Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Online International Journal Available at http://www.cibtech.org/jls.htm
2025 Vol. 15, pp. 30-38/Saiyed et al.
Research Article (Open Access)

NUTRITIONAL ELECTRIC PARAMETER ASSOCIATED WITH PHYSIOCHEMICAL CHANGES IN APPLE (*MALUS DOMESTICA*) FRUIT

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ABSTRACT
A large number of studies have been made to understand the Biophysical and Biochemical changes in apple fruit. However, no research has been conducted on this aspect & we report first time these changes, manifested in the form of varying Nutritional Electric Parameter (NEP), which have been measured with the help of self-designed Digital Bimetallic Potentiometer (DBPM) for a set of apples of same class & observed that the transportation of electric charges in the form of cluster of ionic minerals, and other chemical compositions found with sufficient abundance in apple. It was also found that a group of ten apples of same variety (*Malus domestica*) kept at room temperature continuously for 7 days, became softer, squeezed texture with increased mobility of ionic cluster of abundant minerals from 4 to 6 times in magnitude and enhanced NEP up to 37.6 %.

Keywords: *Nutritional Electric Parameter (NEP), Mobility, Digital Bimetallic Potentiometer, Cluster, Elemental Charges, apple (Malus domestica).*

INTRODUCTION
In India, apple (*Malus domestica*) is the main fruit of northern region of Himalayan terrain. Himachal Pradesh is a horticulture state of India and apple cultivation is more common in dry and temperate regions of Himachal Pradesh territory. The genus *Malus* belongs to the family Rosaceae (Velasco *et al.,* 2010). *M. domestica* is a small to medium-sized, much-branched, deciduous tree with a single trunk and a broadly spreading canopy. The whole fruit is edible except seeds; apart from that, many other products are produced from them: such as ciders and juices, jams, compotes, dehydrated apple (Watkins, 2003). They are unique in human nutrition since, they increase immunity, have a positive effect on stress resistance, and they contain many bioactive substances that are helpful for humans (Masoodi and Chauhan 2007; Verma *et al.,* 2010). Fruit ripening refers to the series of processes that occur from the later stages of growth and development until the fruit is ready for consumption. As the fruit matures, the quality characteristics of the fruit change. Usually, the firmness of the pulp becomes softer, the sugar content increases, and the acidity decreases. Aromatic substances are released and the original taste of the fruit is created. Typically, the fruit will be darker in colour, the skin and pulp will be softer, and the green background will fade. Apple constitute an important part of the human diet all over the globe, as of now they have become a basic source of monosaccharides, minerals (Ca^{++}, Fe^{++}, Mg^{++}, P^{+}, K^{+}, Na^{+}, Zn^{++}, Cu^{++} and Mn^{++}), salutary fibre, and colourful biologically active composites, similar as vitamin C, and certain phenolic composites which are known to act as natural antioxidants (Knekt *et al.,* 2002; Wolf & Liu, 2003). Some experimenters also consider poly phenol oxidases to be antimutagenic and anticarcinogenic properties (Lee and Mattick, 1989; Miller and Rice- Evans, 1997). Along with sugars and organic acids, phenolics determine the quality of apple (Fuleki *et al.,* 1994). They have important places in furnishing taste characteristics, similar as flavour, bitterness and astringency, and also colour (Bengoechea *et al.,* 1997; Miller and Rice- Evans, 1997). Apple represents one of the most nutritive foods in a healthy diet for its content of water (> 80), sugars (fructose> glucose> sucrose), organic acids (0.2 –0.8), vitamins

(substantially vitamin-C, 2.3 –31.1 mg, / 100 g DM), minerals (= ash 0.34 –1.23) and salutary fibres (≈ 2 – 3 and pectin < 50% apple fibres) (Cannella, 2008; Karakasova *et al.,* 2009). According to couple of chemistry-based studies done by Aprikian *et al.,* (2003); Boyer and Liu (2004);

Fig.1. Represents health benefits of an apple

Drogoudi *et al.,* (2008) apple is known to have significant levels of polyphenol antioxidants (second only to cranberries), accounting for 20–25% of all fruit polyphenols ingested in the US and 10–30% of daily potassium and fibre intake. Eating an apple prevents many diseases like cancers, cardiovascular diseases, asthma and diabetes (Boyer and Liu 2004). The health benefits of an apple are depicted in Fig. 1. When apple is eaten the body converts its chemical ingredients during digestion in many forms as glucose, fats and pectin fibers which enter into blood stream so as to reach rapidly to cells wherein they are turned into energy for body to feel afresh. This mechanism of conversion of chemical energy of an apple is typical to understand in our body because it involves indirectly the electrical characteristics of an apple associated with their percentage abundance as well as mobility of ionic elemental clusters. In fact, the electrical characteristic developed in an apple depends upon number of factors such as cultivation environments during its growth, time length of cold and open storage before its consumption, kind of packaging for mode of transportation to market for sale, and solar irradiance when it is sold in open market (Zhichao *et al.,* 2023). Know, how the percentage of abundance and mobility of mineral electric charges vary in an apple as a function of time and environmental conditions (temperature, humidity, solar irradiance, open storage places etc.), is a research gap still unraveled. In order to fill this research gap, we have conducted a study of NEP associated with physiochemical changes occurring in apple fruit specifically during its storage at room temperature. The results and significant outcomes obtained are presented in this paper.

MATERIALS AND METHODS

In this study, we took ten apples (*Malus domestica*) as a sample group from easily available source (apple seller in market). The chosen apples were kept open in the laboratory at room temperature 32 ºC for 7 days and the potential difference on each day was measured using a self-designed Digital Bimetallic Potentiometer (DBPM).

Potential difference directly related to the cluster of elemental minerals electric charges, transported per unit dielectric constant of apple and could be directly related to the Nutritional Electric Parameter (NEP). Hence, it serves the main purpose of the study how the nutritional electric charge transportation of the apple fruit changes day by day at room temperature under other normal conditions of the laboratory.

The DBPM in fact is a simple instrument designed in our Physics laboratory using two different pure metal material wires of copper and aluminum. Each wire had 10 cm long length and thickness of 2 mm diameter. These were kept apart for fix distance of 1 cm,

which could be varied from 1 cm to 3 cm with the help of two bad conducting rubber block of size 1cm x 1cm x 9 cm as shown in Fig. 2.

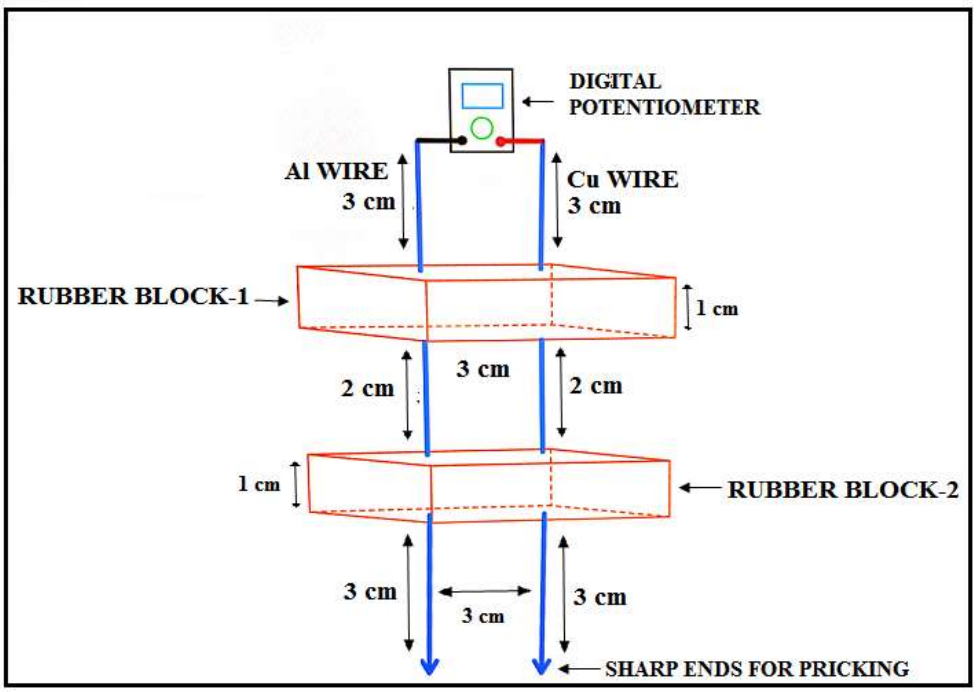

Figure 2: Diagram of Digital Bi-metallic Potentio-Meter (DBPM)

In DBPM, rubber block-1 and rubber block-2 are used to support or constant 1cm distance between bimetal wires of Cu & Al. The end points of both wires are sharp pointed so as to prick deep inside each apple sample of group ten. At opposite ends of both wires a digital potentiometer is soldered in order to measure d c. potential difference established by the cluster of elemental electric charges transported by the dielectric properties of the matter contained in our sample (apple).

The working principle involved with DBPM is easy to understand. The bimetals, Copper and Aluminium with different electron densities in conduction band, develop an electric field ($-dV/dx$) at any distance (x) with in 1cm gap (d) between two wires. The developed electric field mobilizes the clusters of electric charges (ne) of apple available in the form of free ions (gaining or loosing electrons by atoms or molecules associated with vitamins, carbohydrate, minerals, metallic compounds etc. in sample) and according to electrostatics it may be written as,

$$-dV/dx = ne/(4\pi\varepsilon k x^2) \quad (1)$$

Where, dv = potential difference between two wires, ε= Electric permittivity in vacuum and k= Dielectric constant of apple.

Integrate Eq. (1) with respect to 'x' under the limits between 'd' and ∞= Infinity, we get as

$$-\int_0^V dV = ne/4\pi\varepsilon k \int_\infty^d dx/x^2 \quad (2)$$

Or

$$-V = ne/4\pi\varepsilon k\left[-(1/x)\,_\infty^d\right]$$

Finally, the expression of measurement of volt by DBPM for our sample at room temperature becomes

$$V = ne/4\pi\varepsilon k d \quad (3)$$

Therefore, different clusters of electronic charges transported per unit dielectric constant of *Malus domestica*, may be written as-

$$n/k = (V(4\pi\varepsilon d))/e \quad (4)$$

Where physical quantity, n/k could be directly related to electrical nutrition value and used for its measurement in the physical unit of "different clusters of electric charge transported to per dielectric constant". More is the value of n/k more is the electrical nutrition value of apple and vice-versa, and is called Nutritional Electric Parameter (NEP).

Figure -3: Pictures taken for Apple during observations over successive 7 days

Observations:

Physical observations of ten *Malus domestica* (apples) were taken from the first day on which sample was procured from market for the present study, was considered as our or preliminary data of observation. The chosen ten apples were kept open in room at ambient condition for successive 7 days and potential difference on each day was measured in the month of April, 2024 by self-designed Digital Bimetallic Potential Meter (DBPM).

The physical measurements and pictures of *Malus domestica* (apples) are depicted in Table 1, and Fig. 3, respectively as given below. Table 1, shows the 10 real time data (in units of Volts) taken on each day pricking needles of DBPM at different of places on same sample. Apple's NEP was computed with standard error using Origin software as tabulated in last row.

Fig. 3, Shows the Biophysical and Biochemical changes responded under observation by an apple (*Malus domestica*) out of group of ten apples during storage at room temperature. Evidently degradation was noticeable in apple and real time data revealed it implicitly in the form of measured NEP. In fact, it could be a Bioelectrical impedance of apple expressed as NEP used to assess composition and nutrition status including energy values of carbohydrate, sugar, proteins, vitamins, salts, fatty acids, total fats, and moisture content. Apples exhibit the drastic temporal variations in the Bioelectrical impedance through computed NEP and in the present study we demonstrated it as shown in Fig. 4, below.

Table 1: **Data taken over the 7 days of Ten Apples using DBPM at room temperature at 32^{0}C.**

S. No.	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
1	0.48 volt	0.34 volt	0.51volt	0.45volt	0.29volt	0.45volt	0.49volt
2	0.31volt	0.42 volt	0.45volt	0.43volt	0.36volt	0.33volt	0.42volt
3	0.45 volt	0.45 volt	0.42volt	0.34volt	0.31volt	0.47volt	0.42volt
4	0.41 volt	0.38 volt	0.45volt	0.24volt	0.44volt	0.46volt	0.41volt
5	0.41 volt	0.4 volt	0.47volt	0.26volt	0.31volt	0.29volt	0.44volt
6	0.39 volt	0.44 volt	0.48volt	0.25volt	0.28volt	0.38volt	0.37volt
7	0.44 volt	0.52 volt	0.45volt	0.31volt	0.42volt	0.32volt	0.49volt
8	0.4 volt	0.37 volt	0.46volt	0.42volt	0.35volt	0.42volt	0.5volt
9	0.42 volt	0.41 volt	0.34volt	0.28volt	0.38volt	0.46volt	0.52volt
10	0.42 volt	0.35 volt	0.31volt	0.24volt	0.49volt	0.48volt	0.48volt
Average	0.413 volt	0.408 volt	0.434 volt	0.322 volt	0.363 volt	0.406 volt	0.454 volt
Standard error	± 0.04 volt	± 0.05 volt	± 0.06 volt	± 0.08 volt	± 0.07 volt	± 0.07 volt	± 0.05 volt
n/k	(2.87±0.06) x10^6	(2.83±0.059) x10^6	(3.01±0.06) x10^6	(2.23±0.060) x10^6	(2.52±0.062) x10^6	(2.82±0.058) x10^6	(3.15±0.05) x10^6

3.1. Physical properties

Apple (*Malus domestica*) has apparent physical properties which can be easily measured using measuring flask, sensitive chemical balance and calliper in laboratories. An apple is easily available in city markets and class (*Malus domestica*) of it is most of time produced in temperate zone of north India hills. It is delicious and consumed as food gradient in ripe state and also its juice**.** The following physical properties are measured for each apple in study for our used sample. Data below show for one of the apple only and in analysis average values of ten apples have been used.

1. Volume = 110 c.c.
2. Average diameter = 6.68 cm
3. Weight = 106.22 gram
4. Average density = 0.96 gm/c.c.
5. Colour = Reddish pink

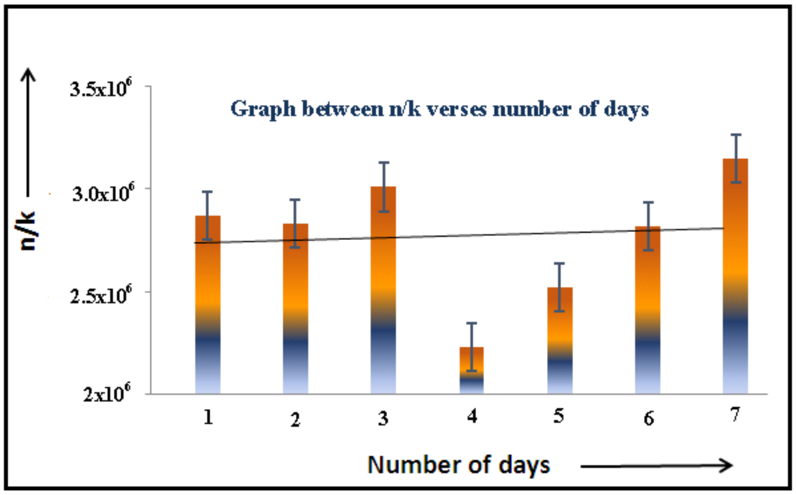

Figure 4: Represents a time dependent trend between 'n/k' (Nutritional Electric Parameter) and 7-days

RESULTS AND DISCUSSION

Observations were recorded for apple measuring potential difference '**V**' have been analysed using computer software "Origin". The formula of NEP (Nutrition Electric Parameter) of an apple sample can be expressed as

$$n/k = \frac{(4\pi\varepsilon d)V}{e} = 6.94\text{x}10^6 \text{ v} \quad (5)$$

Where constant ($4\pi\varepsilon d/e$) value in MKS system is estimated to be 6.94x10^6. The measurements for '**V**' were done using 'DBPM' for apple at room temperature on successive days (continuous 7 days) and tabulated in observation Table 1. The NEP computed values from the measurement of potential difference 'V' can further be justified by another formulation with regards to different mobile atomic clusters carrying electric changes present with the minerals and other ingredients of apple. Let us assume N_i atomic clusters of different variety exist in apple of mass 'm' with their different atomic weights $(A.W.)_i$, and collectively give rise NEP which can be written in the form of mathematical equations as give below

$$n/k = (emN\_a)/k \sum_{i=1}^{N} N\_i/(A.W.)\_i$$

$$= 1.46\text{x}10^5 \left(\textstyle\sum_{i=1}^{N} N\_i/(A.W.)\_i\right) \quad (6)$$

where 'e' is charge (1.6x10^{-19} coulomb) multiple on ionic atom, and N_a is Avogadro number (6.02x10^{23} atoms per mole) measurable in SI-units. However, the term $\sum_{i=1}^{N} N\_i/(A.W.)\_i$ represents a series summation of N_i atomic clusters of different varieties available in a sample of apple under our study. Dielectric constant of apple is k = 70 at 25ºC at frequency 10^8-10^9 Hz. (Wen-chuan Guo *et al.,* 2007). The estimation of NEP depends upon both N_i & $(A.W.)_i$ as given in Table 2, and justification of observed value of NEP given in Table 1, is done just to establish authencity of results reported for apple.

The data recorded and/presented of N_i & $(A.W.)_i$ are shown in Table 2, for the metallic ions and other prominent ingredients to reveal the number of their mobile atomic clusters present in apple and it is found to increase 4-6 times in analysis in justifying the increase of NEP.

The present research work of apple appears to be important from nutritional point of view. The evident variation in the measured value of (NEP) n/k in terms of measured voltage and atomic cluster N_i has been the strong clues that apples kept for long time had become more nutrient. The more n/k indicates that charge transported are larger in number at lower dielectrical value of ingredients of apples and on contrary decreased value of n/k shows less charge transportation at higher value of dielectrical constant. It could be understood by the observed trends as we have come across only after plotting n/k verses number of days of observations in Fig. 4. In fact, an apples demonstrated their fundamental rheological quality and properties. With respect to first day on second day, n/k value insignificantly decreased (-1.39%) but on 3rd day it increases up to 6.3%. But on fourth day n/k parameter decreased significantly (- 25.9%) and on succeeding rest days a consistent increase in n/k is found to be 13%, 11.9%, and 11.7% on 5th, 6th& 7th day respectively. At the end of the last day of observations net rise in NEP amounts to 37.6 %. It could be critically correlated to physical appearance variation like freshness, softness and texture as evident in photographs of apples taken on each day as depicted in Fig. 3. However, it has been quite interesting to record variation for the n/k in our observations and may be explained on the basis of the chemical properties of apples in subsequent part of discussion.

Table 2: Atomic cluster N_i present in Apple sample per 100 gm responding to $\frac{n}{k}$.

S.No.	$(A.W.)_i$ or $(M.W.)_i$	Nutrition ingedients presen in Apple	Natural Abundance N_i /100 gm
1	40.078 u	Ca^{++}	6 mg
2	55.845 u	Fe^{++}	0.12 mg
3	24 u	Mg^{++}	5 mg
4	30.97 u	P^{+}	11 mg
5	39.0983 u	K^{+}	107 mg
6	23 u	Na^{+}	1 mg
7	65.38 u	Zn^{++}	0.04 mg
8	63.546 u	Cu^{++}	0.027 mg
9	54.93 u	Mn^{++}	0.035 mg
10	286.45 g/mol	Vitamin A	.003 mg
11	169.18 g/mol	Vitamin B6	0.041 mg
12	176.124g/mol	Vitamin C	4.6 mg
13	376.36 g/mol	Riboflavin	0.026 mg
14	265.35 g/mol	Thiamine	0.017 mg

In above context, the role of charged mineral atoms given in Table 2, has been significant and are found in mineral pectate enzyme of an apple. These are quite large in abundance (namely Ca^{++}, Fe^{++}, Mg^{++}, P^{+}, K^{+}, Na^{+}, Zn^{++}, Cu^{++} and Mn^{++}), as compared to majority of elements C, H, O for basic chemical composition. All these are found in the single bite taken of an apple providing Vitamins A, B complex, C and E which include riboflavin, thiamine and B-6. In another category few structural classes of polyphenols are present in an apple among which flavanols (quercetin, kaempferol and rutin), dihydrochalcones (phloretin and phloridzin), flavon-3-ols (epicatechin and procyanidins) and phenolic acids (caffeic acid and coumaric acid) are main components with decreased abundance. All these chemical compositions of an apple are encompassed collectively into a known physical parameter called dielectrical constant ‘k’, which is an important part in NEP and is a result of ratio of external electric (E) set by bimetal electrodes of DBPM and the net responded electric field ($E-E_o$). Here, E_0 is induced electric field due to electrical composition of an apple. However, the accumulative electrical charges of clusters ‘n’ transported under dielectric property of all chemical composition state of an apple will measure the observed potential difference ‘V’. The contribution to NEP is more (37.6 %) likely due to minerals clusters having free charges in an apple. The analysis of data N_i & $(A.W.)_i$ depicted in Table 2, observed the increase in mobility of atomic clusters from 4-6 times of minerals during study of apples from the first day of observations to the last day.

During the study of freshness, softness and texture of an apple varied strongly see Fig. 3, is due to major change in the presence of mineral calcium pectate enzyme. With ripening the respiratory activity increases and the breakdown of calcium pectate to pectic acid with the help of Pectinase enzyme. It does have sugar binding capacity and as a result increases softness in apple and hence, the mineral particles become free. pectin are the major constituents of prime Pectin and are the major constituents of the primary cell wall & middle lamella, which help to give the texture and quality of an apple (Munarin, *et al.,* 2012). Decomposition of pectin during ripening is responsible for tissue softening in several fruits. pectin is also major source of dietary fibre in apple for its medicinal properties. Ethylene gaseous phytohormone plays a central role in ripening of an apple, it increases gradually to peak then gradually decreases, the fruit then moves into aging stage (Li *et al.,* 2016). All apple turn colour before converting all of the yeast starch to sugar so the flavour is still the more important indicator than colour. Apple often change their texture as they ripen going from hard to either crisp or meely. All these could help in enhancing the mobilities of clusters of electric charges in an apple.
We finally conclude that for the first few days (<4days) when apple is kept at room temperature is edible, but after that tightness is lost (apple becomes soft with deformed texture) with extra rise of NEP (n/k) to 37.6 % and conduction of clusters of minerals increased from 4 to 6 in later stage of apple. This shows that juice of an apple is more nutritional for health and apple can be used till couple of days without harm. Therefore, juice producing companies can store apple for their economic gain in market for couple of days before processing in the juice production at room temperature.

ACKNOWLEDGEMENT
Authors are thankful and express their deep gratitude to Admistrators Dr. Vaseem Khan and Mrs. Neema Khan, RNT group of College, Kapasan for their generous help and providing research facilities in carrying out this study smoothly in prescribed time frame of teaching of U.G. and P.G. students.

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