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**MATURITY INDICES OF TROPICAL  
AND SUB-TROPICAL FRUIT CROPS****Tanmoy Sarkar<sup>1</sup> and Arghya Mani<sup>2</sup>***<sup>1</sup>Department of Fruit Science, BCKV, Mohanpur, India**<sup>2</sup>Department of Post-Harvest Technology, BCKV, Mohanpur, India**tsarkarbckv@gmail.com*

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**ABSTRACT**

Maturity is one of the most important processes in fruits, which involve changes in flavour, colour and texture, and thereby making them most acceptable for edible purposes. Such obvious changes generally occur in a coordinated fashion. An understanding of these changes during ripening is of prime importance in checking post harvest losses for developing technologies in enhancing the shelf life of fruits.

Key words: climacteric, fruits, maturity, non-climacteric, sub-tropical, tropical,

**1. Introduction**

Fruit quality is a composite of many components including attributes, properties and characteristics that give the fruit its value. These quality components may differ depending upon the fruit/vegetable and its intended use, producers, handlers and consumers. For instance, fruit quality parameters will differ depending on whether it is to be used for fresh consumption or for processing. Farmers are more likely inclined towards high yields, good appearance and tolerance to long distance transport. Marketers are likely to consider appearance, firmness and shelf life while consumers consider appearance, firmness, flavor and nutritional value of the fruits they purchase.

Most postharvest technologists consider for maturity that the definition should be “that stage at which a commodity has reached a sufficient stage of development that after harvesting and postharvest handling (including ripening, where required), its quality will be at least the minimum acceptable to the ultimate consumer.” Maturity at the time of harvest is the most important factor that determines post harvest life and final quality of the produce. Harvesting should be done when the produce is at a stage that will allow it to be at its peak quality (including sensory attributes) when it reaches consumer, at the same time it must also be not toxic and have an adequate shelf life. The maturity has been divided into two categories i.e. physiological maturity and horticultural maturity. Physiological maturity means that stage at which a commodity has reached a sufficient stage of development that after harvesting & postharvest handling (including ripening, where required), its quality will be at least the minimum acceptable to the consumer. Horticultural maturity is that stage of development when a plant or plant part possesses the prerequisites for utilization by consumers for a particular purpose or market requirement. Matured fruits are having completed natural growth and development. They are categorized by two on the basis of ethylene production at the stage of maturity i.e. climacteric and non-climacteric fruit. The climacteric is a stage of fruit ripening associated with increased ethylene production and respiration, whereas non-climacteric fruit is lack of ethylene –associated respiratory peak at ripening.

#### **List of climacteric and non-climacteric fruits**

<b>Climacteric fruit</b>		<b>Non-climacteric fruit</b>	
<b>Name</b>	<b>Scientific Name</b>	<b>Name</b>	<b>Scientific Name</b>
Avocado	<i>Persia americana</i> Mill	Citrus	<i>Citrus spp.</i>
Apple	<i>Malus X domestica</i> Borkh	Grape	<i>Vitis vinifera</i> L.
Banana	<i>Musa spp.</i>	Litchi	<i>Litchi sinensis</i> Sonn.
Mango	<i>Mangifera indica</i> L.	Strawberry	<i>Fragaria spp.</i>
Papaya	<i>Carica papaya</i> L.	Pomegranate	<i>Punica granatum</i> L.
Pear	<i>Pyrus communis</i> L.	Raspberry	<i>Rubus idaeus</i> L.
Kiwi	<i>Actinidia deliciosa</i>	Loquat	<i>Eriobotrya japonica</i>
Apricot	<i>Prunus Americana</i> L.	Ber	<i>Ziziphus mauritiana</i> Lam
Fig	<i>Ficus carica</i> L.	Jamun	<i>Syzygium cuminii</i> L

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Custard apple	<i>Annona spp.</i>	Pineapple	<i>Annanas comosus L</i>
Guava	<i>Psidium guajava L.</i>	Cherry	<i>Prunus avium</i>
Sapota	<i>Manilkara zapota L.</i>	Phalsa	<i>Grewia subinaequalis</i> DC.

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### 1.1. Importance of maturity indices

- i) It is important to know the stage of development when a commodity is of optimum quality in order to know when to harvest the crop.
- ii) Ensure sensory and nutritional quality of harvested produce.
- iii) Ensure post harvest shelf life of produce
- iv) Facilitate marketing operations and scheduling
- v) Facilitate of produce fresh to the consumer and good market availability.
- vi) Reduce postharvest losses

### 1.2. Maturity Index

This involves to determination of the stage of maturation of fruit availability to consumer and for market place. Physical, physiological, biochemical and Chronological indices are used to establish the maturity of fruits. There is several ways to assure the maturity of fruit like,

- i) Visual effect i.e. changes of skin color, size, shape and texture etc.
- ii) Physical method i.e., Fruit retention strength, firmness, specific gravity etc.
- iii) Chemical measurement i.e. Total soluble solid (TSS), Acidity, Sugar content, starch content etc.
- iv) Physiological method i.e. Respiration rate and ethylene evolution rate.
- v) Days from flowering to fruit set.

#### 1.2.1. Maturity indices of tropical fruit crops

##### A. Mango

Mango is a climacteric fruit. Harvesting of mango fruit at proper stage of maturity is of fundamental importance. The effect fruit quality and storage life depends upon the maturity stage of fruit crop<sup>[1]</sup>. The fruits are usually harvested when,

- i) The fruit increase in size, weight and skin color as it grows are regularly used to assess harvest maturity. Some fruits bear colored pigments on the skin (Alphonso, Kesar, Pusa Arunima, Arka Puneet, Ambika) and flavor comes from the fruit<sup>[2]</sup>. Different varieties and maturity stages may have different skin and flesh color. Kent has a skin color of green-yellow and a deep yellow flesh, Tommy Atkins has a skin color of yellow to orange and a yellow to deep yellow flesh while Vandyke has a skin color of bright yellow ground color and orange yellow color flesh<sup>[3]</sup>.
- ii) Few ripe fruits have fallen from the tree, also called as 'Tapka'. The rest of the fruits are considered as sufficiently mature.
- iii) The days of fruit maturity from flowering depends upon the variety to variety. Generally it takes about 90-110 days to mature. Whereas, Bombay Green variety mature at 90-100 days after full bloom (DAFS), Amrapali (130-140 DAFS), 135 DAFS in Fazli and Langra mature at 120 days after full bloom<sup>[4]</sup>. Specific gravity is scientific maturity index for mango. The specific gravity of most of the mango fruits reaches between 1.01 and 1.02; it indicates that fruits are ready for harvesting<sup>[5]</sup>.
- iv) Fruit has good total soluble solids (TSS); less total acidity and pH content indicate maturity of fruit. Arumanis mango is best for consumption when the TSS content of the fruit is not less than 16.8 °Brix, total acidity 0.18%, pH 4.8<sup>[6]</sup>.

### ***Harvesting***

As the mango trees grow tall, harvesting of fruits becomes difficult and time consuming. Climbing thin branches becomes risky, as the wood is brittle. Therefore use of a traditional harvesting stick is advisable. The harvesting stick is prepared by tying two iron or bamboo hooks 5-6 cm long at the tip of a straight, long bamboo. A net made of jute or coir rope, attached to an iron ring of 30-40 cm diameter, is tied to the bamboo, around the hook. Mangoes can be harvested by placing them in the net and then pulling the stem through the hook. The harvested fruits remain in the net without any damage.

### **B. Banana**

Optimum maturity stage of banana fruits reduced the postharvest losses and extended the storage life of fruits. The stage of maturation at which the fruit is harvested greatly influences the green-life or storage

longevity and eating quality. Every fruit attains its full characteristics e.g. flavour, taste and colour during storage if it is picked at optimum time. Depending on season and cultivar, bananas become matured at 90-120 days after appearing of first flower<sup>[7]</sup>. Poovan, Manthan, Rasthali and Dwarf Cavendish are ready for harvest in 11-12 months after date of planting. Grande Naine' and 'Williams' may be harvested from 22 and 24 weeks<sup>[8]</sup>. The fruits are harvested when top leaves start drying. The color of the fruit changes from deep green to light green. The ridges on the skin surface of the skin change from angular to round i.e. attainment of 3/4<sup>th</sup> full stage.

### ***Harvesting***

Banana is harvest throughout the year with no intervals between harvests. The selection of bunches to be cut is made by virtue of visual assessment when those with the fullest fruit (the more rounded) are taken. A more yellowish internal appearance indicates that the fruit is at the ideal moment to be harvested. Harvesting is carried out by only one person, partly by cutting the pseudo-stem with a machete, and lowering the bunch down slowly. Once harvested, the fruit is manually transported to a location where it is collected by truck.

### **C. Papaya**

Papaya is categorized as one of climacteric fruits<sup>[9]</sup> with the ability to continue ripened off the tree when harvested at the suitable maturity stage. Papaya trends to set too many fruits. Such crowded fruit do not get proper space resulting poor development of fruit and quality. Thinning of fruits while they are small, so, the remaining fruits develop proper size and quality. Papaya fruit set within 8-10 months of their planting. It also varies by variety and season.

In north India, fruits ripen during spring and summer while in hills, it is restricted 3-4 months from February to May because it requires warm climate during ripening. For papaya, its ripening had been commercially described by its skin color, pulp firmness and soluble solids. Change of surface color of fruit with the maturity can be used as a parameter to measure the ripeness. Often, unripe fruits show greenish surface color which changes to yellowish color when they ripen gradually. The instruments that widely used to measure skin color of the fruits are colorimeter<sup>[10]</sup>. The development of colorimeter is to overcome optical illusion because color may appear differently to different individuals. However, local farmers still sort the fruits traditionally by using visual inspection when the fruit has turned greenish yellow color.

High humidity and comparatively high temperature during ripening period may not be conducive to development of attractive color in fruits which may remain pale green even on ripe. The fruit considered ready for harvesting when the latex of fruit become almost watery.

#### **D. Pineapple**

Pineapple is one of the most popular tropical fruits for consumption around the globe. The maturity of pineapple can be determined based on the change of color of the skin of the fruit. Pineapple can be said to be mature when there is skin color change at the base of the fruit from green to yellow as mentioned by Rosnah et al.<sup>[11]</sup>. Pineapples are considered ripe and at their best eating quality when the fruit surface colour is the one quarter to one-half yellow. If the fruit is not harvested until the full-yellow stage it will have a flatter, less desirable taste due to excess sugar content and decreased acidity. Pineapples for the domestic markets should be harvested close to full ripeness, when external surface colour is one-half yellow. Fruit intended for the export market should be picked slightly sooner, at the quarter-yellow colour stage.

##### ***Fruitlet Flatness***

The pineapple is a compound fruit comprised of numerous individual fruitlets. The fruitlets mature progressively from the bottom part of the fruit to the top. As the fruitlets mature, they become flatter. The extent of fruitlet flatness is usually a good indicator of overall fruit maturity. A pineapple is typically mature and ready for harvest when the lower one-quarter to one-half of the fruitlets are flat<sup>[12]</sup>.

##### ***Internal Appearance***

Random fruit samples should be sliced horizontally at the point of the largest width. Immature pineapple fruit have appear with white flesh colour, and are slightly clear in appearance while mature or ripe fruit have yellowish-white flesh. Fruit are over-mature when more than half of the cross sectional area of the fruit is transparent.

##### ***Shape, Size and Biochemical indicators***

Fruit at maturity stage should be gained its full size and uniform shape, and firmness. Fruit weight is varied depend on the varieties and ripening stage. The minimum soluble solids content should be 12-14%, specific gravity should be 0.98-1.02% and maximum acidity should be 1% will assure minimum flavor acceptability by most consumers.

### **Harvesting**

Harvesting is done with a sharp knife, severing the fruit stalk with a clean cut retaining 5-7 cm of stalk with the fruit in such a way that the fruit is not damaged.

### **E. Guava**

Guava is an important fruit crop grown under tropical and sub-tropical regions of the world. Because of its better adaptability and rich nutritional value, guava is eulogized as ‘the apple of tropics’. In guava, two distinct seasons of flowering, spring (March-April) and rains (August-September) occur from which fruits ripen during rainy and winter season respectively. Guava tree blooms approximately 2 months after pruning and fruit can be harvested from 3 to 4 months after blooming, depending on the season of the year. The harvest time is an important factor related to post-harvest losses of fruits<sup>[13]</sup>. Guava is climacteric fruit and should be picked when it is mature but firm. For guavas, the harvest time is based in subjective evaluations as fruit size, skin colour and hand firmness, which may vary for the same location according to the cultivar, time of the year, plant age and management procedures. Guava fruit generally takes about 17-20 weeks from fruit set to reach maturity. Fruits are generally harvested when the pulp is still firm and the skin colour starts changing from dark to light green or to a yellowish colour. Changes in colour are the most apparent external symptoms of ripening in guava<sup>[14]</sup>.

### **Harvesting**

Individual fruits are picked when they are still hard and firm at regular intervals. Guava fruit must be harvested with great care because of their soft, thin skin. Harvesting normally carried out by hand to avoid physical injuries.

### **F. Sapota**

Sapota is a climacteric fruit, it ripens properly and improves in its quality after harvesting. The maturity stage of sapota at harvest is very difficult because no external color has changes during fruit development and ripening processes. The erratic flowering habit and the presence of fruits at all stages of development on the tree make it difficult to determine optimum harvest time. A non destructive technique using the “Kiwifirm” device (Plant and Food Research, New Zealand) has been shown to be useful in identifying the maturity stage of sapota fruit<sup>[15]</sup>. An in built processor records the resulting collision, analyzes the waveform, and



displays a value on a digital display. This could be applied to predict which fruit are going to ripen during storage and to reduce inconsistent ripening within a batch <sup>[15]</sup>.

Phenol and sugar content increased with development of fruit while acidity and ascorbic acid reduced. Sugar concentration ranges from 12 to 14%. Flavor quality depends on the soluble solids content (13-26%) and acidity (0.2-0.3%) <sup>[16]</sup>. Total soluble solids (TSS) increase during ripening.

Sapota mature 8-10 months after fruit set. The fruit shed off brown scaly external material and become smooth when reaching physiological maturity. Fruit ready for harvest will not show a green tissue or latex when scratched with finger nails. Fully mature fruit will have a brown skin, and fruit will separate easily from the stem without leaking latex. At the time of maturity, dried stigma at the end of fruit drop easily, fruit has a smooth surface, shining potato color and rounded styler end is considered mature <sup>[17]</sup>.

### ***Harvesting***

Harvesting of fruits has been done by ladder and baskets and the peduncle is cut with a knife or scissors. Selection can be based on size and maturity of the fruits. Any fruit presenting deterioration or mechanical injury are discarded <sup>[18]</sup>.

### **G. Custard apple**

Custard apple fruits are climacteric in nature, therefore they are harvested when they are mature, firm and plumpy and turn light green on maturity fruit. Custard apple matures during October-November/December in dry region, whereas in humid areas harvesting is done during August. The inter aereolar space widens the fruits turn creamy white, the skin between the segments or tubercles turn into light yellow colour.

### ***Harvesting***

For transporting over distant market, the fruits are to be picked before full ripening and are packed in single layer, well ventilated wooden boxes with soft cushioning material. A good bearing tree gives about 100-150 fruits i.e., about 8-10 tonnes/ha. The fruits are highly perishable and cannot be stored for long duration. It can be stored in good condition up to 7 days by treating them with 8% wax emulsion.

### **H. Jackfruit**

Jackfruit is climacteric fruit, so it harvest when mature. Fruits

require 3-8 months to develop from flower emergence to full maturity <sup>[19]</sup>. There are different indicators to identify fully mature fruits- 1) The skin colour turns from light green to yellowish. 2) The spines grow further apart and flatten slightly. 3) The skin yields slightly to pressure 4). The last leaf on the stalk turns yellow. 5) The fruit produces a dull, hollow sound when tapped with hand. After harvesting a mature fruit, it ripens in 3-7 days and begins to emit a strong jackfruit odor.

### ***Harvesting***

It is always best to harvest and handle fruits with care to prevent mechanical injuries while harvesting, one person on the ground will keep on moving the sacks around the tree, while the person on the tree will drop the fruits on the sacks. For harvesting fruits on high branches it is advisable to lower the fruit on a rope or collect in a sack or basket and then lowered slowly to the ground. Harvesting of ripe fruits between mid morning and late afternoon can help reduce latex flow <sup>[19]</sup>.

### **I. Mangosteen**

Mangosteen is one of the most praised fruits regarded as 'Queen of tropical fruits'. Mangosteen bear fruit at 7 years of age. The time of fruiting is August-October. Fruits are harvested when color starts changing from green to purple. Fruits are picked with peduncle when slightly soft and color change. Ripe fruit falling from tree can be collected and used.

### ***Harvesting***

As mangosteen tree grow very tall, long bamboo poles or steel ladders are helpful in harvesting. The yield varies from 500-1500 fruits depending on development of the tree and climate.

### **J. Persimmon**

The persimmon fruit is a berry resembling a tomato in shape and size, but the seeds are large, almond shaped and few in number in older cultivars and absent in newer cultivars. Persimmon fruits are categorized as climacteric fruit, which means they are very sensitive to exogenous ethylene exposure and are induced to ripen with autocatalytic ethylene production by exposure to exogenous ethylene <sup>[20,21]</sup>. The external skin colour of this fruit is the index currently used as the nondestructive index for harvesting persimmons. The colour evolution displayed by persimmon cultivars comes from immature fruit that has a homogenous green skin to fruit with its characteristic orange or orange-reddish tones in the commercial maturity stage<sup>[22]</sup>. Persimmon cultivars can be classified into two general

categories, non-astringent and astringent at harvest, depending on the concentration of the soluble tannins present in fruit flesh. Although the fruits of both groups are very astringent when small and immature, the former lose astringency while they grow on trees <sup>[21]</sup>. During growth and ripening, non-astringent cultivars show fewer soluble tannins at levels that are sensorially non-detectable, even before fruit colour breaking, while the fruits of astringent cultivars maintain a high content of soluble tannins, even when fully coloured. Values of soluble tannins that come close to 0.03% have been reported in non-astringent 'Jiro' and 'Harbiye' persimmons <sup>[23]</sup>, while astringent cultivars such as 'Hiratanenashi', 'Rojo Brillante' or 'Tipo' have presented a content of soluble tannins of 0.5-1% <sup>[22,24]</sup>. Therefore, it is necessary to apply postharvest treatments to remove astringency prior to commercializing cultivars that are astringent at harvest.

### ***Harvesting***

Harvesting persimmons is to clip fruits from trees with small secateurs, and to leave the calyx and a short stem attached to fruits. It is possible to snap fruits from trees, but this requires skill and increases its susceptibility to injury and subsequent decays. Generally, two to three picks are required depending on the cultivar and seasonal conditions.

### **K. Carambola**

The fruit changes its color from the green mature stage when it is firm and green in color to half-ripe when although its waxy in texture is still firm but color changes to yellowish green to finally leading to the ripe stage when the fruit possesses a soft texture and its color turns to a total yellow. The pH of the fruit increases with the advance in maturity and ripe fruits are significantly less acidic (pH-3.44) than green mature (pH-2.40) and half-ripe (pH-2.71) fruits <sup>[25]</sup>.

### ***Harvesting***

The star fruit are usually harvested by hand from the tree or shaken down by a machine. They are harvested when the fruit becomes a yellowish-green color. It is preferred to harvest in the morning when the temperatures are cool. With preferred weather conditions trees can produce 45 kg up to 136 kg pounds of fruit in a year.

#### **1.2.2. Maturity indices of Subtropical fruits**

### **L. Citrus**

The citrus fruit crop is represented by different species and varieties

that display unique aesthetic, organoleptic and nutritional characteristics. However, fruits of the different varieties share common mechanisms and many biochemical pathways during growth, development and ripening, that are critical factors for determining the maturation indexes and harvest time for each variety. Harvest time determination is challenging and dependent on citrus growing areas and market requirements.

#### *Maturity Signs of Mandarin and Sweet Orange*

- i) Fruit mature in about 210 to 240 days.
- ii) Color changes from green to pale green or yellow or orange.
- iii) Outer rind looks shiny and one can see oil glands on the fruit.
- iv) Mandarin 0.4% acidity and 12-14% TSS. Orange 0.3% acidity and 12% TSS.
- v) Fruits become soft.

#### *Maturity Signs of Lemon*

- i) In India, a ripening period of 165 to 195 days with more than 50% juice content and a total acidity of 9%, are considered as good indicators of a mature fruit.

#### *Maturity Signs of Grapefruit*

Grapefruit maturity standards vary with the growing regions and among red, pink and white varieties. The yellow color should be present in two-thirds of the fruit surface with a minimum TSS of 6–7 ° Brix and a ratio around 5.5–6.

**Table 1. Variations in the main maturity indices required for fruits of the more important commercial citrus varieties**

Citrus species	TSS (%)	Minimum Acidity	TSS: Acid ratio	Juice (%)	Surface coloration
<b>ORANGES</b>	8	0.4-0.7	8-10	>33	>4/5
Naval oranges			8-8.5	>33	
Blood oranges			7	>30	
others				>35	
<b>MANDARINS</b>	>8.5	0.3-0.5	6.5-7.5		>1/3
Satsumas			6.5	>33	
Clementines			7	>40	

Hybrids/others	7.5		
<b>LEMONS</b>		>20	
<b>GRAPEFRUITS</b>	5.5-7	>35	>2/3

Sources: Based on EU [24,25\*\*], California [26] standards

### **Harvesting**

In India the fruit picker collect the fruits manually by climbing on a ladder when the tree is tall, with a collecting bag on his shoulders. In U.S.A mechanical harvesting is done particularly for processing industry.

### **M. Ber**

The ber is a hardy fruit tree and is well known for its ability to thrive under adverse conditions of salinity, drought and water logging. It is often called the poor man's fruit [29]. The time required for ber fruit to develop from fruit set to maturity is dependent on cultivar and location. The fruit skin color is one of the most reliable maturity indices. Fruits are harvested at the mature golden-yellow stage in 'Umran' [30] and 'Kaithli' [31], and at the mature green stage in 'Mallasey' and 'Bambawi' [32].

The ratio of sucrose, glucose, and fructose should be 3:1:1 at maturity time of ber [33] (**Bal 1981a**), while biochemical characters like TSS, acidity, and ascorbic acid content vary between 12-21%, 0.13-1.42%, and 39-166 mg per 100 g, respectively, on the basis of fresh weight of fruit in different cultivars and regions. Fresh ber fruits can be processed into a number of desirable products for utilization during the off season. The ber products like sun dried and dehydrated fruits, candy and preserve, canning in sugar syrup and fruit pulp and squash can be prepared. The fruits of 'Sanaur 2' harvested at early stage are dried best in a mechanical drier at  $60 \pm 2^\circ\text{C}$  for 31 h for making Chhuharas [34].

### **Harvesting**

The peak harvesting season of ber in North India is mid March to mid April but some early cultivars may ripen by end February. In South India, the fruits are ready for harvest in October to November. The harvesting season of ber fruit in Gujarat is December to March and in Rajasthan it is January to March. Normally four to five pickings have to be made in the fruiting season to harvest the total fruits on the tree.

### **N. Fig**

Figs (*Ficus carica*) are among the earliest cultivated fruit trees in

the world <sup>[35]</sup>. The large number of consumers unaware of figs, combined with positive consumer perception, indicates there is potential for development of a fresh fig market. Fresh market figs must be harvested when almost fully ripe and firm to be of good eating quality. Skin color and flesh firmness are dependable maturity and ripeness indices. 'Black Mission' figs should be light to dark purple rather than black and should yield to slight pressure. 'Calimyrna' figs should be yellowish-white to light yellow and firm. Figs for drying should fully ripen and partially dry on the tree before harvesting and completion of drying to about 17% moisture using either solar drying or a dehydrator at 60°C (140°F).

### **O. Litchi**

As a non-climacteric fruit, litchi does not improve in quality after harvest, but has to ripen on the tree <sup>[36]</sup>. Appropriate physiological maturity at harvest is crucial for proper quality and shelf-life. In practice, growers' decisions often rely on individual experience in terms of size, pericarp structure, colour, flavor, and taste of the fruit as well as a characteristic time after anthesis <sup>[37,38]</sup>. Litchi fruit maturation occurs during the last part of fruit development. For local markets, litchi is ideally harvested when fully red and ripe <sup>[39]</sup>, whereas fruit intended for long shipping distances is often picked when the pericarp partly turns red or at 75–80% maturity <sup>[40,41,42]</sup>. The international trade standard of the Codex Alimentarius <sup>[43]</sup> requires minimum ripeness without defining details, but peel coloring of litchis should vary from pink to red.

Various strategies have been followed for decision of harvest time. The contents of titratable acids (TA) and hence the sugar/acid ratio (TSS/TA) highly correlated with the litchi taste and were thus favored over total soluble solids (TSS) as maturity indicators <sup>[44]</sup>. A wide range of TSS/TA ratios from 15 to 65 (based on TA as malic acid and TSS in g hg<sup>-1</sup>) was recommended for mature fruit of different producing areas <sup>[44,37,45]</sup>.

### ***Harvesting***

The best time to pick litchi fruit is in the morning. Harvesting during the hottest part of the day or on rainy days should be avoided in order to avoid desiccation and decay. Harvesting should be done by breaking or cutting the whole fruit panicle with de-stemming of fruit afterwards. Multiple harvesting is more common than single harvesting due to differences in ripening. Fruit must be handled with care at all times, as mechanical damage to the fruit increases desiccation and decay. Fruit should be taken to the packing house as soon as possible after harvesting.

## P. Pomegranate

Pomegranate (*Punica granatum* L.) has gained popularity in recent years due to its multi-functionality and nutritional value in human diet [46]. During pomegranate fruit development, advancing maturity stages correspond to a number of coordinated physiological, biochemical, and structural processes that result in changes in size, colour and flavour, ultimately making the fruit desirable for consumption [47]. Quality assessment of pomegranate fruit is based on important external attributes such as size, shape and colour [48,46]. However, because fruit skin colour does not indicate the extent of ripening or its readiness for consumption, internal attributes such as colour, total soluble solids and acidity are also considered in assessing readiness for harvest to meet market requirements [48,46]. The timing of harvest is of utmost importance if fruit, either for immediate fresh market or for storage, are to reach the customer in prime condition. A wide range of methods used to evaluate quality and physiological attributes of pomegranate fruit.

### *Physical changes*

Physical properties of fruit such as weight, volume, and juice content are important from a marketing viewpoint because the attributes influence consumer preference [49,46]. 'Bhagwa' cultivar, fruit arils was below 50% of the fruit weight until 110 DAFB, when the fruit was considered semi-ripe and reaching 58% of the fruit weight at full ripe stage [48]. Colour is an important factor affecting marketability and consumer preference of fruit. Depending on cultivar and maturity stage, fruit external colour varies considerably from yellow, green, or pink overlain with pink to deep red or indigo to fully red [49].

### *Biochemical changes*

Total soluble solids (TSS) which is mostly made of sugars, increased significantly during three major fruit developmental stages. The TSS content increased from 10.30°Brix in immature fruit at 20 days after fruit set (DAFS) to 19.56°Brix in fully ripe fruit at 140 DAFS [51]. In India, Ganesh variety TSS content of 13% in 40 day-old fruit increased but this was not significant until the 100th day of fruit development when the TSS value exceeded 15%. The highest TSS content of 16.3% was recorded in 140 day-old fruit [52]. The maturity indices, viz. total soluble solids (TSS) and brix-acid ratio (BAR) determined for harvesting the fruits of pomegranate with better edible quality is as follows: ie. 15.95°B TSS and 31.90 BAR at 180 DAFB for Bhagwa, 15.80°B TSS and 32.91 BAR at

175 DAFB for Ruby, 16.10°B TSS, 37.44 BAR at 150 DAFB for Ganesh, 16.20°B TSS, 36.00 BAR at 145 DAFB for Jalore Seedless, 15.40°B TSS, 34.22 BAR at 140 DAFB for Arakta and 15.50°B TSS, 33.69 BAR at 140 DAFB for Mridula <sup>[53]</sup>. Juice from fully mature pomegranate fruit has 12–16% sugar content, consisting mainly of glucose and fructose <sup>[54, 55, 50, 56]</sup>. Glucose was the more predominant sugar than fructose. Decrease in titrable acid levels during fruit development with a concomitant increase in TSS content, is an inherent process during growth and development of pomegranate. In ‘Bhagwa’ pomegranate, the ratio of TSS/TA varied considerably from 16.68 at 54 DAFB to 39.19 at 140[56].

### Harvesting

On account of the common problem of splitting, most varieties are harvested before fully ripen. Mature fruits become slightly yellowish and further pink to red. On tapping, the fruits give sound and when pressed they give a crunch sound. The fruits are harvested with the help of secateurs. The period of harvested time is November to March in Mrig bahar, June to August in Ambe bahar and February to May in Hast bahar.

### Q. Grape

Worldwide, grape (*Vitis vinifera* L.) is widely cultivated for its delicious and nutritive berries. It holds a unique position among the fruits and grown in large scale. The grape berry is a non-climacteric fruit with a low rate of post-harvest physiological activity. Grapes must be harvested when they have reached optimum levels of colour development and of important solutes such as sugars and acids. The main maturity index is the sugar content, determined as the percentage of total soluble solids (TSS). Minimum TSS levels are given as 13°Brix for all other seeded varieties, and 14°Brix for all seedless varieties <sup>[57]</sup>. According to the AGMARK, the TSS of berry should be 16°B and sugar acid ratio of 20:1 and this has to be complied or export and domestic market. Physical appearance takes the major role for maturity index, under which bunch and berry size with uniform colour development is a reliable index of ripening in coloured varieties. In white grape varieties, uniform green colour is considered in the export market <sup>[58]</sup>.

The quality dried products of grape depends upon the harvesting time. This is determined by size of berry, uniformity of berry colour, texture of the skin and pulp, chemical composition and presence of decay and foreign matter <sup>[59]</sup>. The timing of wine grape harvest is very critical. Too early harvested grapes are too acid and too late may lack of acidity or



suffer reduced yields from biotic and abiotic stresses. The berries must contain the correct balance of flavour and aromatic compounds. The typical maturation levels of sugars should lie between 16% and 24% and acid between 0.6% and 1% <sup>[60]</sup>.

### **Harvesting**

To reduce dust contamination, irrigation is usually withheld between vines before harvesting. The harvester is trained to select appropriate bunches as per maturity indices described above. Grapes for drying purpose are usually harvested by hand-picked. Generally, mechanical harvesting causes too much damage of berry but the canes can be pruned mechanically with the bunch still attached and hung to dry on the vine <sup>[61]</sup>.

### **R. Phalsa**

The fruit is non-climacteric in nature and very short shelf life. Fruit yield is unstable and non-uniform ripening are the major bottlenecks in cultivation of phalsa. Fruit is a globose drupe, 1.8-2.2 cm in diameter, indistinctly lobed, red or purple, finely warty and with stellate hairs; flesh soft, fibrous, greenish- white stained with purplish-red, tasting pleasantly acid. Generally fruits are harvested on the basis of changing of colour. Fruits require 50-60 days for maturity to fruit set <sup>[62]</sup>.

### **Harvesting**

The fruit should be harvested in the morning hours and pick up by hand. The harvesting of fruits are very time consuming and can create labour scarce because it harvest in every 2-3 days interval. For uniform ripening, pre-harvest spray of ethaphon 500ppm during colour changes of fruits. The annual yield is 3-5 kg per plant or 4.5-6 t/ha <sup>[63]</sup>.

### **S. Aonla**

Aonla (*Emblica officinalis*), popularly known as the Indian gooseberry, it is minor subtropical fruit and grows widely along the hill sides and sub mountainous areas of North India. Aonla is also one of the oldest fruit of India and considered as “Wonder fruit for health” because of its unique nutritious qualities. It is a rich source of Vitamin C and its content of ascorbic acid is next to only that of Barbados cherry <sup>[64]</sup>.

The maturity indices of aonla viz., number of days from fruit set, appearance, size, shape, colour, texture specific gravity, soluble solids etc., are used for determining the maturity of fruits. Fully developed fruits are harvested. Delay in harvesting time results in heavy fruit drop. Delay

harvesting time also delay the next bearing season. Colour change of seed from creamy-white to brown is a basic indicator of maturity. Specific gravity of fruits varied due to maturity levels among different cultivars, which maintained always more than 1.0 (sinker) throughout growth period. Quality in terms of TSS, acidity, vitamin-C and tannin contents varied significantly due to cultivars and stages of harvest. The TSS content increased invariably up to 3rd stage and decreased gradually till final harvest. The TSS, acidity and vit-C range should be 8-9.5<sup>o</sup> Brix, 1.15-1.545/100gm and 300-400 respectively on maturity <sup>[65]</sup>. Killadi et al., <sup>[66]</sup> found that the TSS of variety Krishna was 9.45%, NA-10 (9.10%), and the acidity of Chakaiya variety was 1.28% and NA-10 (1.65%) at the time of maturity of fruits. The fruit takes about 8 months from flowering to fruit maturity.

### **Harvesting**

Mature fruits are generally hard with the stalk and they do not fall by gentle touch, therefore vigorous shaking is required for harvesting of fruits. Fruits are also harvested by bamboo poles attached with hooks.

### **T. Avocado**

Avocado fruit (*Persia Americana* Miller) is one of the major economically important subtropical fruit crops. The fruit does not give obvious indication of maturity as it does not ripen as long as it remains attached to a tree. Harvesting avocado fruit at full physiological maturity, a stage at which it will continue normal development plays a vital role in the postharvest physiological processes and the successful postharvest management of the fruit. Harvesting immature avocado fruit can result in economic losses due to poor fruit quality once the fruit has ripened. Symptoms of poor quality resulting from harvesting immature avocado fruit include shrivelling, rubbery texture, stringy vascular tissue, insipid flavour and increased rots <sup>[67, 68, 69]</sup>.

Common maturity parameters used in various avocado fruit industries include mesocarp oil content, moisture content (MC) and dry matter (DM) <sup>[70,71]</sup>. Determination of total soluble solids (TSS) is a quicker and less expensive maturity parameter to measure compared to oil content and dry matter. The oil content of avocado fruit increases after fruit set <sup>[72]</sup>. In most countries, the use of the percentage of dry matter as a maturity indicator for avocado is widely accepted and minimum values have been established as a legal standard for each cultivar. The dry matter minimum requirement varies from 19 to 25%, depending on the cultivar (19.0% for Fuerte, 20.8% for Hass and 24.2% for Gwen) and the country (21% for

Australia, 21.6-22.8% for USA and 23.0% for Mexico, South America and South Africa for 'Hass' avocado) <sup>[73]</sup>. Hailu <sup>[74]</sup> reported at Ethiopia that the dry matter of Hass and Fuerte cultivar were 22.827% and 22.7.0 % and oil content 11.43% and 14.53%.

Advancement in science and technology has launched several non-destructive methods of analysing biological and chemical components of agricultural products <sup>[75]</sup>. Some of these technologies include magnetic resonance imaging (MRI) and NIRS. The former is an application of NMR and is an analytical tool used for chemical analysis. Several authors have recorded successes in using NIRS and MRI to determine DM and thereby avocado fruit maturity <sup>[74]</sup>. Such technology can be used to quantify the oil, sugar and protein concentration of a given commodity, thereby increasing profitability as a result of production expansion <sup>[76]</sup>.

### **Harvesting**

Avocados should be harvested with sharp clippers by severing the stem slightly above the fruit shoulder. Fruits should never be pulled off the tree since the stem needs to remain attached. The stem length should be 1 cm (0.4 in) or less, in order to avoid puncture damage of adjacent fruit in the harvest container. Avocados should be harvested carefully as even small cuts, scratches and abrasions can spoil the appearance of the fruit and lead to decay. Hand gloves should be use to reduces the likelihood of skin damage during harvest. Harvesting of fruit by standing or climbing, a picking pole can be used to harvest the fruit. A cutting device is put at the end of the pole, with a catching bag below. The bag should be made from a soft fabric to prevent damage to the fruit.

### **U. Jamun**

Jamun (*Syzygium cumini*), a potentially indigenous important minor commercial fruit crop to South East Asia and India, but also reported in Hawaii, Australia, Phillipines, Kenya, Florida etc. Jamun is available in May-June and its harvesting time is short for 30-40 days. It is non-climacteric fruit so it harvested after ripening of fruit. Fruits are immediately harvested when they change green to dark purple colour because they are not retained on the tree. The fruits are picked by hand and care should be taken to avoid to all possible damages. The fruits are harvested on daily basis and sell to the market on same day. The seedling tree can give yield 90-100kg/plant and grafted plant 70-80kg/plant.

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