Measurement of Nutritional Electric Parameter (NEP) of Apple (*Malus domestica*) Fruit During Storage at Room Temperature.

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Abstract:

Nutritional Electric Parameter (NEP) has been measured to understand the Biophysical and Biochemical changes in Apple fruit. First time these changes, manifested in the form of varying NEP have been reported with the help of self-designed Digital Bimetallic Potentio-Meter (DBPM). The NEP reveals transportation of electric charges in the form of cluster of ionic minerals, and other chemical compositions available with sufficient abundance in Apple. Ten numbers of Apples as samples for study, kept at room temperature for continuously 7 days, observed to became more soft, squeezed texture and showed increased mobility of ionic cluster of abundant minerals from 4 to 6 times with enhanced NEP up to 37.6 %.

Keywords: Nutritional Electric Parameter, mobility of charges in fruits, Digital Bimetallic Potentiometer, Cluster of ionic element, Elemental Charges in Apple (*Malus domestica*).

Introduction:

The specific variety of Apple known as *Malus domestica* is the main fruit of northern region of Himalayan terrain of India. The Horticulture state of India is Himachal Pradesh where Apple cultivation is more common in dry and temperate regions. Variation in microclimatic conditions, wide altitudinal range and geographical diversification in Uttarakhand state has been considered as one of the suitable area for Apple cultivation and is the third largest Apple producer state after Jammu & Kashmir and Himachal Pradesh. (Spengler, 2019)

In temperate regions the *Malus* belonging to the rose family (Rosaceae) are found over 100 genera with 3000 species all over the worldwide (Velasco et al., 2010).The anatomy of *M. domestica* tree is very typical having a small to medium-sized, much-branched, a single trunk with a extended canopy. Except seeds whole fruit is eatable and moreover products like Ciders, juices, jams, compotes, tea, wine, or dry Apples etc are produced from them: All these 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)

Apple fruit has been contemplated in several studies as an important source of polyphenols, carbohydrates, and dietary antioxidants (Knekt *et al.*, 2002; Wolf *et al.*, 2003) and besides many more properties like colour, shape, texture, taste, aroma, nutritional value (Lurie, 2008). The process of fruit ripening begins from the ending stages of growth and development till the firmness of the pulp becomes softer, the sugar content increases, and the acidity decreases. Soon after the release of Aromatic substances the original taste of the fruit is installed with major changes like dark in colour, soft skin, delicious pulp, and fading of the greenness.

Apples as a part of human diet all over the globe have become a important source of monosaccharides, minerals (Ca^{++}, Fe^{++}, Mg^{++}, P^{+}, K^{+}, Na^{+}, Zn^{++}, Cu^{++} and Mn^{++}), salutary fibre, vitamin C, polyphenolic antioxidants which are antimutagenic and anticarcinogenic composites (Lee and Mattick, 1989, Miller and Rice- Evans, 1997) and determine the chemical and physical quality of Apples (Dolenc and Stampar, 1997, Fuleki *et al.*, 1994). Moreover the furnishing taste characteristics, such as flavour, bitterness and astringency, and also colour (Bengoechea *et al.*, 1997, Miller and Rice- Evans, 1997) of Apple make it one of the most nutritive food in a healthy diet. The 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 ($\approx 2 - 3$ and pectin $< 50\%$ apple fibres) (Kiczorowska and Kiczorowski, 2005; Cannella, 2008; Karakasova *et al.*, 2009) dignify the apple at top in the list of the fruits.

Few chemistry based studies (Aprikian *et al.*, (2003), Boyer and Liu (2004), Drogoudi *et al.*, (2008) proved Apples to have significant levels of polyphenol antioxidants and Pissard *et al.*, (2013) reported that primary phenolic compounds found in Apples include epicatechin, procyanidins, phloretin, quercetins, and chlorogenic acid. However the time length of storage of apples, composition of these compounds varies according to the variety, maturation stage, environmental factors, and cultural practices done on apples.

On eating an Apple, many diseases like cancers, cardiovascular, asthma and diabetes (Boyer, J. and R.H. Liu., 2004) are prevented. The human health gets more benefits by Apples due to being rich in fibers and cholesterol particles are removed by them before absorbed in the body for the risk of arteries blockages. Similarly the presence of Triterpenoids in apple reduces the risk of cancer whereas the embodied Antioxidants in an apple suppress the Alzheimer and Parkinson diseases. Chewing of an apple stops the decay of teeth while it detoxifies and cleanses our lever. Feskanich *et al.*, (2000) showed that when an apple is eaten the body converts its ingredients chemical energy during digestion in many forms as glucose, fats and pectin fibers which enter into blood stream. The conversion of chemical energy is typical to understand in our body because it involves electrical characteristics of an Apple associated with their percentage abundance as well as mobility of ionic elemental clusters. The ionic elemental clusters developed in an Apple little varied by 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 (Zhichao et al. 2023). Now how the mobility of mineral electric charges are influenced by temperature, humidity, solar irradiance, open storage places in an Apple as a function of time, is a research gap still unaddressed. We focused on NEP associated with biophysical and biochemical changes occurring in Apple fruit specifically during its storage at room temperature in this study .The results and significant outcomes obtained are presented in order to fill research gap, in this paper.

Experimental:

In laboratory at room temperature (32 ºC) for 7 days, the samples of chosen ten Apples (*Malus domestica*) for the study were used and the potential difference for NEP was measured with help of self-designed Digital Bimetallic Potentio Meter (DBPM). The value of

NEP represents electrical charges of the cluster of elemental minerals transported per unit dielectric constant in the sample of an apple and reveals the mechanism how the nutritional electric charge transportation changes day to day at room temperature.

DBPM was designed using two wires of copper and aluminum as shown in figure -2. Both wires of length 10 cm, diameter of 2 mm, were kept apart at 1 cm, with the help of two rubber blocks.

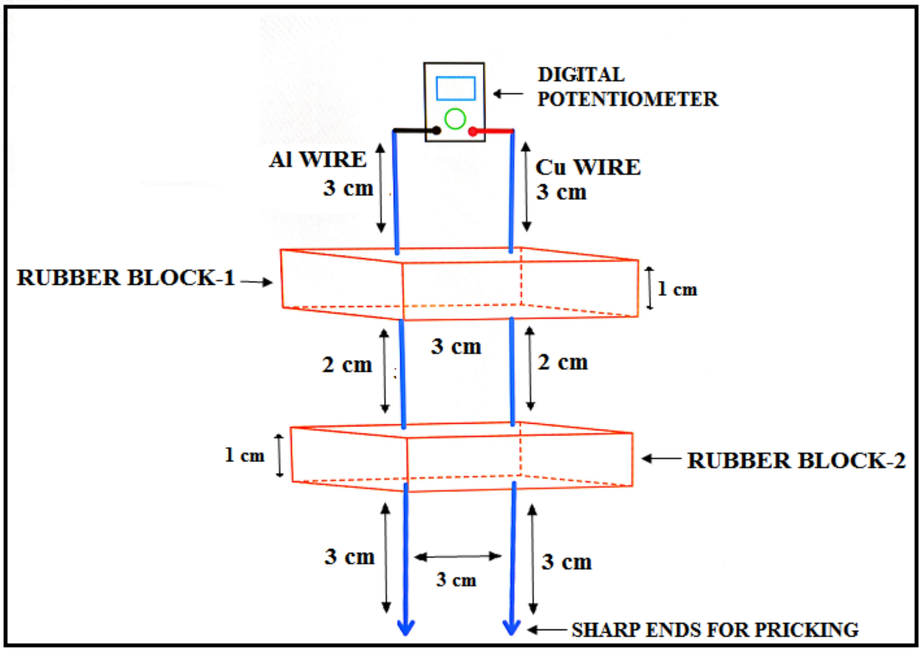

Figure: 2 Rudimental labelled diagram of Digital Bi-metallic Potentio-Meter (DBPM).

The sharp ends of both wires are pricked deep inside Apple to obtain in meter d.c. potential difference which is generated by the group of elemental electric charges transported under the dielectric properties of the matter contained in our sample (Apple). In principle Copper and Aluminium metal wires have different electron densities between them in their conduction band and thus develop an electric field ($-\frac{dV}{dx}$) as a differential function of distance (x) with in gap (d). In fact this electric field mobilizes the clusters of electric charges (ne) of Apple available in the form of free ions (transferring of electrons among atoms or molecules of vitamins, carbohydrate, minerals, metallic compounds etc. in sample). Equation according to electrostatics it may be written as,

$$-\frac{dV}{dx} = \frac{ne}{4\pi\varepsilon k x^2}$$

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

On integration with respect to 'x' under the limits between 'd' and ∞= Infinity, we get as

$$-\int_0^V dV = \frac{ne}{4\pi\varepsilon k}\int_\infty^d \frac{dx}{x^2}$$

Or

$$-V = \frac{ne}{4\pi\varepsilon k}\left[-\left(\frac{1}{x}\right)\frac{d}{\infty}\right]$$

Final equation of potential voltage becomes,

$$V = \frac{ne}{4\pi\varepsilon kd}$$

Now different clusters of electronic charges transported per unit dielectric constant of *study sample* may be written as

$$\frac{n}{k} = \frac{V(4\pi\varepsilon d)}{e}$$

Where physical quantity, $\frac{n}{k}$ is called Nutritional Electric Parameter (NEP) measured in the physical unit of "different clusters of electric charge transported to per dielectric constant". More is the value of $\frac{n}{k}$ more is the electrical nutrition value and vice-versa.

Observations:

Under observation, the chosen ten Apples were placed at dry place in open area at room temperature 32° C for successive 7 days and potential difference on each day was measured in the month of April, 2024 by DBPM.The data and pictures of *Malus domestica* (Ten Apples) are depicted in table-1, and figure-3 respectively showing the 10 real time data (in units of Volts) taken on each day pricking needles of DBPM on ten samples. Data were computed with standard error using Origin software.

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

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**

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

Figure-3 Shows the Biophysical and Biochemical changes occurred during observation for an Apple (*Malus domestica*). Seemingly real time data reveal the changes in Apple implicitly indirectly in the form of measured NEP. Probably it could be a Bioelectrical impedance of apple expressed as NEP used to assess composition and nutrition values of Carbohydrate, Sugar, Proteins, Vitamins, Salts, Fatty Acids, Total Fats, and Humidity. Evidently all Apples exhibit time dependent NEP associated to bioelectrical impedance as shown in figure -4 below.

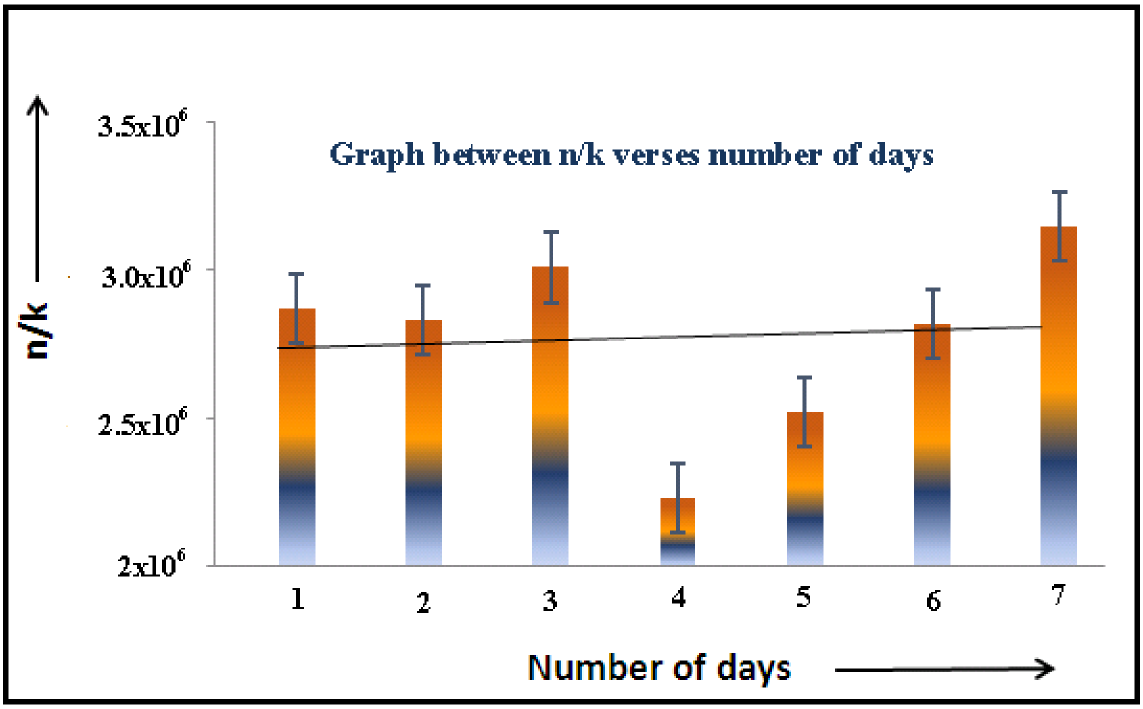

Figure 4: represents a time dependent trend between 'n/k' (Nutritional Electric Parameter) and 7- days (Apples were kept in open atmosphere at room temperature 32^{0}c in the month of April, 20-26, 2024).

Physical properties:

The following given average values of Physical properties were measured using measuring flask, sensitive chemical balance and calliper in laboratories for Ten Apples available in Kashmir-Himachal Pradesh (States of India).

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

Data analysis and Results:

The measured potential differences '**V**' have been analysed using computer software "Origin" after simplifying formula of NEP (Nutrition Electric Parameter) of Apples sample as

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

Where constant $\left(\frac{4\pi\varepsilon d}{e}\right)$ value in MKS system is computed to be 6.94×10^6.

The computed values of NEP 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 N_i be the number of 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

$$\frac{n}{k} = \frac{emN_a}{k} \sum_{i=1}^{N} \frac{N_i}{(A.W.)_i}$$

$$= 1.46 \times 10^5 \left(\sum_{i=1}^{N} \frac{N_i}{(A.W.)_i}\right)$$

Where 'e' (1.6×10^{-19} coulomb) is multiple charges on ionic atoms, and N_a is Avogadro number (6.02×10^{23} numbers of atoms per mole). The term $\sum_{i=1}^{N} \frac{N_i}{(A.W.)_i}$ represents a series summation of N_i atomic clusters of different Atomic Weights $(A.W.)_i$ available in a sample of Apple. The value of Dielectric constant of Apple taken to be k = 70 at 25°C at frequency 10^8-10^9 Hz. (Wen-chuan Guo *et al.*, 2007). Based upon these data, the estimated values of NEP are given in table-2 which are in good agreements with the observed value of NEP given in table-1 prove the authencity of results reported for Apple.

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

The data used for N_i & $(A.W.)_i$ of an Apple 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.

Discussion:

From nutrition point of view Apple appears to be important to investigate variation in the (NEP) n/k associated with multi-electrical charges on atomic cluster N_i It has been observed that more n/k indicates more the charge transported at lower dielectrically value of ingredients of Apple and on contrary decreased value of n/k shows less charge transportation at higher value of dialectical constant. . It led to strong clues that Apple kept for long time had become more nutrient. This rheological property of apples was unfolded by the plot between n/k verses number of days of observations in figure-4. Initially falling trend on second and fourth day of n/k value showed decrease from 1.39% to 25.9% whereas on 3rd day it arose up slightly to 6.3%. But 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 with net rise of 37.6 % in NEP. Physical appearance like freshness, softness and texture as evident in photographs of Apple taken on each day as depicted in figure-3 and these observed variation might be related to varying trends in NEP. 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 Apple in subsequent part of discussion.

In table-2 displayed data represent the key role of charged mineral atoms 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 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 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 composition 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 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 & $(A.W.)_i$ given in table-2 showed the increase in mobility of atomic clusters from 4-6 times of minrals during study of an Apple from the first day of observations to the last day.

During study the freshness, softness and texture of an Apple varied strongly (see figure-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 starts to pectic acid. It does have sugar binding capacity and as a result increases softness in Apple and hence the mineral particles become free. Pectins are the major constituents of prime Pectins and are the major constituents of the primary cell wall & middle lamella, which help to give the texture and quality of an apple. Decomposition of pectin during ripening is responsible for tissue softening in several fruits. Pectins are also major source of dietary fiber 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 the moves into aging stage. (Li et al., 2016). All Apples turn colour before converting all of the yeast starch to sugar so the flavour is still the more important indicator then colour. Apples often change 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 eatable, 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 urge in market for couple of days before processing in the juice production at room temperature.

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