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Physico-Chemical Properties and Arsenic Residue Patterns in Locally Ripened Mango Fruits

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Abstract**—** *This research paper investigates the physico-chemical attributes of mango fruits undergoing commercial ripening processes in local fruit markets. Focusing on key parameters such as color, firmness, pH, sugar content, acidity, and nutritional composition, the study explores the dynamics of commercially induced ripening, emphasizing the unique context of local markets. The relationship between firmness, maturity, and ripeness throughout the season is examined. Initially, higher firmness suggests the use of unripe fruit, necessitating more CaC_2 for ripening. Towards the season's end, total soluble solids (TSS) and total sugar peak, indicating ripeness, while acidity decreases. As the season progresses, reducing sugar increases, signalling ripeness, and less CaC_2 is required for ripening. Carotenoid levels are highest in late-season samples. Calcium carbide treatment results in higher TSS, reduced acidity, and altered carotenoid concentrations. The analysis of arsenic residue in traditionally ripened mangoes reveals higher levels (106.3-100.7 ppb) at the season's start, decreasing as the season progresses (92.2-86.0 ppb), with the lowest mean residues (83.3-76.9 ppb) observed in the final part of the season. The study suggests a correlation between the quantity of CaC_2 used for ripening and the stage of the mango season. The presence of arsenic residue can potentially serve as a tool for detecting CaC_2 use in local markets for fruit ripening.*

Keywords**— Mango, Fruit, Market, Arsenic, Residue, CaC_2**

This study examines the physico-chemical properties of mango fruits bought in local fruit markets. Focusing on simple parameters together with color, firmness, pH, sugar content, acidity, and nutrient content, the study explores the dynamics of commercially induced ripening, emphasizing the unique context of local markets. Relationships between firmness, maturity and ripeness are explored over the years. Increased early firmness suggests immature fruit, and greater CaC2 is required for fermentation. At the end of the season, both total soluble solids (TSS) and total sugars peak, indicating ripeness, at the same time as acidity reduced. As the season progresses, reducing sugar increases, signalling ripeness, and less CaC_2 is required for ripening. Carotenoid levels are highest in late-season samples. Calcium carbide treatment results in higher TSS, reduced acidity, and altered carotenoid concentrations. Analysis of arsenic residues in traditionally ripened mangoes reveals higher levels (106.3-100.7 ppb) at the season's start, decreasing as the season progresses (92.2-86.0 ppb), with the lowest mean residues (83.3-76.9 ppb) observed in the final part of the season.

The study suggests a correlation between the quantity of CaC_2 used for ripening and the stage of the mango season. The presence of arsenic residue can potentially serve as a tool for detecting CaC_2 use in local markets for fruit ripening.

I. INTRODUCTION

Mangoes are adored worldwide for their delightful taste and health perks. People crave ripe mangoes, leading to various ripening methods, especially in local markets. This study delves deeply into how mangoes ripen in local markets, conducting a detailed examination of the physico-chemical aspects of commercially ripened mango fruit, with a specific focus on a local market case study.

We aim to understand the intricate processes involved in mango ripening by assessing parameters like color, firmness, TSS (Total Soluble Solids), sugar content, acidity, and carotenoid (Ellong et al., 2015). Our goal is to gain valuable insights into the quality of ripe mangoes by studying local market practices. This understanding benefit everyone, from consumers to those in the mango industry.

Examining how different ripening techniques, influenced by consumer demand and market dynamics, impact vital attributes like color and nutrition is crucial. This study aims to offer comprehensive insights into the quality of commercially ripened mangoes by concentrating on local market practices. By doing so, we seek to enhance discussions about mango supply chains, providing informed perspectives to consumers and industry stakeholders.

Studies by Ikhajiagbe et al. (2021) shed light on traditional ripening methods involving exposure to ethylene, a natural plant hormone, versus the prevalent use of artificial ripening agents like calcium carbide and ethylene gas. Understanding the effects of these distinct ripening methods is vital for evaluating the physico-chemical attributes of mangoes, as emphasized by Cissé et al. (2020).

When mangoes ripen, it's a crucial step in making them ready for us to eat, influencing qualities like color, firmness, sweetness, and nutrition (Ibarra-Garza et al., 2015). This study closely examines how mangoes are ripened for us to buy in local markets. We aim to grasp all the details of this process, focusing on color and chemical properties, ensuring that the mangoes we get are of good quality and offer the right nutrition.

A focused case study within the local fruit market context is essential to uncover specific outcomes of these practices, contributing valuable insights to the ongoing discussion on mango quality, supply chains, and consumer preferences. This study doesn't just look at mango fruits; it's a detailed exploration of how they are ripened and prepared for sale in our local markets. Through this examination, we aim to share useful information about mango quality, their journey to our markets, and preferences of people like us. This knowledge helps everyone better understand the workings of our local fruit markets.

II. MATERIAL AND METHODS

During the period from April 2012 to June 2012, mangoes that underwent traditional ripening methods by traders were obtained from the local fruit and vegetable market in Solan (Himachal Pradesh). The procurement occurred at regular intervals of 15 days.

Wet digestion for Arsenic

Sample preparation for wet digestion

The fruit samples were divided into surface, peel, and pulp parts. To measure the amount of arsenic and calcium on the fruit surface, one kilogram of each treated fruit was washed in one liter of special water for 30 minutes. The water used for washing was then analyzed to determine the residues on the fruit surface. For the peel and pulp, one kilogram each was crushed and blended separately.

Wet digestion method

20 grams of the blended sample (pulp or peel) and the water used for washing were placed in a digestion flask. To keep the sample fluid, a few glass beads, 10 ml of H2SO4, and 10 ml of HNO3 were added to the flask. The mixture was gently heated until the liquid noticeably darkened in color. Then, small amounts (1 to 2 ml) of HNO3 were added, and heating continued until darkening occurred again. The addition of nitric acid was continued until fuming for 5 to 10 minutes, indicating the oxidation of all organic matter. After cooling, 10 ml of distilled water was added, and the mixture was gently boiled to fuming. Upon cooling, 5 ml of water was added, and the solution was boiled gently again to fuming. Finally, the digest was cooled and adjusted to a known volume using double distilled water. After wet digestion, the residues of arsenic in different samples were determined using ICP-AES (Inductively Coupled Argon Plasma - Atomic Emission Spectrometry), while calcium was determined using the Flame Photometric method.

Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES)

In the Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES, Model 6300), the sample solution obtained after wet digestion was turned into an aerosol using a device called a nebulizer. A specially designed spray chamber separated larger droplets from the smallest ones. The smallest droplets (1-10 µm) were carried by an argon flow into the core of the ICP-AES, known as the argon plasma. The larger droplets (>90%) were discarded. In the plasma, atomic emission reaches its highest level at temperatures ranging from 7,000 to 10,000 K. Plasma is a gaseous state of matter with a high concentration of free electrons and highly charged ions, making it an effective medium for the volatilization, atomization, and ionization of liquid droplets.

As the aerosol droplets entered the hot area of the plasma, they transformed into salt particles through desolvation. These salt particles broke into individual molecules, which then further disintegrated into atoms and ions. In the plasma, additional energy was transferred to the atoms and ions, causing the excitation of their electrons to higher energy levels. When these excited atoms and ions returned to their ground state or a lower excitation state, they emitted electromagnetic radiation in the ultraviolet/visible range of

the spectrum. The intensity of this radiation was proportional to the concentration of the element being analyzed. In the spectrometer, a multi-component part containing mirrors, prisms, etc., was used to separate the specific wavelength of interest. A plasma source dissociated the sample into its constituent atoms or ions, exciting them to a higher energy level. Upon returning to their ground state, they emitted photons of a characteristic wavelength depending on the element present. This emitted light was recorded by an optical spectrometer. When calibrated against standards, this technique provided a quantitative analysis of the original sample (Anonymous, 2012).

The arsenic residue in the sample was calculated as under:-

20 g of mango fruit part contain arsenic = X ppb

100 g of mango fruit part contain arsenic = (X × 100)/ 20

= 5X ppb

Physico-chemical characteristics of commercially ripened Mango fruits in local fruit markets.

The fruits were gathered from the local fruit and vegetable market in Solan, Himachal Pradesh. This collection occurred every 15 days, spanning from April to August 2012. The aim was to conduct a thorough analysis of these fruits, focusing on diverse physico-chemical characteristics. The parameters under scrutiny included total soluble solids, titratable acidity, sugars, carotenoids, firmness, and surface color. Various established methods were employed to measure and evaluate each of these attributes, ensuring a comprehensive understanding of the fruits' composition and quality during this specified period.

Total Soluble Solids (TSS) (°B)

The measurement of total soluble solids in mango fruits was conducted using an Erma Hand Refractometer with a scale ranging from 0 to 32 degrees Brix (°B). To obtain this measurement, a drop of juice extracted from the mango fruit was carefully positioned on the prism of the refractometer. The reading was observed through an eyepiece. The recorded reading underwent correction for temperature variations, aligning it to 20 degrees Celsius based on the International Temperature Correction table (Horwitz, 1980). The results were then expressed in degrees Brix (°Brix), providing valuable information about the concentration of soluble solids in the mango fruit juice.

Titratable acidity (%)

The experimental procedure involved crushing a known weight of the sample, placing it in a 250 ml volumetric flask, and adjusting the volume by adding distilled water. After filtration, 10 ml of the filtrate was transferred to a separate conical flask and titrated against 0.1 N sodium hydroxide solution using phenolphthalein as an indicator until a faint pink color appeared, marking the end point of the titration. The titratable acidity value was then calculated using the expression provided by Ranganna (2008) and expressed as a percentage of citric acid on a fresh weight basis.

$$\% \text{ Titratable acidity} = \frac{\text{Titre x Normality of alkali x Volume made up x Eq.wt.of acid x 100}}{\text{Volume of aliquot taken for estimation x Wt or vol. of sample x 1000}}$$

Sugars (%)

Total and reducing sugars were determined using the Lane and Eynon (1923) volumetric method, as detailed by Ranganna (2008). Deleaded samples were titrated against 10 ml of standardized Fehling's solution with methylene blue as an indicator, resulting in a brick red precipitate for the determination of reducing and total sugars, respectively.

For the analysis, a known weight of crushed mango fruit sample was mixed with 100 ml of distilled water and neutralized with 1 N NaOH, using phenolphthalein as an indicator. To this neutralized sample, 2 ml of neutral lead acetate (45%) was added, shaken well, and left for ten minutes. Subsequently, 2 ml of potassium oxalate (22%) was introduced to eliminate excess lead. The volume was adjusted, and the mixture was filtered. The resulting aliquot was employed for the estimation of reducing and total sugars.

Reducing sugar: The filtered sample was transferred into a 50 ml burette and titrated against 10 ml mixed Fehling's A and B solution, with methylene blue serving as an indicator. The endpoint was determined by the appearance of a brick red color. The calculation for reducing sugar was then performed based on the titration results.

$$\% \text{ Reducing sugars} = \frac{\text{mg of invert sugar x dilution}}{\text{Titre x wt. or vol. of sample}} \text{ X } 100 \quad \text{(a)}$$

Total sugar: For the estimation of total sugar, 50 ml of clarified filtrate was placed into a 250 ml conical flask. To this, 5 g of citric acid and 50 ml of water were added. The mixture was gently boiled for ten minutes and then allowed to cool. After cooling, the mixture was neutralized with 1N NaOH, using phenolphthalein as an indicator, and the volume was adjusted to 250 ml. The determination of total sugars was carried out in the same manner as for reducing sugars.

% Total sugars as invert sugars = calculated as in (a) making use of titre value as obtained in the determination of total sugars after inversion

Carotenoids

To extract the color, one gram of the sample was dissolved in acetone and ground until the entire color was extracted. The extract was then transferred into a separating funnel, and 5% sodium sulfate was added. After separation, the colored portion was collected, and the final volume was adjusted to 25 ml (Ranganna, 2008). The optical density of the extract was measured at 450 nm against a blank (3% acetone in petroleum ether), and the reading was compared with the standard curve. The quantity of carotenoids was calculated accordingly.

$$\text{Carotenoids (mg/100 g)} = \frac{\text{Concentration x final volume x dilution}}{\text{Weight of sample}} \times 100$$

Colour

The color of ripened mango pulp and peel was measured using Horticultural color charts published by the Royal Horticultural Society. The codes for color were obtained by matching the color of the peel and pulp with the color charts.

Firmness

To assess freshness and consumer acceptance, mango fruit firmness or texture was measured with precision using the Stable Microsystem Texture Analyzer Model TA.HDPlus (Surrey, U.K.). The instrument included various load cells, different-sized cylindrical probes, and a data recorder. Calibration involved selecting a 100 kg load cell, choosing probe (P/2), and adjusting the speed settings for pre-test, test, and post-test movements. Load range, trigger force, and chart speed were set to determine penetration depth and pressure applied during the test. Readings were taken by placing the mango fruit on the platform and allowing the probe to penetrate until the fruit ruptured. Fruit firmness was expressed in kilograms or Newtons of force required for puncturing the sample.

III. RESULTS

Estimation of arsenic residues in ripened mango fruit collected from Solan fruit market

The effect of different date of sampling of ripened fruits from the fruit market on the presence of arsenic residues on fruit surface, peel and pulp are presented in Table 1. The data reveal that the mean value of arsenic residues in mango fruits varied from 76.9 to 106.3 ppb. Among different fruit parts, the level of arsenic residues in fruit surface ranged between 72.2-110.8 ppb, in peel 89.0-118.5 ppb and in pulp 69.4-89.5 ppb. Thus, the maximum level of residues was found in the peel and on the fruit surface, which suggests that arsenic (AsH_3) gas is released from the calcium carbide which gets deposited on the fruit surface and the peel. Being a gas, it also enters the fruit through peel and pulp. Analysis of arsenic residues in traditionally ripened mango fruits collected from the market further reveal that level of residues was more in the samples collected during starting season of mango ripening. With the advancement in mango harvesting season (in the middle of season 8.5.12 to 22.5.12), the mean level of arsenic residues was found to be 92.2-86.0 ppb from the initial level of 106.3-100.7 ppb (during the start of season 10.4.12 to 24.4.12). During the last part of mango season, the arsenic residues were found to be lowest (83.3-76.9 ppb) in samples collected on 5.6.12 and 19.6.12. Thus, the results clearly indicate that during the early part of mango season higher quantity of CaC_2 is used for ripening of the fruit while during the peak mango season, the quantity of CaC_2 is reduced for ripening of mango fruits

Physico-chemical characteristics of ripened mango fruit of Solan fruit market

Peel and pulp colour

Table 2 provides the color codes for the peel and pulp of various calcium carbide-ripened mangoes collected from the local market at 15-day intervals. The color codes were determined by matching the colors with the Royal Horticultural Society's color charts. The mango peel predominantly exhibited a yellowish color, corresponding to card numbers 13 (AB) to 13 (BC). In contrast, the pulp color ranged from orange 24 (AB) to 24 (BC) at the beginning of the mango ripening season and shifted to Orange 25 (AB) to 25 (BC) towards the end of the season. This indicates that the peel color of ripened mangoes generally remains yellow, while the pulp color undergoes a transition from deep yellow to orange.

Firmness

The data presented in Table 3 reveals the firmness of mango fruit collected at different intervals from the fruit market, ranging from 1.30 to 4.13 N. The highest firmness was observed in the fruit collected at the beginning of the mango season, indicating the use of immature fruit for ripening during this period. As the mango harvesting season progressed, the firmness of the fruit decreased, with values of 4.13 N (10.4.2012), 4.11 N (24.4.2012), 3.40 N (8.5.2012), and 2.83 N (22.5.2012). Towards the end of the mango season, the fruit exhibited significantly less firmness, measuring 1.30 N on 19.6.2012. The degree of firmness serves as an indicator of fruit maturity and

ripeness, with higher firmness values at the beginning of the season suggesting the use of unripe fruit, necessitating a higher quantity of CaC_2 for ripening.

Chemical characteristics of ripened mango fruit of Solan fruit market

Total soluble solids

The data in Table 3 shows that the Total Soluble Solids (TSS) content of traditionally ripened mangoes, collected at intervals of 15 days from the local market, ranged from 10.0 to 15.0°B. The lowest TSS was observed in the fruit collected during the initial stage of the mango season, gradually increasing until the last sampling date. As the mango ripening season progressed, the mean TSS levels in mangoes also increased, reaching 12.0-14.0°B from the initial levels of 10.0-11.0°B. Towards the end of the mango season, the TSS was found to be the highest (14-15°B) in samples collected on 5.6.2012 and 19.6.2012. The level of total soluble solids in mango fruit is indicative of the degree of ripeness.

Titratable acidity

The data in Table 3 regarding the titratable acidity of traditionally ripened mango fruits, collected from the local fruit market during April to June 2012, varied between 0.55% and 0.18%. The highest acidity values were recorded on the first date of sampling, gradually decreasing until the last date of sampling. Across different intervals of sampling, the titratable acidity in mango fruits collected at various dates was 0.55% (10.4.2012), 0.28% (24.4.2012), 0.26% (08.5.2012), 0.21% (22.5.2012), 0.19% (05.6.2012), and 0.18% (19.6.2012). With the progression of the mango harvesting season, the mean acidity level decreased from 0.21-0.28% (samples from 24.4.2012 to 22.5.2012) from the initial level of 0.28-0.55%. During the last part of the mango ripening season, the acidity was found to be the lowest (0.19-0.18%) in samples collected on 5.6.2012 and 19.6.2012, respectively.

Reducing sugars

The data in Table 3 regarding the reducing sugar content of calcium carbide ripened fruit indicate a significant increase in reducing sugar content until the last date of sampling. The reducing sugar content of mango fruit sampled from 10.4.2012 to 19.6.2012 ranged between 6.94% and 12.26%. With the progression of the mango harvesting season, the mean level of reducing sugar increased to 10.89-11.71% during the middle of the season from the initial level of 6.94-8.58%. During the last part of the mango season, the reducing sugar was found to be the highest (12.0-12.26%) in samples collected on 5.6.2012 and 19.6.2012. The values of reducing sugar in mango fruits on different sampling dates were recorded as 6.94% (10.4.2012), 8.58% (24.4.2012), 10.89% (08.5.2012), 11.71% (22.5.2012), 12% (05.6.2012), and 12.26% (19.6.2012). Thus, the results indicate that initially, fruits were mature but not ripe. As the fruit season advanced, the reducing sugar increased, indicating the ripeness of the fruits. Therefore, during the last part of the mango season, the quantity of CaC_2 used for ripening also appears to be decreased.

Total sugar

The data in Table 3 reveal a significant increase in the total sugar content of calcium carbide-ripened mango fruit until the last date of sampling. The total sugar content of mango ranged between 7.20% and 13.60%. Among different intervals of sampling, the total sugar content in mango fruits collected at different dates was 7.20% (10.4.2012), 9.10% (24.4.2012), 11.04% (08.5.2012), 13.26% (22.5.2012), 13.47% (05.6.2012), and 13.60% (19.6.2012). With the advancement in the mango ripening season, the mean level of total sugar for mango fruit of mid-season (8.5.2012 to 22.5.2012) also increased to 11.04-13.26% from the initial level of 7.20%. During the ending season of mango ripening, the total sugar was found to be the highest (13.47-13.60%) in samples collected on 5.6.12 and 19.6.12.

Carotenoids

The data in Table 3 indicate that the carotenoid content in traditionally ripened mangoes collected from the local fruit market at intervals of 15 days varied between 1.69 to 2.37 mg/100g. The lowest carotenoid values were recorded on the 1st date of sampling (10.2.2012), which increased gradually to become the highest by the last date of sampling (10.6.2012). With the advancement in the mango harvesting season, the mean level of carotenoid increased to 2.00-2.10 mg/100g in mangoes collected on 8.5.2012-22.5.2012 from the initial level of 1.69-1.87 mg/100g. During the last part of the mango ripening season, the carotenoid was found to be the highest (2.13-2.37 mg/100g) in samples collected on 5.6.2012 and 19.6.2012. These results indicate that fruit during the early part of the mango season were unripe, which is why a comparatively higher quantity of CaC_2 might have been used by the traders for ripening the fruits.

IV. DISCUSSION

Detection of residues in commercially ripened Mango fruits in local fruit markets

Arsenic residues in ripened mango fruit of Solan fruit market

The analysis of arsenic residues in mango fruits from the local fruit market at different intervals showed that the highest level of arsenic residues was observed in fruits collected from April 10, 2012, to April 24, 2012 (106.3-100.7 ppb). This suggests that a higher amount of calcium

carbide was used for ripening immature fruits during the initial season of mango harvesting, specifically more than 10 g of calcium carbide (Table 1). These findings align with the observations of Smith and Thompson (1987), who recommended the use of higher amounts of calcium carbide for ripening more raw and immature fruits. In comparison, lower levels of arsenic residues (76.9 ppb) were recorded in fruits collected during the last sampling stage on June 19, 2012. This implies that traders used a relatively lesser amount of calcium carbide for ripening mangoes during the concluding season of mango harvesting. Therefore, the pattern of arsenic residues in fruits at different sampling intervals indicates that traders employ a very high dose of calcium carbide for ripening fruit during the initial season of mango harvesting, and the quantity required may decrease thereafter.

Aliyu et al. (2023) revealed that high heavy metal concentration in the peel is due to the direct contact of banana has with the chemical of CaC2 and it increases with increase of the concentrations at both pulp and peel.

These findings are in accordance with the work of Maduforo et al., (2020) On heavy metals in Banana variety sold by fruit vendors in Enugu State Nigeria. The effect of heavy metals increases with increasing amount of chemical molecule. Similar work was also done by Adekalu et al., (2020) Survey on the use of Calcium Carbide as repening agent in Ilorin metropolis, his findings revealed that banana ripened with CaC2 contains high levels of heavy metal in comparison to naturally fermented materials (observation). This study showed that carrot treatment increased iron contamination on fruit surfaces. The concentrations of As, Ca, Pb and Cd in the treated banana were found to be high. The FAO and WHO Joint Expert Committee on Food Additives (JECFA) designated As and Pb as toxic heavy metals, with PTWIs of 15 g/kg (equivalent to 2.1 g/kg). per day) and 25 grams per pound. As and Pb are also classified as carcinogens by the International Agency for Research on Cancer (IARC) (Alimentarius 2019).

Physical characteristics of ripened mango fruit of Solan fruit market

Peel and pulp colour

The mango peel typically has a yellowish color, while the pulp can vary from yellow to orange (see Table 2). Previous research by Tucker and Grierson (1987) highlighted that the ripening of fruit involves a color change caused by the degradation of chlorophyll and the revelation of previously present pigments. The agents responsible for this degradation include the oxidative system, pH changes, and enzymes like chlorophyllases (Wills et al., 1982, Tucker and Grierson, 1987).

These findings align with the observations of Doreyappa-Gowda and Huddar (2001), who noted an increase in carotenoid concentration during the ripening of green mature Alphonso and other mango varieties stored at 18-34°C. As ripening progresses, the peel color shifts from light green or green to light yellow or yellow-orange due to chlorophyll breakdown, while the pulp color changes from white or pale yellow to yellow or orange-yellow due to carotenoid development.

However, studies by Tandon and Kalra (1998) suggest that fruits ripened with calcium carbide may develop attractive surface color but are inferior in taste, flavor, and have a shorter shelf life. Similarly, Smith and Thompson (1987) found that while fruits treated with calcium carbide developed good peel color, the intensity of color correlated with the concentration of calcium carbide used. However, these fruits were lacking in flavor volatiles and had a reduced shelf life. Importantly, calcium carbide primarily changes the skin color, leaving the fruit raw inside. Using higher amounts of calcium carbide for ripening, especially in raw/immature fruits, can result in a tasteless, less healthy, and slightly toxic fruit. Additionally, it can break down the organic composition of vitamins and other micronutrients in the fruit.

In many fruits, color development is an important indicator of maturity and is associated with season (Maduwanthi and Marapana, 2019). The degradation of chlorophylls and the production of anthocyanins and carotenoids reduce the existing colour, which is a common cause of discoloration during fruit ripening (Lizada, 1993) There is also no significant difference in endocarp colour. This would simply mean that exogenous chemical application did not enhance these results beyond the changes in skin color. Unfortunately, most consumers buy citrus based on its appearance (skin color) and can be very fooled into thinking the fruit will taste as expected if their fruit is yellow which is highlighted by this finding that non-climacteric fruits are insufficient when uprooted from their parent trees and control is simply immature

Firmness

The firmness of mango fruits, observed between 10.4.2012 and 19.6.2012, showed a range of 4.13 N to 1.3 N (see Table 3). The highest firmness (4.13 N) was observed in mango fruits collected at the beginning of the mango ripening season, while fruits collected during the peak or ending season of mango ripening exhibited the lowest firmness (1.3 N).

Firmness in fruits is often associated with pectic substances, which are structural polysaccharides responsible for maintaining fruit firmness. The softening of fruit occurs when these pectin polymers become less tightly bound in

the cell walls during ripening. Therefore, firmness can be used as an index for determining the optimum stage of maturity for harvest (Kudachikar et al., 2001).

The findings regarding the decrease in firmness with the use of calcium carbide (CaC_2) for fruit ripening align with previous studies by Randhawa et al. (1984), Cissé, et al. (2020) and Ashwani et al. (1995). These studies treated pear fruits (cv. Nakai) and mango fruits (cv. Dashehari), respectively, with calcium carbide and concluded that fruit firmness decreased with calcium carbide treatments and prolonged storage period. The decrease in firmness during storage could be attributed to the breakdown of insoluble pectic substances into soluble forms through physicochemical changes induced by pectic enzymes, such as pectin methylesterase and polygalacturonase, formed in the tissues during ripening (Weichmann, 1987).

Low calcium levels may decrease calcium-pectin interactions, causing free pectin to be released from the flesh, resulting in decreased firmness as the fruit ripens. Further damage can cause the mango fruit to be shriveled or overly ripe. The softening effects of soy fruits primarily result from cell wall alterations, resulting in structural changes of starchy and nonstarchy polysaccharides (Waldron et al., 1999). The textural changes and softening of fruits are caused by depolymerization and dilution of cell wall materials, as well as disruption of cell structure (Li et al., 2010; Chime et al., 2016; Ogwu et al., 2019; Ikhajiagbe). et al., 2021). Changes in turgor pressure, breakdown of cell wall polysaccharides, and enzymatic breakdown of starch all contribute to fruit softening.

Chemical characteristics of ripened mango fruit of Solan fruit market

Total soluble solids

The Total Soluble Solids (TSS) content of the mango fruits collected at different ripening dates showed a significant increase as the fruit season progressed (refer to Table 3). This rise in TSS can be attributed to alterations in cell wall structure and the breakdown of complex carbohydrates into simple sugars. The increase in TSS is directly associated with hydrolytic changes in starch, and the conversion of starch to sugar serves as a crucial indicator of the ripening process in mango and other climacteric fruits (Kays, 1991; Kittur et al., 2001).

Similar trends in TSS have been observed in green mature Alphanso and seven other hybrids or varieties of mango fruit that underwent a series of physicochemical changes during ripening, stored at temperatures ranging from 18 to 34°C (Doreyappa-Gowda and Huddar, 2001). In line with our findings, studies by Nagaraj et al. (1984), Ashwani et al. (1995), Guha and Bhuiyan (1997), Joon et al. (2001) and Cissé, et al. (2020) explored the response of mango fruits to calcium carbide treatment at 2 or 4 g/kg fruits. They reported that calcium carbide treatment led to the highest Total Soluble Solids compared to the control group.

Titratable acidity

The change in titratable acidity of mango (cv Suffaida) collected from the Solan market revealed that the percent titratable acidity ranged from 0.18% to 0.55%, with an average value of 0.28% (refer to Table 3). It was observed that titratable acidity decreased with the increase in the sampling date. This decline may be attributed to the degradation of citric acid due to increased activity of citric glyoxylase during ripening, or the reduction in acidity may result from the conversion of acids into sugars, further utilized in metabolic processes within the fruit (Rathore et al., 2007).

These findings are consistent with the observations of Doreyappa-Gowda and Huddar (2001), who reported a decrease in titratable acidity from 2.71% to 0.04% during the ripening of different varieties of mango fruit. Similarly, studies by Nagaraj et al. (1984), Ashwani et al. (1995), and Joon et al. (2001) explored the response of total acidity of mango fruits to calcium carbide treatment at 2 or 4 g/kg fruits, recording a decrease in total acidity with calcium carbide treatments and increasing storage duration. However, the titrable acidity of chemically ripened mango were higher than the naturally ripened mango (Cissé, et al., 2020).

Sugars (Reducing and Total sugar)

The reducing sugars content of mango fruit was estimated to be in the range of 6.94% to 12.26% (refer to Table 3). The data reveal that the levels of reducing sugar increased with the progression of ripening. However, it's noteworthy that appreciable reduction in reducing sugar was observed in calcium-treated fruit, as reported by Katrodia (1988).

The total sugar content of mango fruit collected from the Solan fruit market ranged between 7.20% and 13.60% (Table 3). The data in Table 3 indicate that the total sugar content in mango fruit increased with the progression of fruit ripening. Chaudhary and Farooqui (1969) have also reported total sugars in different mango cultivars ranging between 10.00% and 17.30%. Additionally, the total sugars content of the pulp of Baiganpalli and Totapuri mangoes was reported to be 554.20 mg/100 g and 535.60 mg/100 g, respectively (Jadhav et al., 2009). The sugars in mangoes include sucrose, glucose, fructose, and maltose, with other sugars such as xylose, arabinose, sedoheptulose, and mannoheptulose also present (Ogata et al., 1972).

Carotenoids

The carotenoid content of mango fruit ranged between 1.69 to 2.37 mg/100g (refer to Table 3). The characteristic color

of mango fruit skin and edible flesh is primarily due to the presence of carotenoids. In line with our results, studies by Jadhav et al. (2009) and Veda et al. (2007) reported the β-carotene content of the pulp of Baiganpalli and Totapuri cultivars of mango to be 2.10 and 1.95 mg/100 g, respectively. The slightly lower concentration of carotenoids in traditionally ripened mangoes could be attributed to the findings of Tandon and Kalra (1998), who reported that mango fruits ripened with calcium carbide at a concentration of 2g/kg had impaired flavor and decreased amounts of total carotenoids in the fruits.

V. CONCLUSION

This study investigates mango ripening dynamics, focusing on firmness, Total Soluble Solids (TSS), acidity, reducing sugar, total sugar, and carotenoid levels. Higher initial firmness suggests the use of unripe fruit, requiring more CaC_2 for ripening. Towards the season's end, TSS peaks, acidity decreases, and reducing sugar increases, indicating fruit ripeness. The quantity of CaC_2 used for ripening decreases in the last part of the season. Total sugar and carotenoid levels are highest during the season's end, suggesting initial unripeness. Calcium carbide treatment results in higher TSS and decreased acidity. Analysis of arsenic residue in traditionally ripened mangoes revealed higher levels at the season's start. As the harvesting season progressed (8.5.12 to 22.5.12), mean arsenic residues decreased from 106.3-100.7 ppb to 92.2-86.0 ppb. In the season's final part (5.6.12 and 19.6.12), the lowest mean residues (83.3-76.9 ppb) were found. The study suggests higher CaC_2 use for ripening in early season, reducing during the peak. Traditionally ripened mangoes from Solan's local market were also collected for periodic residue comparison with various ripening methods using calcium carbide. It is concluded from the above study that mangoes ripened using calcium carbide did contain harmful residue of arsenic on the fruit surface, peel and pulp. The presence of a higher proportion of arsenic in commercially ripened mangoes from market suggests the use of a very high dose of calcium carbide (more than 10 g/5kg) by traders for ripening mangoes. The estimation of arsenic residues in mangoes can serve as a tool to detect mangoes that have been ripened using calcium carbide within a lot.

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Table 1 Physico-chemical characteristics of CaC_2 ripened mango fruit (cv Suffaida) collected from fruit market Solan HP at different intervals

Date of sampling	**Firmness (N)**	**TSS (°B)**	**Titratable Acidity (%) (CA)**	**Reducing Sugar (%)**	**Total Sugar (%)**	**Carotenoids (mg/100g)**
10-4-2012	4.13	10.00	0.55	6.94	7.20	1.69
24-4-2012	4.11	11.00	0.28	8.58	9.10	1.87
08-5-2012	3.40	12.00	0.26	10.89	11.04	2.00
22-5-2012	2.83	14.00	0.21	11.71	13.26	2.10

05-6-2012	1.95	14.00	0.19	12.00	13.47	2.13
19-6-2012	1.30	15.00	0.18	12.26	13.60	2.37
Mean	**2.95**	**12.67**	**0.28**	**10.40**	**11.36**	**2.03**
$CD_{0.05}$	**1.210**	**0.981**	**0.069**	**0.553**	**0.472**	**0.345**

Table 2 Colour in different parts of CaC2 ripened mango fruit (cv Suffaida) collected from fruit market Solan HP at different intervals

Date of sampling	**Colour Codes**	
	Peel	**Pulp**
10-4-2012	Yellow-Group 13 (BC)	Orange-Group 24 (BC)
24-4-2012	Yellow-Group 13 (BC)	Orange-Group 24 (AB)
08-5-2012	Yellow-Group 13 (AB)	Orange-Group 25 (BC)
22-5-2012	Yellow-Group 13 (AB)	Orange-Group 26 (AB)
05-6-2012	Yellow-Group 13 (BC)	Orange-Group 25 (AB)
19-06-2012	Yellow-Group 13 (BC)	Orange-Group 25 (BC)

Table 3 Residual arsenic contents (ppb) in different parts of CaC2 ripened mango fruits collected from fruit market Solan HP at different intervals

Date of sampling	**Residual arsenic (ppb) in different fruit parts**						
	Fruit surface	**95% Probability Limits**	**Peel**	**95% Probability Limits**	**Pulp**	**95% Probability Limits**	**Mean**
10-4-2012	110.8	110.79-110.85	118.5	118.10-118.92	89.5	89.46-89.50	**106.3**
24-4-2012	98.6	98.56-98.64	115.5	115.09-115.81	88.2	88.14-88.20	**100.7**
08-5-2012	93.0	92.95-92.99	107.4	107.12-107.58	76.2	76.21-76.27	**92.2**
22-5-2012	84.0	83.97-84.05	99.1	98.99-99.29	74.6	74.53-74.63	**86.0**
05-6-2012	76.1	76.07-76.11	97.2	96.98-97.34	76.6	76.55-76.63	**83.3**
19-6-2012	72.2	72.15-72.21	89.0	88.69-89.21	69.4	69.38-69.44	**76.9**
$CD_{0.05}$	**2.475**		**2.539**		**1.988**		