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Significance of physical properties of apple fruit influenced by preharvest orchard management factors

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ABSTRACT

Understanding the significance and level of variation for physical properties in apple fruit with respect to preharvest factors is important while having manual or mechanistic interaction for efficient conveyance, categorization and designing of processing equipments. In the light of previous research studies, importance of physical properties i.e. color, size, weight, density, etc. of apple fruit is elaborated and influence of selected preharvest factors i.e. variety, tree age, fruit position within tree canopy, on the properties is discussed in this study. It has been noted that the properties carry special contribution while optimizing and reforming the growing and postharvest handling procedures to ensure good quality of fresh produce at the gates of consumer market and processing unit. Further, the preharvest factors have special significance as can potentially influence the physical properties of apple fruit. The ignorance of the factors yields result in deterioration and heterogeneous quality of fresh fruit and its processed products. This necessitates the consideration and understanding of the fruit physical parameters and preharvest tree management factors while managing the orchard, postharvest handling and selection of the raw material for further processing. Moreover, the cumulative or interactive influence of the preharvest factors on post harvest quality properties of apple fruit is required to be researched and reported in the future.

Keywords: Apple, physical properties, variety, tree age, fruit position

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INTRODUCTION

Knowledge of physical properties of agricultural produce is of great value while formulating the proper standards of design for systems of harvesting, grading, conveying, processing, and packaging [1]. Level of consideration of the properties during post harvest handling and processing of fruit determines the standard of quality management practices adopted. An appropriate handling with respect to properties leads to good quality of fresh produce at consumer level and also reduces the heterogeneity of quality in the raw material for processed finished products. There could be many factors which bring qualitative variability of fruits and vegetables including the prevalent vegetative and climatic situations. However, variety, tree age and fruit position within tree canopy are the most commonly found and highly influencing factors contributing to qualitative heterogeneity of the fresh produce and processed products thereof.

Apple fruit is one of the important temperate fruits for its attractiveness, nutritional value, part of human diet, and raw material for many finished products [2]. The fruit in its fresh state has been recognized for its attractive color, unique taste and smell, enriched minerals, vitamin, and other health beneficial constituents. A greater quantity of the fruit is being consumed as in fresh state while remainder is processed for its juice contents and into its canned and dry products. Apple tree needs a cool climate as its buds exhibit long rest period and require more chilling compared to the buds of other deciduous fruit trees. Therefore it is well adapted to temperate climate and is native in many parts of the Europe and Asia [3].

In the world apple is the fourth most widely produced deciduous fruit and its fresh weight yield is around 69.60 million metric tons from more than 7500 recognized cultivars grown in 94 countries on 4.85 million hectares of land [4; 5]. However, China, USA and Iran are the leading producers of apple in the world with a worth of 10 billion US dollars [4]. In Pakistan, apple trees are grown on an area of 1,13,000 hectares present in temperate parts (hilly tracts) with a total production of 4,41,600 tones [6]. In northern areas of Pakistan especially Gilgit-Baltistan, Kashmir, Murree and Kotli Satian, apple farming serves as a primary source of income for the farming families [7].

Physical properties of fruits from different species have been studied, i.e. apricot [8], guna fruit [9], aonla [10], myrtle [11], fresh oil palm [12], strawberry [13], tomato [14], peaches, nectarines, plums [15], cider apple [16], sweet cherry [17], cactus pear [18], mango [19], orange [20], pear [21], wild plum [22], gumbo [23], wild medlar [24], orko [25], and also the apple [26]. Investigation and development in the field of selection and designing of appropriate machines are necessary for the economical and processing significance of apple with the objectives of overcoming world market and decreasing product losses.

Different cultivars may yield fruits of different physical quality and thereby leads to heterogeneous quality of processed products for the physicochemical features [5; 27; 28; 5; 29; 30; 31; 32]. This could be owing to different maturity times and physical characteristics as a consequence of different genetic makeup of varieties. Similarly, within a cultivar, fruits from different tree age groups [33, 34, 35, 36] and within a tree from different positions [35, 36, 37] exhibit varied physicochemical properties. Limited review studies for physical properties of apple fruit have been done up to now. The objective of this study is to report the previous studies on the importance and measurement of physical properties of apple to achieve a complete profile of the physical properties of apple. The physical characteristics discussed in this study specifically include length, width, thickness, unit mass, apparent and true volumes, geometric & arithmetic mean diameters, aspect ratio, surface area, sphericity, true & bulk densities, porosity, and static coefficient of friction on four frictional surfaces. Furthermore, this study is designed to elaborate the work of various scientists pertaining to the influence of selected preharvest factors i.e. variety, tree age, fruit position, on physical properties of apple fruit.

Significance and measurement of physical properties of apple fruit

Physical parameters while inherently linked with chemical properties comprise the main component of the fruit quality i.e. color, size, weight, density, packaging coefficient, etc. For the stakeholders including producers, transporters, processors, and consumers it is a relevant aspect to consider while interacting with and selecting the fresh fruit produce for respective prime objectives. Among the stakeholders that know the significance of the properties are able to already select and separate the produce into categories based on the official standards of quality without having destructive and time requiring chemical analysis of the produce.

Physical properties of fruits affect the handling/conveying features and are used to estimate the cooling and heating loads [38]. Different physical properties have different levels of significance. Fruit color indicates the type of variety and is associated with quality of the fruit while size and shape determine the maturity state and number of fruits that can be accommodated in a container or packaging of provided size. Fruits are graded into different count size categories at the time of packing. Hence, in addition to the average fruit weight, knowledge of the spread of individual fruit weights to make forecasts of the count size profile is essential [39].

Similarly, weight of a fruit denotes the yield of plant and load to be transported or conveyed while volume and surface area can be used to predict drying rates and duration in the dryer while it's processing. Frictional characteristics i.e. coefficient of friction are important, because it determines the level of resistance to hold the fruits on the conveying surface without slipping or sliding backwards. In this respect, rougher surfaces are used where fruit handling is required while smoother surfaces are adopted where faster product discharge is required. Physical properties such as size, shape, bulk density and porosity while having influence on resistance to airflow of stored mass, are of special significance while designing the hopper, drying and aeration systems [40]. In addition to specific consumer requirement regarding the physical characteristics of fruits, the consumption patterns of the produce can also be changed and more purchase options can be generated. This can be achieved by increasing the market segmentation through diversification of quality with respect to shape, color, flavor, ways of preparation, and packaging of the produce.

Difference of color among the cultivars is an important indicator of varietal identification. It makes the fruit attractive and good looking for the consumer choice [41] and is the most easily assessable parameter while determining the freshness and ripeness of the fruit within a variety. In terms of both intensity and uniformity, it is the external decisive parameter for most of the fruits. But in climacteric fruits like apple, due to suffering from post harvest physiological changes, it becomes less decisive and serves as an indicator of the degree of ripeness only. Hue and chroma describes the color intensity that changes from green to red (for red colored cultivars). Such gradual change is a good indicator of harvesting maturity in apples [42]. In apple, color of fruit skin is a blend of various quantities of chlorophyll, carotenoids and anthocyanins/flavonols. A variety of red colors are produced by cyanidin glycosides copigmented with flavonols and other compounds.

Skin color of the apple fruit is measured in various ways. The intensity of color can be measured on the cheek area of the fruit with a chroma meter or colorimeter [43]. The measuring parameter is the luminosity 'L' that varies between 0 and 100 (from black to white, respectively), together with the coordinates of color contrast 'a' & 'b'. The coordinate 'a' considers negative values for green while positive for red, whereas coordinate 'b' assumes negative values for blue and positive for yellow. The total color difference ΔE is calculated using the coordinates that provides an overall assessment of the variation in color affected when a fruit is subject to any handling or processing activity. The total color difference can be estimated using the equation Eq. 1 Table 1.

Determination of fruit mass or weight of apple is useful in the separation and transportation of the produce by any means [8]. It indicates the quantity of solid or tissue content in a fruit and can potentially determines the yield per plant or unit area, packaging and associated transportation requirements, and expected income generation from the market. Fruit yield is of prime importance to growers that grow plants for better yield and good quality production. The yield is calculated both in terms of number of fruits per plant and fruit weight per plant. The fruit weight is measured using electronic balance with 0.01g sensitivity.

The size, shape, volume, and surface area of the fruit have special significance not only due to being components of yield but they also determine the time of harvesting and acceptance of fruit by the stakeholders in the field and the market. Its importance as a decisive quality parameter has greatly been increased during the past few years due to its association with different aspects of quality i.e. flavor, texture, etc. Fruit size within a tree canopy is highly variable compared to average fruit size between the different canopies owing to varied environmental conditions. This within tree variation is triggered by the type of the canopy architectural components, fruit position and the interaction with other neighboring structures. These are the plant factors that can potentially influence the process of fruit growth and development [44; 45]. Understanding the within-tree variability of fruit quality will facilitate developing efficient estimates of average fruit size for a tree and at higher levels. The consumer's choice for large fruit creates the big variability of price between larger and smaller fruit sizes. The income from smaller fruit is usually lower compared to the costs incurred on picking and handling of the fruit [46]. Volume of a fruit is measured by the water displacement method. The axial dimensions, namely, length L (longest diameter), thickness T (shorter diameter), and width W are measured using a vernier caliper (Figure 1).

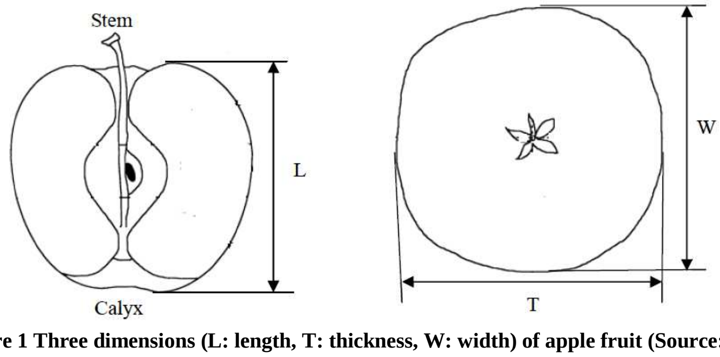

Figure 1 Three dimensions (L: length, T: thickness, W: width) of apple fruit (Source: [29])

The importance of knowing dimensions of apple fruit is useful for determining the aperture size in the machines particularly when the separation is required. The dimensions are also useful in computing the size of the machine components and spacing required for slicing discs and number of slices to be produced from an average fruit. Fruit shape is determined using the dimensions and is a useful indicator for description of cultivars for its plant variety rights and evaluation of consumer preference [53]. Size of the fruit is measured either using the length or breadth that varies significantly among the cultivars. Knowing the shape and physical dimensions enables the screening of solids to separate foreign materials while sorting and sizing the fruits and can be computed using the Equation 2 to 11, Table 1.

Table 1 Measuring indices for physical attributes of apple fruit

Eq. No.	Equation	Description	Reference
1	$\Delta E = \sqrt{(L_o - L)^2 + (a_o - a)^2 + (b_o - b)^2}$	ΔE: total color difference, L: luminosity, a & b: coordinates	[43]
2	$Da = \frac{L + W + T}{3}$	D_a: arithmetic mean diameter, L: length, W: width, T: Thickness	[47]; [48]
3	$Dg = \sqrt[3]{(L \times W.T)}$	Dg: geometrical mean diameter, L: length, W: width, T: Thickness	[49]; [20]
4	$BD = \frac{M_C}{V_C}$	BD: apparent specific density (g/cm^3), Mc: carton mass (g), Vc: carton volume (cm^3)	[49]; [20]; [18]
5	$SD = \frac{M}{V}$	SD: solid density (g/cm^3), M: fruit mass (g), V: fruit volume (cm^3)	[49]; [18]
6	$P = \frac{V_C - V_O}{3} \times 100$	P: porosity, Vo: volume of the apples present in the carton (cm^3)	[40]; [49]
7	$\varphi = \frac{D_g}{L} \times 100$	φ: sphericity, Dg: mean geometrical diameter, L: longest diameter of the fruit	[49]; [50]; [23]; [11]; [24]; [17]; [18]
8	$S = \pi(Dg)^2$	S: surface area, Dg: mean geometrical diameter	[20]
9	$\lambda = \frac{V_O}{V_C}$	Vo: volume of fruit present in the carton, Vc: volume of carton	[20]
10	$Ra = \frac{L}{W}$	R_a: aspect ratio, L: length, W: width	[51]
11	$\mu_s = tan\theta$	μ_s: coefficient of friction, θ: tilt angle of the friction device	[52]

Data regarding geometric mean diameter of fruit is useful while designing the grading process. Variation in geometric mean diameter of apricot fruit has been noted [54]. Sphericity of fruit describes its shape relative to the shape of a sphere of the same volume. Whereas, aspect ratio is the relationship of fruit width to its length and indicates its tendency towards being oblong in shape during its handling and processing [51]. Projected area of apple fruit is useful for accurate modeling of heat and mass transfer during the cooling and drying process and should be considered during harvesting, handling and processing of the produce.

Preharvest factors influencing physical properties of apple fruit

Physical properties of apple fruit are greatly influenced by a few preharvest tree management factors including variety, tree age and fruit position on the tree. Inherent characteristics of different varieties yield fruit of varied quality. Similarly, within a variety a growing tree gradually increases its canopy volume and architecture that potentially influences the sunlight penetration, its interception by the leaves, carbohydrate assimilation rate and its transmission to fruits, and consequently fruit growth and development. Moreover, as tree age determines the size of canopy thereby decides the fruit load and individual fruit size (Figure 2). A summary of previous studies indicating the significant influence the preharvest factors on physical properties of apple fruit are mentioned in the Table 2.

Table 2 Influence of preharvest tree management factors on physical attributes of apple fruit

Factor affecting	Fruit physical attribute influenced	Observed by
Variety	Length, width, thickness, the geometric, arithmetic and equivalent mean diameter, projected area, surface area, sphericity index, aspect ratio, mass, volume, true density	[5]
	Shape ,size ,color	[55]
	Firmness, crispness, juiciness, mealiness, stiffness	[31]
	Weight loss, firmness and density	[56]
	Color, taste, fruit size, fruit weight, fruit yield	[7]
Tree age	Fruit size	[35]
	Fruit length ,fruit weight ,fruit number	[57]
Fruit position	Size, skin color, yield	[37]
	Fruit color , fruit size	[58]
	Fruit color	[59]

Variety

In apples, even within a variety, fruits which are redder often taste better compared to the greener ones owing to their higher sugar and flavoring contents [60]. Bicolored cultivars of apple are more popular than the traditional cultivars [61]. The success of red and bicolored fruits is recognized by their visual appearance, better taste and flavor [62]. When unpeeled fruits are tasted, the red apples cultivars are generally have sweet descriptors while green apple cultivars have acidic, sour or grassy descriptors [63]. In contrast, when peeled fruits are tasted it has been noted that red cultivar is described as sour tasting while the green cultivar is described as sweet. Ozturk [64] reported that since non-red apples, such as Granny Smith and Golden Delicious, accumulate quercetin glycosides and catechin/epicatechin, the color production in red apples is likely to involve the induction of enzymes between leucocyanidin and cyanidin glycosides [65, 66]. Eren *et al.* [67] noted the L, a and b values of Starking Delicious apple cultivar grown in Mediterranean area of Turkey as 46.60%, 23.06% and 17.45%, respectively.

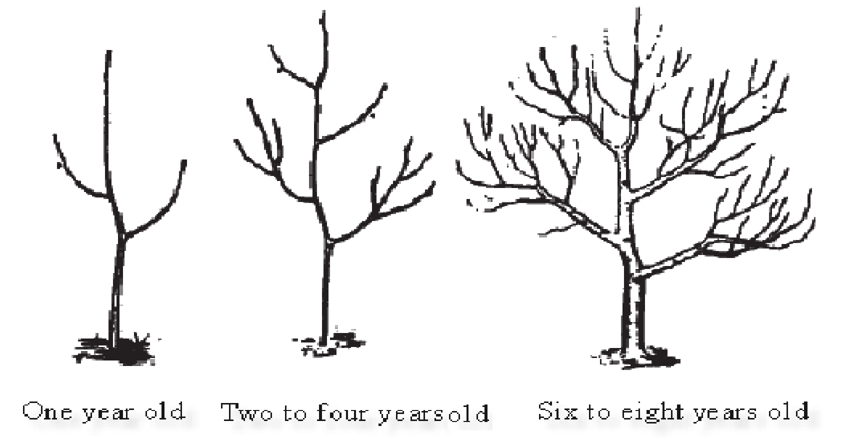

Figure 2 Apple tree age stages

Fruit load and the genetic biological carrying capacity of each cultivar define the potential for fruit size development in apple. But this potential is attenuated by the environment within which the fruit grow and the effect of associated factors including light and temperature. Average weight per fruit and tree and size per fruit vary among the cultivars for apple. Average weight of per fruit of Starking Delicious was found significantly higher among all the nine cultivars i.e. Sky Spur, Nugget, Red Chief, Red Golden, Kandhari, Ida Red, Sparton, and Golden Russet [64]. But in the same study, Sky Spur surpassed all the other apple cultivars for average fruit weight per plant. Whereas, minimum fruit weight per plant was noted in Golden Russet. Regarding fruit size, Starking Delicious, Red Chief and Nugget obtained significantly higher fruit size followed by Sky Spur and the lowest by the rest cultivars.

Kheiralipour *et al*. [5] studied the several physical properties i.e. length, width, thickness, the geometric and arithmetic mean diameter, projected area, surface area, sphericity index, aspect ratio, fruit mass, volume, density, coefficient of static friction, of two apple varieties (Redspar and Delbarstival) and found significant difference between the varieties. In contrast, Gorji Chakespari *et al*. [29] found none significant difference for aspect ratio among the same apple varieties. Ozturk *et al*. [64] studied several physical properties (fruit mass, fruit density, dynamic coefficient of friction, color intensity, projected area, surface area, sphericity) of three early maturated apple cultivars (Vista Bella, Summerred and Jerseymac), grown in same orchard in Northeast part of Turkey, and reported important statistical differences among the cultivars for most of the physical properties.

Javaid *et al*. [7] observed that apple cultivars i.e. Sky Spur, Red Chief, Sparton, Ida Red, Starking Delicious, Kandhari, Red Golden, Nugget and Golden Russet performed significantly different for the number of fruits per plant, fruit weight per plant & total soluble solids. Physical properties including firmness, stiffness and energy-to-rupture in two cultivars of apple i.e. LeM Braeburn, Cripps Pink were studied by Vanolia *et al*. [31] and values of the properties were found significantly higher in former compared to the later cultivar. Fruit geometrical parameters i.e. length, surface area, of apple varieties namely Atirli, Kapak, Kowse, and Paiez, were studied by Jalali *et al*. [32] and significant differences among the cultivars were observed.

Tree age

Fruit tree age influences the yield and physical characteristics of fruit owing to gradual change in the efficiency of a natural biological system. Significant variations for fruit yield per plant have been noted by Volz et al. [35] on branches of apple trees with different ages (1 year old & 2 years old) within each of the three cultivars i.e. Braceburn, Golden Delicious, Granny Smith. Tree age may or may not influence the fruit size within the cultivar. Denne [68] noted the absence of any relationship between fruit size and tree age, but Khalid et al. [57] explored the effects of tree age (3, 6, 18 and 35 years) on rind and fruit quality of 'Kinnow' mandarin. Rind thickness, percentage of rind mass and rag mass, ascorbic acid, pH, non reducing sugars, rind manganese, and iron contents were significantly higher in young trees compared to the older ones. Treder *et al.* [34] studied the fruit thinning effect for four successive years on 'Gala' apple trees. Trees were 5 years old when the experiment started and three thinning treatments were performed with the assumption that apples at harvest should be medium sized (8 fruits per kg), large

(7 fruits per kg), or very large (6 fruits per kg). It was concluded that with tree aging fruit load must be decreased to assure the same mean fruit weight.

Volz *et al*. [35] studied the influence of wood age of the tree canopy on fruit mineral content and quality for several apple cultivars. Size and Ca, Mg and K content of individual fruit on one-year (lateral and terminal positions), two-year and older than three-year wood were compared for the four cultivars i.e. Royal Gala, Braeburn, Granny Smith and Fuji. Fruit on two-year spurs and one-year terminals was generally larger at commercial harvest than that on one-year laterals and spurs older than three years. Terminal fruit with total spur leaf areas and fruit size were similar to those on two-year spur fruit with higher Ca content. Asrey *et al*. [36] studied the fruit of Guava cultivar Allahabad Safed for its physico-chemical properties in relation to tree age and found that fruits from upper canopy of 15-year-old trees had higher TSS, total sugars and lowest acidity. Percent seed content (weight basis) of the fresh fruits decreased with the advancement of tree age and found lowest in the 20 years old plants. Respiration rate did not show any definite pattern in relation to plant age in the same study.

Fruit position

Under preharvest situations, fruits exposed to varied climatic factors due to their position within the tree canopy. Light and temperature are the two major varied influencing factors in this regard. Fruits developing inside the canopy experience lower light and temperature situations compared to outer canopy fruit. In a 'Granny Smith' apple variety grown in an orchard with a tree height of 3 m and canopy width of 2.5 m, it was noted that inner canopy fruits received only 2% of full incident sun light compared to 10% in the middle and 54% in the outer canopy on an average during the fruiting season [69]. Similarly, peel temperatures of outer canopy fruits on the northern side of the rows were exceeded the air temperatures by 5 ºC on average while fruit from the inner canopy did not differ from the air temperature.

The appearance of apple fruit is generally varied with the concentrations and distribution of the pigments i.e. chlorophylls, carotenoids, anthocyanins. A combined influence of high light situations and cool temperatures has been noted to increase the anthocyanin contents in apple fruits [60]. Although light has a significant role in the chlorophyll synthesis at the beginning of fruit development [70] but during fruit maturation, its synthesis decreases and even its degradation due to exposure of carotenoids [71]. The fruits inside the canopy experiencing intense shade situations are always lighter in green color owing to having lower chlorophyll contents (Figure 3) [69].

Figure 3 Effect of canopy position on skin color of apple fruit

Fruit dry matter or weight of apple is significantly higher in fruits located outside the canopy compared to the one located inside the canopy [72]. The effects of position of bearing on overall fruit quality especially the significant effect on size, maturity, skin color, flesh color, and yield of fruit was summarized by Pandey *et al.* [37]. Similarly, Volz *et al.* [35] reported the influence of position of fruiting and leaf area within the tree canopy on fruit mineral content and quality for several apple cultivars. In this study size of the individual fruit located on lateral and terminal positions of apple tree cultivars i.e. Royal Gala, Braeburn, Granny Smith and Fuji was compared and noted the larger fruit size on terminals than that on laterals branches. Asrey *et al.* [36] studied a guava cultivar (Allahabad Safed) and compared the fruits harvested from upper, middle and lower canopies at light green stage for a few physical properties. It was noted that upper canopy fruits indicated the higher specific gravity and early maturity compared to the fruits from middle and lower canopies in all the age group trees.

Cumulative influence of three preharvest apple tree management factors: variety, fruit position, tree age, on physical properties of apple fruit is evident with the progression of tree age. A specific genotype has a unique pattern of growth and development as reflected by its way of dry matter accumulation, source sink relationship and distribution of assimilates to the fruits within the tree [73; 74; 75]. This specificity differentiates it from the rest of the genotypes for the extent of the tree branches and formation of the canopy with the time. Having linked with tree age, increase in canopy volume, its architecture and microclimate goes on altering and influencing the physics of apple fruits at different positions within the tree.

CONCLUSION

This discussion with the support of results from previous studies indicates the importance of physical properties of apple fruit while it is harvested, conveyed and processed to avoid any physical damage associated with physiological deterioration. Moreover, observed significant influence of preharvest factors especially variety, tree age and fruit position on the tree necessitates the appropriate orchard management, grading and processing operations to ensure uniform quality of fresh produce and processed products. The study also suggests the research on preharvest factors including variety, tree age and fruit position for their individual and accumulative influence on physical properties of apple fruit.

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