparing four cabbage cultivars and then creating cabbage mechanization and processing convenient reference table for packaging.

MATERIAL AND METHODS

Study area: The present study was achieved during February-July, 2020 at the Collage of Science, Prince Sattam Bin Abdulaziz University, Saudi Arabia.

Chemicals and plant materials: The cabbage cultivars used were Red, Savoy, Green and Napa, respectively. Twenty heads of each cultivar had a random selected from a local supermarket in Al-Kharj. Free radical scavenging assay (DPPH), Ascorbic acid, methanol, Fluorescence recovery after photobleaching (FRAP reagent) and Trolox Equivalent Antioxidant Capacity (TAEC) were from (Sigma, MO, USA).

Extraction: Cabbage cultivars were washed, cut into small slices and freeze-dried (ALPHA 1-4 LSC, Germany). Exactly 100 g were weighed, extracted triplicate with (10 mL of 80%) methanol solution in dark at ambient temperature by shaking and sonicating followed by filtration using Whatman 4. The supernatants were pooled and stored at 5°C.

DPPH assay (free radical scavenging): Aliquot of 3 mL (0.1 mM) methanolic solution of DPPH was mixed with 0.04 mL cabbage cultivar extracts, shaken and allowed in dark for 30 min at ambient temperature. Changes cabbage absorbance was estimated at 517 nm[9].

FRAP assay (fluorescence recovery after photobleaching): Aliquot of 3 mL cabbage cultivar extracts were mixed with (1.8 mL) FRAP reagent and the absorbance was estimated at 593 nm after incubation for 10 min at ambient temperature[10,11].

TEAC assay (trolox equivalent antioxidant capacity): Aliquot of 0.3 g cabbage cultivar extracts were mixed with 50% methanol under regular shaking at 300 rpm for 12 hrs supernatants were recovered and estimated for antioxidant activity at 734 nm[12].

Cabbage estimations: Cabbage moisture content (M_c) was determined[9]. Three linear dimensions, (L, W, T) namely as length, width, thickness and mass (M) were evaluated by a digital caliper and balance, respectively. The D_g, D_a, D_s, D_e and R_a represented geometric, arithmetic, square, equivalent diameters and aspect ratio, respectively[13]. The actual volume (V_m), (V_{psp}) prolate spheroid and (V_{ell}) ellipsoid volumes were calculated as:

$$V_m = \frac{w}{\gamma},\ V_{psp} = \frac{4\pi}{3}\left(\frac{L}{2}\right)\left(\frac{W}{2}\right)^2,\ V_{ell} = \frac{4\pi}{3}\left(\frac{L}{2}\right)\left(\frac{W}{2}\right)\left(\frac{T}{2}\right) \quad (1)$$

where, γ is the density.

Surface area (S), sphericity (φ) and packing coefficient (λ) have been considered by the following equations[14]:

$$S = \pi D_g^2,\ \phi = \frac{D_g}{L},\ \lambda = \frac{V}{V_o} \quad (2)$$

The true density (ρ_t) was calculated as follows:

$$\rho_t = \frac{M}{V_m} \quad (3)$$

Bulk density (ρ_b) was obtained[15] as:

$$\rho_b = \frac{M_b}{V_b} \quad (4)$$

The density ratio ρ_r and the porosity (P) were considered by the following equation[16,17]:

$$P = \left[1 - \frac{\rho_b}{\rho_t}\right] \times 100 \quad (5)$$

Project areas PAL, PAW and PAT were evaluated by the method of image processing, while CPA presented the criteria project area which evaluated as follows:

$$CPA = \frac{PAL + PAW + PAT}{3} \quad (6)$$

Coefficients of static and dynamic friction estimations: The static and dynamic coefficients of frictions were determined for different structural materials, namely stainless steel, galvanic iron, glass and plastic. All the observations were replicated twenty times and the average values were reported. The static friction was considered as follows:

$$\mu_S = \tan(\theta) \quad (7)$$

where, θ is the tilt of the angle.

The dynamic friction was considered as follows[18].

$$\mu_d = \frac{F_d}{N} \quad (8)$$

where, F_d and N are friction and normal forces, respectively.

Statistical analysis: For the analysis ANOVA test 16.0. SPSS Inc was used with the correlation between cultivates by the Principal Component Analysis (PCA).

RESULTS AND DISCUSSION

DPPH assay: DPPH activity results for cabbage extracts were exposed as μmol TE g^{-1} fw in Fig. 1. Green cabbage extracts were found to be the highest in DPPH activity 91.22 μmol TE g^{-1} fw followed by Savoy 47.25 μmol TE g^{-1} fw, while Napa observed the least activity value 3.15 μmol TE g^{-1} fw, respectively. Similar DPPH activity values in cabbage have been observed[19].

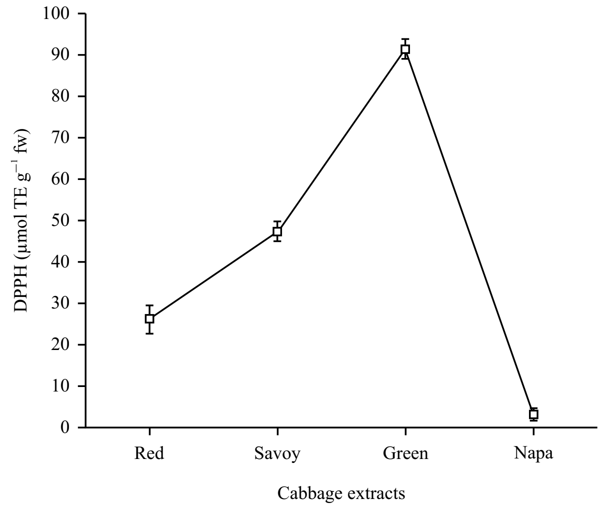

Fig. 1: 2,2-diphenyl-1-picrylhydrazyl (DPPH) activity for cabbage extracts

FRAP assay: The FRAP values are summarized in Fig. 2. Among all cabbage cultivars, Red cabbage had the highest FRAP activity value 79.77 μmol TE g^{-1} fw followed by Napa 45.01 μmol TE g^{-1} fw, while Savoy and Green varieties had a little equal value.

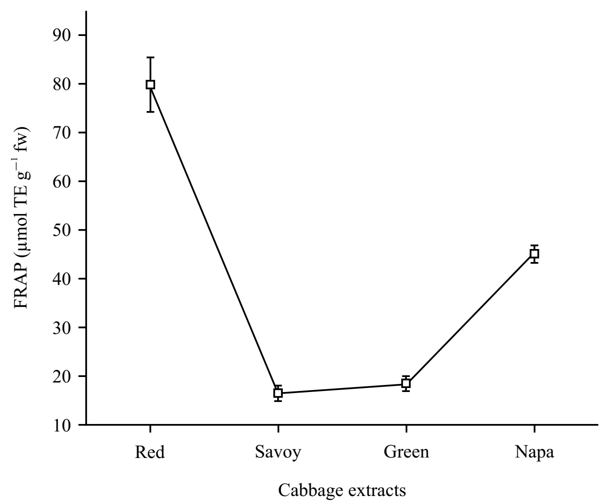

Fig. 2: Ferric Reducing Antioxidant Power (FRAP) assay for cabbage extracts

TEAC assay: Figure 3 showed that the Red cabbage cultivar obtained the least TEAC value as 1.13 μmol TE g^{-1} fw, while the Napa cabbage cultivar obtained the highest 5.69 μmol TE g^{-1} fw. Several European cabbage cultivars have been observed (2.92-8.13 μmol TE g^{-1} fw) for TEAC values[19].

Cabbage estimation results: As seen in Table 1, much estimation of the cabbage head cultivars was found to be statistically significant at different. The moisture contents ranged from 92.39-94.91%, for Green head and Napa head, respectively. Our results are in agreement with the previous study[6].

Table 1: Some estimations of cabbage cultivars

Cultivars	Red	Savoy	Green	Napa
M_c	92.84±0.07^{b}	92.53±0.11^{c}	92.39±0.06^{c}	94.91±0.19^{a}
L	14.45±1.59^{b}	12.69±2.49^{bc}	11.81±1.46^{c}	31.30±1.31^{a}
W	16.12±1.77^{b}	18.18±1.07^{a}	15.43±0.97^{b}	14.34±1.97^{a}
T	16.55±2.36^{ab}	17.81±0.88^{a}	15.60±0.90^{b}	14.83±1.70^{b}
M	1645.71±435.39^{bc}	2449.44±904.82^{a}	989.45±228.33^{ab}	2002.98±638.76^{ab}
D_g	155.80±17.37^{b}	158.82±14.84^{b}	140.65±6.44^{b}	186.98±16.31^{a}
D_a	157.04±17.46^{bc}	162.28±12.64^{b}	142.79±6.25^{c}	201.69±14.03^{a}
D_s	28.95±2.18^{bc}	29.49±1.68^{b}	27.14±0.81^{c}	33.34±1.78^{a}
D_e	113.93±12.33^{bc}	116.86±9.71^{b}	103.53±4.48^{c}	140.67±10.68^{a}
V_m	1558.68±353.42^{c}	2044.38±391.82^{a}	1438.95±352.49^{c}	2873.57±360.84^{a}
V_{ell}	2070.65±638.92^{b}	2173.72±540.44^{b}	1485.48±197.79^{b}	3541.76±914.36^{a}
V_{psp}	2016.53±612.82^{b}	2226.02±587.46^{b}	1475.52±245.41^{b}	3447.40±986.97^{a}
R_a	1.12±0.07^{b}	1.49±0.34^{a}	1.32±0.18^{ab}	0.46±0.06^{c}
S	770.07±164.95^{a}	797.83±140.26^{b}	622.22±56.05^{b}	1104.80±191.67^{a}
φ	1.08±0.05^{b}	1.28±0.19^{a}	1.20±0.11^{ab}	0.60±0.04^{c}
λ	0.29±0.02^{c}	0.37±0.02^{b}	0.22±0.01^{d}	0.42±0.01^{a}
$L\,W^{-1}$	0.90±0.05^{b}	0.70±0.12^{b}	0.77±0.11^{b}	2.21±0.31^{a}
$L\,T^{-1}$	0.88±0.10^{b}	0.71±0.13^{b}	0.76±0.11^{b}	2.13±0.21^{a}
$L\,M^{-1}$	0.09±0.02^{bc}	0.06±0.02^{c}	0.12±0.03^{b}	0.17±0.06^{a}
$L\,D_g^{-1}$	0.93±0.04^{b}	0.79±0.10^{c}	0.84±0.08^{bc}	1.68±0.13^{a}
$L\,\phi^{-1}$	134.26±16.69^{b}	102.57±29.33^{b}	99.89±21.79^{b}	526.47±44.59^{a}

Each value is presented as the Mean±standard deviation (n = 20), data with different uppercase superscript letters in the same column of cultivar respectively indicate a significant difference ($p<0.05$) analyzed by Duncan's multiple range test, Mc: Moisture content, D_a, D_s, D_g and D_e: Arithmetic, square, geometric and equivalent diameters, L, W and T: Length, width and thickness, M: Mass, Ra: Aspect ratio, V_m: Actual volume, V_{psp}: Prolate spheroid, V_{ell}: Ellipsoid volumes, φ: Sphericity; λ: Packing coefficient, S: Surface area, $L\,W^{-1}$: Length/width, $L\,T^{-1}$: Length/thickness, $L\,M^{-1}$: Length/mass $L\,D_g^{-1}$: Length/geometric, $L\,\varphi^{-1}$: Length/sphericity

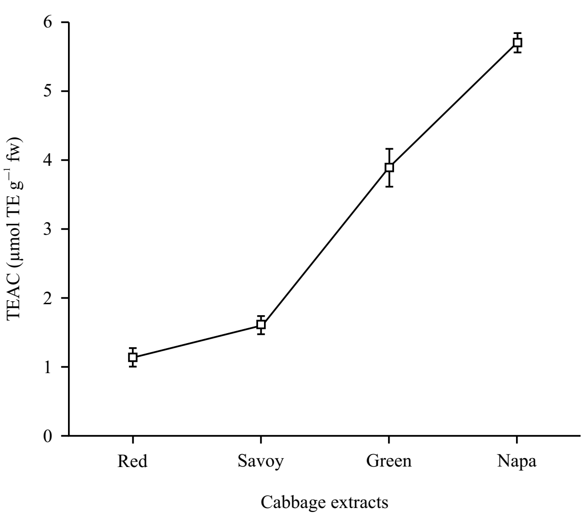

Fig. 3: Trolox Equivalent Antioxidant Capacity (TEAC) assay for cabbage extracts

Napa head produced the longest head length against results[20]. The head length recorded 31.30 cm and Savoy head produced the largest head width and thickness. Savoy head produced the heaviest weight (2.45 kg) that followed by Napa, Red and Green which had 2, 1.65 and 0.99 kg, respectively. The results were in agreement with the common commercial has grown cabbage heads which were in range (2.1-2.4 kg)[4].

The diameters of cabbage cultivars (D_a), (D_s), (D_g) and (D_e) were reported in different as 157.04, 28.95, 155.80 and 113.93 mm for Red head, 162.28, 29.49, 158.82 and 116.86 mm for Savoy head, 142.79, 27.14, 140.65 and 103.53 mm for Green head and 201.69, 33.34, 186.98 and 140.67 mm for Napa, respectively. These results confirmed Napa head was the biggest and the Green head was the smallest in surface area. Napa cultivar recorded the highest V_m, while V_{psp} and V_{ell} were (2070.65 and 2016.53 cm^3), (2173.72 and 2226.02 cm^3), (1485.48 and 1475.52 cm^3) and (3541.76 and 3447.40 cm^3) for Red, Savoy, Green and Napa, respectively.

The head cultivars (φ) were 1.08, 1.28, 1.20 and 0.60 for Red, Savoy, Green and Napa, respectively. Highly (R_a) 1.49 indicates that cabbage heads will rather roll smoothly on flat surfaces. Though, (R_a) value is being close to (φ) values observed that the cabbage heads can be controlled for sliding flat surfaces[20]. Napa head (λ) had recorded the highest value 0.42, while Green head the recorded the lowest value 0.22. (ρ_t) and (ρ_b) were recorded (502.79-1060.19 kg $m^{3\ -1}$) and (154.16-496.13 kg $m^{3\ -1}$), respectively (Table 2). The highest value of the density ratio was for Napa and Savoy 52.84-52.28 and the lowest was for Green head cultivar 21.98. Green head recorded the highest porosity value of 78.02%; on the other hand, Napa and Savoy recorded the lowest value 47.16-47.72%.

Table 2: Volume and density parameter of different cabbage extract

Cultivars	Red	Savoy	Green	Napa
ρ_t	831.78±7.27^{ab}	1060.19±381.55^{a}	707.70±82.99^{bc}	502.79±18.79^{c}
ρ_b	240.49±15.57^{b}	496.13±59.29^{a}	154.16±12.46^{c}	265.59±9.03^{b}
$\rho_b \rho_t^{-1}$	28.91±1.81^{b}	52.28±18.41^{a}	21.98±2.50^{b}	52.84±1.12^{a}
P	71.09±1.81^{a}	47.72±18.41^{b}	78.02±2.50^{a}	47.16±1.12^{b}

Each value is presented as the mean±standard deviation (n = 20), data with different uppercase superscript letters in the same column of cultivar respectively indicate a significant difference (p<0.05) analyzed by Duncan's multiple range test, $\rho_b \rho_t^{-1}$: Density ratio, ρ_t: True density, ρ_b: Bulk density, P: Porosity

Table 3: Project area and friction estimations

Cultivars	Red	Savoy	Green	Napa
PAL	323.07±66.55^{bc}	521.07±79.67^{a}	245.75±181.96^{c}	452.32±96.99^{ab}
PAW	322.57±98.04^{b}	555.22±173.13^{a}	358.29±31.45^{b}	552.96±57.72^{a}
PAT	351.22±158.83^{b}	510.53±156.39^{a}	353.46±22.43^{b}	629.07±78.09^{a}
CPA	332.29±74.09^{b}	528.94±124.92^{a}	319.17±73.12^{b}	544.78±34.91^{a}
Static coefficient of friction, μ_s				
Stainless steel	0.27±0.08^{b}	0.46±0.05^{a}	0.35±0.12^{b}	0.32±0.06^{b}
Galvanic iron	0.29±0.09^{b}	0.51±0.05^{a}	0.30±0.15^{b}	0.31±0.02^{b}
Glass	0.25±0.07^{b}	0.43±0.10^{a}	0.29±0.08^{b}	0.30±0.08^{b}
Plastic	0.17±0.09^{b}	0.51±0.12^{a}	0.19±0.08^{b}	0.25±0.01^{b}
Dynamic coefficient of friction, μ_d				
Stainless steel	0.36±0.10^{b}	0.43±0.22^{ab}	0.66±0.18^{a}	0.46±0.26^{ab}
Galvanic iron	0.30±0.09^{b}	0.37±0.23^{b}	0.62±0.21^{a}	0.45±0.14^{ab}
Glass	0.37±0.12^{a}	0.29±0.18^{a}	0.50±0.14^{a}	0.32±0.24^{a}
Plastic	0.35±0.11^{a}	0.34±0.16^{a}	0.52±0.12^{a}	0.46±0.25^{a}

Each value is presented as the mean±standard deviation (n = 20), data with different uppercase superscript letters in the same column of cultivar respectively indicate a significant difference (p<0.05) analyzed by Duncan's multiple range test, PAL, PAW and PAT: Project areas length, width and thickness, CPA: Criteria project area

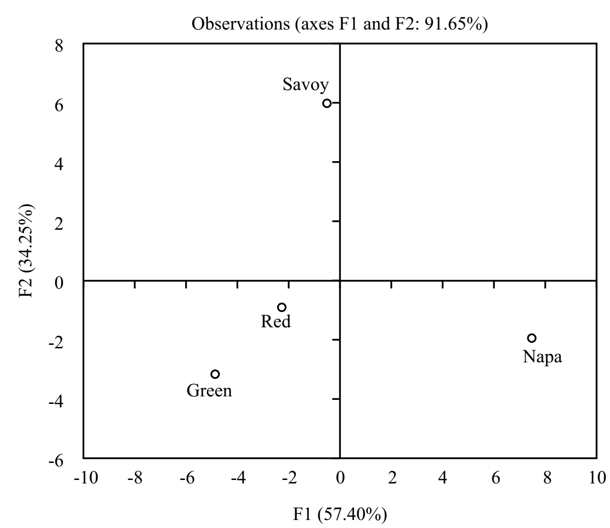

Fig. 4: Principal Component Analysis (PCA) of cabbage heads

The mean project areas (L, W and T) were obtained as 323.07, 322.57 and 351.22 cm^2 for Red, 521.07, 555.22 and 510.53 cm^2 for Savoy, 245.75, 358.29 and 353.46 cm^2 for Green and 452.32, 552.96, 629.07 cm^2 for Napa heads, respectively (Table 3). It was found that the criteria project area for Green cultivar was the lowest (319.17 cm^2), while Napa cultivar was the highest (544.78 cm^2).

Coefficient of static and dynamic friction estimation results: The highest static friction was found on galvanic iron (0.29-0.51) followed by stainless (0.27-0.46), glass (0.25-0.43) and plastic (0.17-0.51). Stainless recorded the highest dynamic friction (0.36-0.66) followed by galvanic iron (0.30-0.62), plastic (0.34-0.52) and glass (0.29-0.50). These estimations had better be carefully applied in the packaging processes of cabbage cultivars.

Principal component analysis of the tested cabbage heads: Cabbage estimation, static and dynamic coefficient of frictions during the packaging process had been submitted to PCA. The total variation showed 91.65%, while (axis 1) and (axis 2) recorded 57.40 and 34.25%, respectively. The inertia was positively by bulk density and the static friction on the iron surface, while negatively by the length to geometrical mean diameter ratio and the dynamic friction on the plastic surface (Fig. 4). Three discriminate structures have been observed, as Green and Red were grouped, while Savoy and Napa were individualized.

Therefore, cabbage antioxidant activities, estimation and frictions had been studied and submitted to principal component analysis. The correlation between all studies presented that there was a discriminate structure. Green and Red were grouped. Savoy and Napa were individualized.

CONCLUSION

DPPH, FRAP and TAEC assays with some physical and mechanical properties of cabbage heads were studied to prevent the mechanical damage and provide useful insight into of sizing machine design and reducing transportation and packaging costs. The results obtained from this research paper can be reflected in the cabbage nutritional values and packaging processing.

SIGNIFICANCE STATEMENT

This work discover the recovering views on the field of the physiochemical and packaging processes combinations that can be beneficial for designing equipments for harvesting, sorting, transporting and sizing machines.

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