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# Comparing odor-active compounds of South Indian mangoes by odor uproot blend analysis and the natural aroma instantaneous input to the sniffing port method for evaluating odor interactions

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This research work identifies odor-active components of four South Indian mangoes. Volatile compounds in the South Indian mangoes Malgova, Alphonso, Senthuram, and Banganapalli, which belong to the *Mangifera Indica* family, were investigated using odor uproot blend analysis (OUBA) and natural aroma instantaneous input to the sniffing port (NAIIS). The evaluation of odor interactions—the connections between a naturally occurring scent and volatile substances extracted using gas chromatography was done using the NAIIS and OUBA approaches. This led to detecting 28 odor-active chemicals, 25 of which were identified. For the first time, three volatile chemicals were found in South Indian mangoes: γ-undecalactone, cis-3-hexenol, and cis-3-hexenyl acetate. The flavor dilution (FD) factor for γ-undecalactone of Malgova, Alphonso, Senthuram, and Banganapalli mangoes was 20542, 10254, 55261, and 49527 by OUBA and 65251, 75681, 82641, and 54216 by NAIIS, respectively. The FD factor for cis-3-hexenol of Malgova, Alphonso, Senthuram, and Banganapalli mangoes was 521, 815, 621, and 115 by OUBA and 2541, 1026, 3521, and 925 by NAIIS, respectively. The FD factor for cis-3-hexenyl acetate of Malgova, Alphonso, Senthuram, and Banganapalli mangoes was 10256, 13254, 18761, 16841 by OUBA and 8256, 9215, 11523, 12145 by NAIIS, respectively. Furthermore, OUBA classified cis-3-hexenyl acetate as green whereas NAIIS defined it as fruity.

**Keywords:** South Indian mangoes, odor-active components, OUBA, NAIIS, flavor dilution (FD) factor

## INTRODUCTION

One of the world's most widely consumed tropical fruits, particularly in India, is the mango (*Mangifera Indica L.*). South Indian mangoes are very special for Indian people and favor people who need enriching foods. However, due to poor maintenance and non-technical approach, the average amount of wasted mango fruit ranges from 30% to 50%, 24% of which is wasted during distribution. The preliminary step of identifying the volatile odor component of such mangoes will help apply a technology to reduce waste and provide it to needy people.

The top four mango varieties from South India are Banganapalli, Alphonso, Senthuram, and Malgova. The village of Banganapalli in Andhra Pradesh, India, is the origin of the Banganapalli mango, sometimes referred to as Benishan or Baneshan [1]. This variety has an unusually sweet flavor, is large and rectangular, and has thin skin. It is exported to many countries and is frequently used to make mango pulp. Over time, the popularity and cultivation of various mango kinds have changed, and each variety has become linked with certain places recognized for their distinct mango features.

Mango farming has a strong cultural and agricultural legacy in India, where these kinds significantly add to the country's vast diversity of mangoes. The Ratnagiri area of Maharashtra, India, is thought to be the birthplace of the variety Alphonso, often known as Hapus [2]. It is well-known for its unique sweetness, taste, and scent. It is regarded as one of the most excellent mango kinds in the world, featuring brilliant yellow skin when mature. Only mangoes from this region may be marketed under the Alphonso name thanks to the geographical indication (GI) certification, which safeguards the brand. The Senthuram mango is a local or regional variety [3] having restricted origin. Local variations can have distinct sizes, tastes, and looks. Senthuram's qualities vary depending on the area and local farming customs. The Malgova mango is thought to originate from Tamil Nadu, India's Salem area [4]. It is distinguished by an

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enormous size, elongated form, silky skin, and sweet flavor. It is well-liked for both export and domestic use. The Malgova mango is grown using conventional techniques, including budding and grafting. Over time, horticulturists and farmers strive to enhance the cultivar.

Solid phase extraction and gas chromatography-mass spectrometry were employed to determine the components of air fresheners thought to be a likely source of volatile organic compounds [5]. Using the wet-digestion method and microwave plasma-atomic emission spectroscopy, the amounts of macro and trace metals in *Rubus steudneri Schweinf* fruit were ascertained [6]. OUBA and NAIIS were used to identify strong odor components in different varieties of mango [7]. The interactions between natural odors and the chemicals extracted from aroma concentrates by GC may be assessed using NAIIS. It has been found that some volatile substances have an effect on one another, even at quantities below the odor threshold [8, 9]. Some of the most significant features of the smell of natural goods are the odor interactions, about which a great deal of study has been published in various sectors, particularly wine [10-13].

Thus, the purpose of this work was to use odor uproot blend analysis (OUBA) and natural aroma instantaneous input to the sniffing port (NAIIS) to clarify the powerful volatile chemicals of four types of South Indian mangoes that have distinct smells. Once the odor-active components present in the south Indian mangoes are determined, they can be used to choose the corresponding odor detection sensor to design an embedded system. Such an embedded system can be utilized for determining and classifying the ripening stages of South Indian mangoes. By doing so, mangoes after post-harvest can be delivered to customers on time as per customer or consumer requirement, which avoids wastage of fruit before reaching the consumer.

## EXPERIMENTAL

### *Materials*

- *Chemicals and reagents.* All chemicals and reagents used in the present work were of analytical grade quality, including dichloromethane (Merck India), magnesium sulfate (Merck India), nitrogen gas (Linde India Ltd), ethanol (Merck India), ascorbic acid (Merck India), helium (Linde India Ltd), TC-WAX column (Restek India) and hydrogen gas (Linde India Ltd).

### *Apparatus and instruments*

- *Blender* (model: Vitamix 5200; Vitamix India): The Vitamix 5200 is a high-power laboratory mixing/homogenizing system powered by a 1.2–1.38 kW variable speed motor, and a 1.9 L processing vessel. The unit offers shear rates adjustable from 10 discreet speed settings for efficient homogenization, dispersion, emulsification and particle-size reduction of liquid and semi-solid samples. The high-speed blade assembly provides for high mechanical shear for quick processing of heterogeneous materials to homogeneous suspensions. The system also has a self-cleaning mechanism, resulting in less downtime between processing cycles and higher system efficiency.
- *Centrifuge* (model: Eppendorf 5804R; Eppendorf India Pvt. Ltd): The Eppendorf 5804R Refrigerated Centrifuge features a benchtop design and has a refrigeration capacity of up to 20°C. It operates at speeds between 200 and 14,000 rpm and reaches a maximum RCF of 20,913 × g. It fits up to four tubes of 250 mL or two microplates and works in the temperature range of –9°C to +40°C. The unit automatically recognizes the rotor and detects imbalance, provides the user with 35 programmable settings, 10 acceleration/deceleration profiles, low noise operation (<58 dB), and is compatible with fixed-angle and swing-bucket rotors for a wide range of laboratory uses.
- *Rotary evaporator* (model: Buchi R-300; Buchi India Pvt. Ltd.): It is an innovative modular rotary evaporator for solvent evaporation, concentration, distillation and drying. The key specifications are: evaporating flask capacity 50 mL-5 L, flask load to 3kg, evaporation rotation speed 10-280 rpm, heating bath temperature range 20-220°C, manual or automatic lift, up to 8 condensation patterns. Automated distillation, remote monitoring with BUCHI software/cloud services, SOP programming, vacuum integration, modular system expansion for R&D, pharmaceutical, chemical, food and academic laboratories.
- *Nitrogen gas cylinder* (Linde India Ltd): Linde India nitrogen cylinders store nitrogen gas at high pressure (47L cylinders of high-pressure steel 150–300 bar) with high purity (99.9–99.999%) in high-pressure steel cylinders and result in about 7–14 $m^3$ of gas. The non-flammable, inert (UN 1066, Class 2.2) gas is used for purging, blanketing, welding, electronics, pharma, and food packaging applications. It should be stored vented to prevent risk of oxygen displacement.

- *GC-olfactometry system* (model: 7890 GC, 5975B MS; Agilent Technologies India): The Agilent 7890 GC is capable of simultaneous instrumental and human sensory analysis of volatiles with the addition of an olfactory detection port (GC-O) for the Agilent 5975B MSD. The 7890 GC is capable of high-resolution capillary separation with programmable temperature control, and the 5975B quadrupole MS performs the mass spectrum, identification (m/z 35-600) under EI (70 eV) conditions. Odor event detection is performed by the sniffing port, while the effluent post-column is divided for chromatographic data collection and spectral data collection for the correlation and confirmation of aroma-active compounds.
- *Sniffing port* (model: Gerstel olfactometer; Gerstel India Pvt. Ltd.): Gerstel GC-O sniffing port is operated with a heated transfer line at approximately 150-250 °C with adjustable effluent split ratios of about 1:1 to 1:4 (nose: detector). Typically, the flow of carrier/make-up gas is 20-60 mL/min. The port supplies almost 100% relative humidity to the nose, so that it doesn't get dry. With sniff port pressure at atmospheric level, the event detection of the odor can be obtained with sub-second to ~1 s time resolution, which allows correlation with the GC retention time.
- *Air pump* (KNF Neuberger India): It is an oil-free gas transfer, polytetrafluoroethylene-coated membrane, polyphenylene sulfide head, fully fluorinated polymer elastomer material (FFPM) valves; flow ~20 – 50 L/min, vacuum up to ~2 mbar abs, pressure up to 0.5 bar. Low maintenance, corrosion resistant, for lab vacuum, distillation and filtration.

*Experimental procedure*

The ripening stages of mango fruit are broadly classified into three stages: unripe stage (initial stage 1), ripe (stage 2), and overripe stage (stage 3) [14]. In the unripe stage, the fruit is hard and slightly yellow or green; in the ripening stage, the fruit is slightly softer, and the color changes from green to full yellow; and during the overripe stage, the fruit is very soft, full yellow with dark brown spotsas shown in Fig. 1.

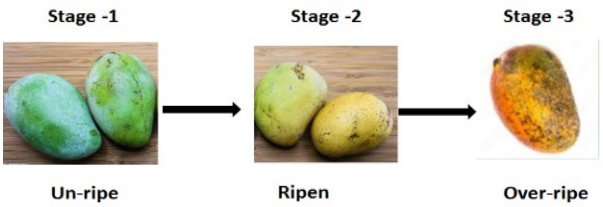



**Fig. 1.** Ripening stages of mango with its firmness and color

The ripened mango fruit samples of Malgova, Alphonso, Senthuram, and Banganapalli were purchased from a mango farm located in the Salem district in the state of Tamil Nadu, India, and stored at 6°C. Steps were followed to prepare aroma concentrations for the four categories of mangoes:

*Step 1*: Each category's fresh, ripe mangoes were peeled, and their seeds were removed individually.

*Step 2:* Mango extracts of Banganapalli, Alphonso, Senthuram, and Malgova were made by blending 1.1 kg of mango pulp at 25 °C for 20 min in each category, using a different blender for each kind of mango flesh.

*Step 3*: After centrifugation (6000 × g, 4 °C, 20 min), the dichloromethane layer was separated and distilled using a solvent-assisted flavor evaporation process (SAFE) to generate volatile fragrance concentrates.

*Step 4*: The aroma distillates were dried to about 2 mL using a rotary evaporation set at 40 °C and 600 mm Hg, with an excess of magnesium sulfate added.

*Step 5:* Finally, a light stream of nitrogen gas was used to prepare 100 µL of the aroma concentrate.

GC-olfactometry investigations were conducted using a 7890 GC system with a 5975B mass spectrometer and a sniffing port equipped with a TC-WAX column specification of 30 m × 0.32 mm and film thickness of 0.50 µm. Helium was employed as a carrier gas at a 1 mL/min rate. The splitless mode was used to inject the samples (0.2 µL) at a temperature of 250 °C. At 70 eV, the mass spectrometer was operated in electron impact (EI) mode. At a pace of 5 °C per min, the oven temperature was increased from 60 to 250 °C. The mass spectrometer and sniffer port shared the effluent at the capillary column's end. By comparing the mass spectra, linear retention indices (RI), and olfactory properties of volatile substances with reference compounds from our lab, two experienced panelists performed GC-olfactometry testing. The n-alkane retention durations were used to calculate the compounds' relative intensities (RIs).

*Analytical method*

- *Odor uproot blend analysis.* The flavor dilution (FD) factors were determined for the odor-active compounds. Each odor-active chemical in the aroma concentrates has an FD factor, the highest dilution factor that gas chromatography-olfactometry can detect [15]. The more the component contributes to the sample's scent, the higher is the FD factor. Ethanol was used to

progressively dilute the mango scent concentrations, resulting in dilution ratios between 1:31 and 1:310 for all mango categories. Using the TC-WAX column, gas chromatography-olfactometry was used to examine each dilution.

*Natural aroma instantaneous input to the sniffing port*

Odor-active components interacting with the mango odor were examined for all the mango categories using NAIIS. This technique is based on odor uproot blend analysis and gas chromatography-olfactometry. 10 g of a 1% ascorbic acid solution was added to a 100-g portion of fresh mangoes of each category cage that had been cut into ~2 cm cubes. The mangoes were kept in a glass container at 25 ºC, and 100 mL per min of air was used to release the mango's natural scent into the sniffing port. NAIIS was carried out by combining sensory mango odor detection with gas chromatography-olfactometry analysis. The odor uproot mix study mentioned that the mango scent was accentuated in serial dilutions. The NAIIS-derived FD factors show how much each chemical contributes to the odor of mangos under each mango category.

## RESULTS AND DISCUSSION

Four panelists assessed the aroma of freshly cut pieces of Banganapalli, Malgova, Alphonso, and Senthuram mangoes. Results showed milky, tropical, fruity, green, hop, fiber-like, fatty, honey, floral, rose, lactone, sweet, coconut, peach, butter, vanilla, sulfur, and plastic-like odor for Malgova mango; tropical, fruity, green, bamboo, terpeny, fiber-like, fatty, honey, floral, rose, lactone, sweet, coconut, peach, butter, vanilla, sulfur, and plastic odor for Alphonso mango; tropical, fruity, green, hop, terpeny, fiber-like, fatty, honey, floral, rose, lactone, sweet, coconut, peach, butter, vanilla, sulfur, and plastic odor for Senthuram mango and milky, tropical, fruity, green, hop, bamboo, terpeny, fiber-like, fatty, honey, floral, rose, lactone, sweet, coconut, peach, butter, vanilla, sulfur, and plastic-like odor for Banganapalli mango. Using the solvent-assisted flavor evaporation method, the volatile aroma concentrations in each category were determined [16].

**Table 1.** OUBA: Determined odor compounds for Malgova, Alphonso, Senthuram, and Banganapalli mangoes.

| S.No | RI | *Compound | #Odor quality | FD factor | | | |
|---|---|---|---|---|---|---|---|
| | TC-WAX | | | Malgova | Alphonso | Senthuram | Banganapalli |
| 1. | 975 | 2,3-butanedione | milky | 3 | - | - | 3 |
| 2. | 1024 | α-pinene | green, tropical | 557 | 763 | 251 | 324 |
| 3. | 1049 | ethyl butanoate | fruity | 62 | 84 | 26 | 72 |
| 4. | 1079 | ethyl 3-methylbutanoate | fruity | 62 | 84 | 26 | 72 |
| 5. | 1087 | hexanal | green | | 5 | 5 | 1 |
| 6. | 1150 | (Z)-3-hexenal | green | 33251 | 29512 | 31265 | 24156 |
| 7. | 1155 | cis-3-hexenol | fresh, green | 521 | 815 | 621 | 115 |
| 8. | 1165 | β-myrcene | green, hop | 61 | | 3 | 12 |
| 9. | 1379 | (Z)-3-hexenol | green, fiber-like | 1524 | 2103 | 976 | 1065 |
| 10. | 1399 | unknown | sulfur | 2513 | 25 | 41 | 7 |
| 11. | 1455 | 3-carene oxide | plastic | 19602 | 2561 | 10213 | 5201 |
| 12. | 1549 | (E)-2-nonenal | green, fatty | 162 | 281 | 91 | 201 |
| 13. | 1830 | (E)-β-damascenone | honey, floral | 240 | 251 | 243 | 249 |
| 14. | 1837 | geraniol | floral, rose | 2051 | 2150 | 2165 | 2230 |
| 15. | 1920 | γ-octalactone | lactone, sweet, coconut | 50269 | 42510 | 41568 | 52143 |
| 16. | 1920 | γ-undecalactone | sweet, fruity | 20542 | 10254 | 55261 | 49527 |
| 17. | 1925 | cis-3-hexenyl acetate | green | 10256 | 13254 | 18761 | 16841 |
| 18. | 1934 | unknown | sweet | 251 | 251 | 251 | 251 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 19. | 1954 | δ-octalactone | lactone, fatty, sweet, coconut | 36521 | 42751 | 3220 | 7162 |
| 20. | 1992 | 4-acetoxy-2,5-dimethyl-3(*2h*)-furanone | sweet | 62512 | 81254 | 65412 | 76524 |
| 21. | 2016 | γ-nonalactone | lactone, sweet | 35216 | 41524 | 51264 | 49527 |
| 22. | 2017 | 4-hydroxy-2,5-dimethyl-3(2H)-furanone (HDMF) | sweet | 59049 | 61254 | 36524 | 59049 |
| 23. | 2059 | p-cresol | animal | 19683 | 881 | 19683 | 2564 |
| 24. | 2128 | γ-decalactone | lactone, peach | 51246 | 33216 | 45621 | 32564 |
| 25. | 2234 | (Z)-7-decen-5-olide | lactone, butter | 723 | 25 | 625 | 381 |
| 26. | 2405 | unknown | bamboo, terpeny | - | 12 | - | 51 |
| 27. | 2535 | vanillin | sweet, vanilla | 50212 | 45621 | 44152 | 48521 |
| 28. | 2550 | (*Z*)-6-dodecen-4-olide | lactone | 1025 | 11265 | 10224 | 1654 |

*Expert agreement was used to identify each odor's active component and assess its mass spectrum, retention index, and odor quality in relation to the standard reference compounds. # Quality of odor as perceived at the sniffing port.

**Table 2**. NAIIS: Determined odor compounds for Malgova, Alphonso, Senthuram, and Banganapalli mangoes.

| S.No | RI | *Compound | #Odor quality | FD factor | | | |
|---|---|---|---|---|---|---|---|
| | TC-WAX | | | Malgova | Alphonso | Senthuram | Banganapalli |
| 1. | 975 | 2,3-butanedione | milky | 1 | - | 1 | - |
| 2. | 1024 | α-pinene | green, fresh | 2193 | 2193 | 2193 | 2193 |
| 3. | 1049 | ethyl butanoate | fruity | 1 | 2 | 1 | 1 |
| 4. | 1079 | ethyl 3-methylbutanoate | fruity | 7 | - | 7 | 7 |
| 5. | 1087 | hexanal | green | 1 | - | 1 | 1 |
| 6. | 1150 | (Z)-3-hexenal | green, fresh | 2185 | 2185 | 2187 | 2185 |
| 7. | 1155 | cis-3-hexenol | fresh, green | 2541 | 1026 | 3521 | 925 |
| 8. | 1165 | β-myrcene | green | | 2 | 1 | 1 |
| 9. | 1379 | (Z)-3-hexenol | green, fresh | 253 | 253 | 253 | 251 |
| 10. | 1399 | unknown | sulfur | 59049 | 25 | 41 | 7 |
| 11. | 1455 | 3-carene oxide | plastic | 20652 | 23561 | 19254 | 54261 |
| 12. | 1549 | (E)-2-nonenal | green | 71 | 3 | 5 | 5 |
| 13. | 1830 | (E)-β-damascenone | honey, floral, potato | 4 | - | 3 | 3 |
| 14. | 1837 | geraniol | floral, rose | 5 | 5 | 51 | 27 |
| 15. | 1920 | γ-octalactone | body, sweet | 19652 | 11211 | 53261 | 5283 |
| 16. | 1920 | γ-undecalactone | sweet, fruity | 65251 | 75681 | 82641 | 54216 |
| 17. | 1925 | cis-3-hexenyl acetate | fruity | 8256 | 9215 | 11523 | 12145 |
| 18. | 1934 | unknown | fruity | 25561 | 42561 | 65821 | 21560 |
| 19. | 1954 | δ-octalactone | body, sweet | 52481 | 21652 | 8562 | 561 |
| 20. | 1992 | 4-acetoxy-2,5-dimethyl-3(*2H*)-furanone | sweet | 65214 | 65843 | 26851 | 35462 |
| 21. | 2016 | γ-nonalactone | lactone, sweet | 17658 | 2561 | 215 | 3126 |
| 22. | 2017 | 4-hydroxy-2,5-dimethyl-3(2H)-furanone (HDMF) | sweet, sugar | 64523 | 42541 | 51026 | 21565 |
| 23. | 2059 | p-cresol | ripe, animal | 651 | 2591 | 21 | 3651 |
| 24. | 2128 | γ-decalactone | fruity | 62514 | 71256 | 50202 | 91562 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 25. | 2234 | (Z)-7-decen-5-olide | sweet, fatty | 6524 | 5231 | 9691 | 10230 |
| 26. | 2234 | (*Z*)-6-dodecen-4-olide | lactone | 12897 | 19876 | 32684 | 41562 |
| 27. | 2405 | unknown | ripe | 251 | - | - | 27 |
| 28. | 2535 | vanillin | sweet | 59049 | 20158 | 14652 | 62150 |

*Expert agreement was used to identify each odor's active component and assess its mass spectrum, retention index, and odor quality to the standard reference compounds. # Quality of odor as perceived at the sniffing port.

After analyzing the aroma concentrates for each of the four categories of mango using OUBA and NAIIS, 28 odor-active chemicals were found, as indicated in Tables 1 and 2. These odor compounds' structures were determined by comparing their mass spectra, RIs, and olfactory characteristics to standard reference compounds in our laboratory. Three newly found compounds (γ-undecalactone, cis-3-hexenol, and cis-3-hexenyl acetate) were among the twenty-eight detected compounds that were identified. Furthermore, previous research indicated that the volatile compounds δ-3-carene and α-terpinolene were plentiful in Malgova mango, but not in OUBA or NAIIS [17]. Accordingly, it was suggested that volatile substances with low odor thresholds can be found by gas chromatography-olfactometry but not by gas chromatography [18].

Table 1 displays the outcomes of the OUBA. 4-Acetoxy-2,5-dimethyl-3(2H)-furanone (FD: 62512), 4-hydroxy-2,5-dimethyl-3(2H)-furanone (HDMF) (FD: 59049), and γ-octa lactone (FD: 51246) exhibit the top three FD factors, while ethyl butanoate (FD: 62), ethyl 3-methylbutanoate (FD: 62), β-myrcene (FD: 61), and 2,3-butanedione (FD: 3) appear to have the least three values for Malgova mango. 4-Acetoxy-2,5-dimethyl-3(2H)-furanone (FD: 81254), 4-hydroxy-2,5-dimethyl-3(2H)-furanone (HDMF) (FD: 61254), and vanillin (FD: 45621) exhibit the top three FD factors, while (Z)-7-decen-5-olide (FD: 25), unknown (FD: 12), and hexanal (FD: 5) appear to have the least three values for Alphonso mango. 4-Acetoxy-2,5-dimethyl-3(2H)-furanone (FD: 65412), γ-undecalactone (FD: 55261), and γ-nonalactone (FD: 51264) exhibit the top three FD factors, while ethyl 3-methyl butanoate (FD: 26), ethyl butanoate (FD: 26), hexanal (FD: 5), and β-myrcene (FD: 3) appear to have the least three values for Senthuram mango. 4-Acetoxy-2,5-dimethyl-3(2H)-furanone (FD: 76524), 4-hydroxy-2,5-dimethyl-3(2H)-furanone (HDMF) (FD: 59049), and γ-octalactone (FD: 52143) exhibit the top three FD factors, while β-myrcene (FD: 12), 2,3-butanedione (FD: 3), and hexanal (FD: 1) appear to have the least three values for Banganapalli mango. β-Myrcene appeared in Malgova, Senthuram, and Banganapalli mangoes with FD factors of 61, 3, and 12, but was missing in Alphonso mango. 2,3-Butanedione appeared in Malgova and Banganapalli mango with FD factors of 3 and 3 but was missing in Senthuram and Alphonso mangoes. Hexanal appeared in Senthuram, Banganapalli, and Alphonso mangoes with FD factors of 5, 5, and 1, but was missing in Malgova mango. γ-Undecalactone, cis-3-hexenyl acetate, and cis-3-hexenol appeared for the first time in South Indian mangoes with a high FD factor. The FD factors of γ-undecalactone in Malgova, Alphonso, Senthuram, and Banganapalli are 20542, 10254, 55261, and 49527, respectively. The FD factors of cis-3-hexenyl acetate in Malgova, Alphonso, Senthuram, and Banganapalli are 10256, 13254, 18761, and 16841, respectively. The FD factors of cis-3-hexenyl acetate in Malgova, Alphonso, Senthuram, and Banganapalli are 10256, 13254, 18761, and 16841, respectively. The FD factors of cis-3-hexanol in Malgova, Alphonso, Senthuram, and Banganapalli are 521, 815, 621, and 115, respectively.

In summary, OUBA found chemicals with low and high odor offsets in each mango category. In general, it is known that interactions between components with low olfactory thresholds and powerful fragrances affect the odors of natural products.

According to a study on beer aromas, none of the odorants alone was responsible for any of the collective characteristics of beer signature odor [19]. Instead, the odor of the beer was mostly influenced by the combined synergistic effects of many odorants. Stated differently, the unique, harmonious aroma of beer results from the interaction and balancing of several odorants. In this study, NAIIS extracted distinct odor components from the four mango category fragrance isolates, combining them with the preexisting mango odor.

The results of NAIIS are shown in Table 2. Generally, NAIIS permits the assessment of these compounds' interactions with the natural flavors, whereas gas chromatography-olfactometry and OUBA permit the evaluation of the odor characteristics of isolated compounds [20]. The flavor dilution factors and odor characteristics of the compound found in NAIIS differed from those in OUBA because of odor interactions. γ-Undecalactone (FD: 62512), 4-acetoxy-2,5-dimethyl-3(2H)-furanone (FD: 65214), and 4-hydroxy-2,5-dimethyl-3(2H)-furanone (HDMF) (FD: 64523) exhibit the top three FD factors, while asgeraniol (FD: 5), (E)-β-damascenone (FD: 4), 2,3-butanedione (FD: 1), ethyl butanoate (FD: 1), hexanal (FD: 1), and 2,3-butanedione (FD: 3) appear to have the least three values for Malgova mango. γ-Undecalactone (FD: 75681), γ-decalactone (FD: 71256), and 4-acetoxy-2,5-dimethyl-3(2H)-furanone (FD: 65843) exhibit the top three FD factors, while (E)-2-nonenal (FD: 3), ethyl butanoate (FD: 2), and β-myrcene (FD: 2) appear to have the least three values for Alphonso mango. γ-Undecalactone (FD: 82641), unknown (FD: 65821), and γ-octalactone (FD: 53261) exhibit the top three FD factors, while (E)-2-nonenal (FD: 5), (E)-β-damascenone (FD: 3), ethyl butanoate (FD: 1), 2,3-butanedione (FD: 1), and β-myrcene (FD: 1) appear to have the least three values for Senthuram mango. γ-Decalactone (FD: 91652), vanillin (FD: 62150), and 3-carene oxide (54261) exhibit the top three FD factors. At the same time (E)-2-nonenal (FD: 5), (E)-β-damascenone (FD: 3), ethyl butanoate (FD: 1), hexanol (FD: 1), and β-myrcene

(FD: 1) appear to have the least three values for Banganapalli mango. Ethyl 3-methyl butanoate appears in Malgova, Senthuram, and Banganapalli mangoes with FD factors of 7, 7, and 7 but was missing in Alphonso mangoes.

(E)-β-damascenone appears in Malgova, Senthuram and Banganapalli mangoes with FD factor of 4, 3, and 3 but is missing in Alphonso mango. β-Myrcene appears in Alphonso, Senthuram and Banganapalli mangoes with FD factors of 2, 1, and 1 but is missing in Malgova mango. Hexanal appears in Malgova, Senthuram and Banganapalli mangoes with FD factors of 1, 1, and 1, but is missing in Alphonso mangoes. 2,3-Butanedione appears in Malgova, and Senthuram mangoes with FD factors of 1 and 1, but is missing in Alphonso and Banganapalli mangoes. Figures 2, 3, 4 and 5 depict the comparison of the FD factors for Malgova, Alphonso, Senthuram, and Banganapalli mangoes by OUBA and NAIIS analyses.

OUBA and NAIIS have their own advantages and disadvantages with different categories of mangoes and odor-active components. Both analyses produce distinct odor-active components which play an important role in effectively differentiating mangoes and their ripening stages. As a result of the analysis, utilizing both methods as the hybrid method for classification would result in excellent performance. According to national and international standards, the weight, size, and color grade system for Indian mangoes are used to determine the ripening phases of the fruit. Internal and exterior quality factors: mangoes can be classified as unripe, early ripe, partially ripe, ripe, or overripe [21]. However, the proposed system uses the odor as the parameter to determine different categories of mango and its ripening stages. The novelty of the proposed work scientifically shows the massive difference in the classification of mangoes and their ripening stages.

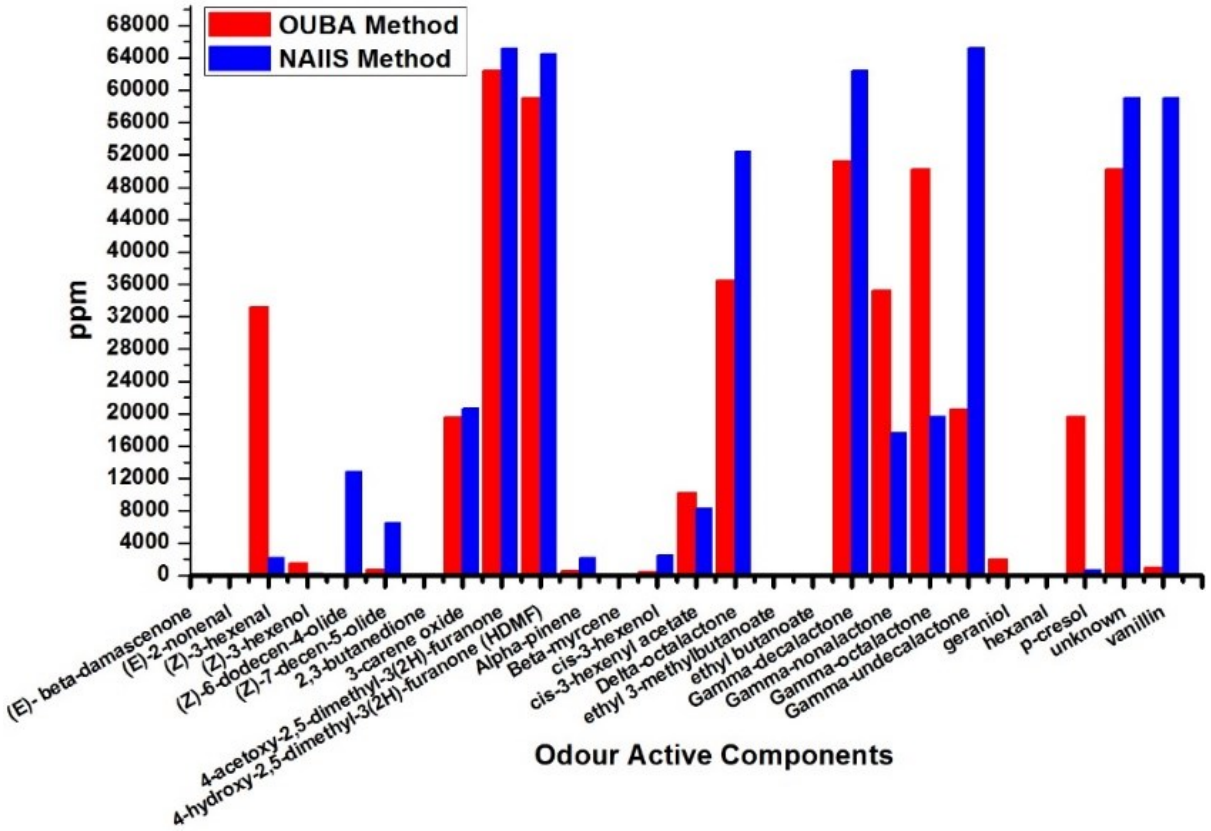



**Fig. 2.** The FD factor for Malgova mango compared using OUBA and NAIIS analyses.

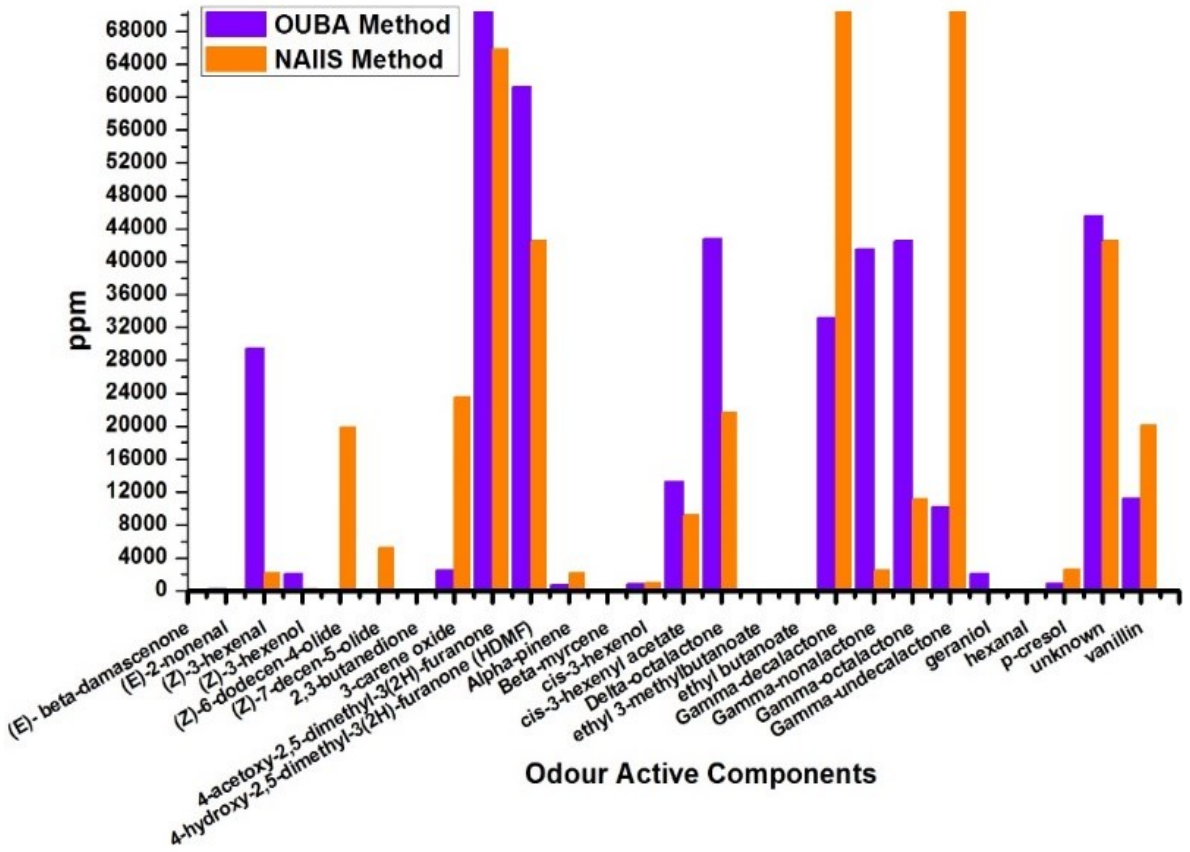



**Fig. 3.** The FD factor for Alphonso mango compared using OUBA and NAIIS analyses.

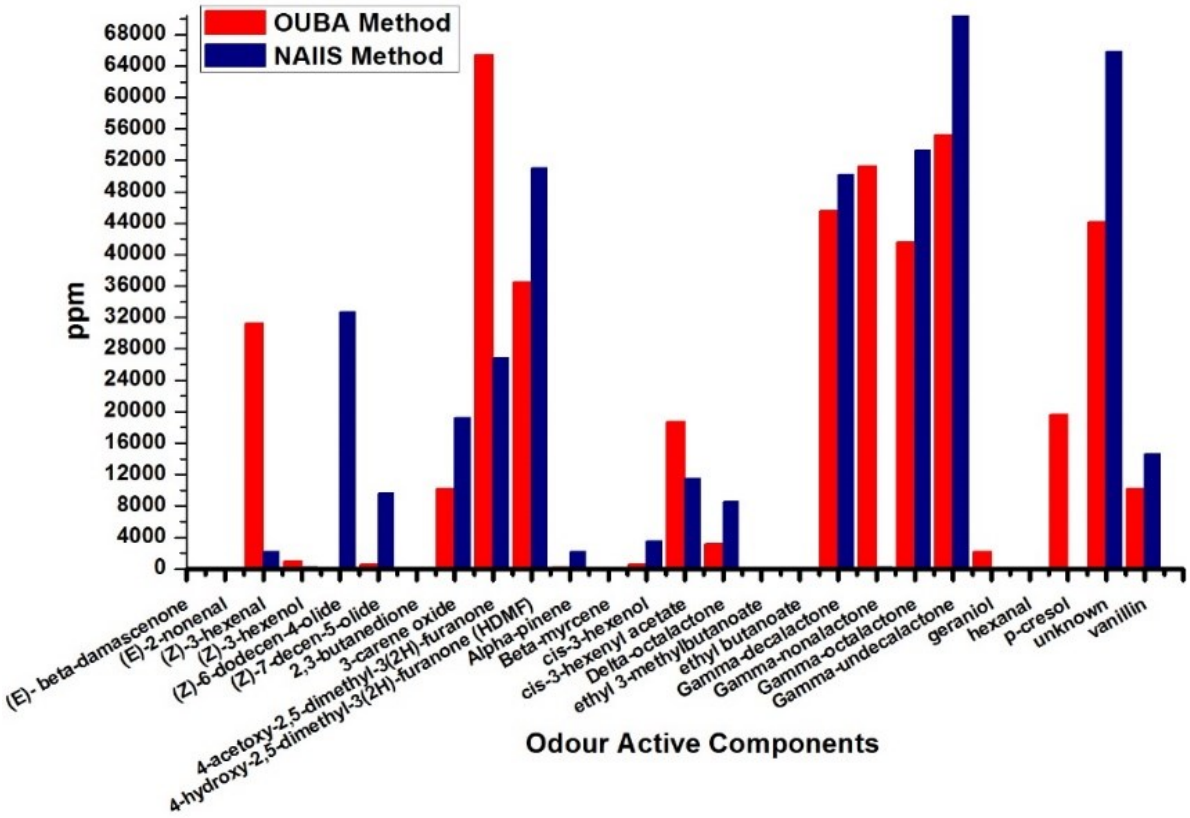


**Fig. 4.** The FD factor for Senthuram mango compared by OUBA and NAIIS analyses.

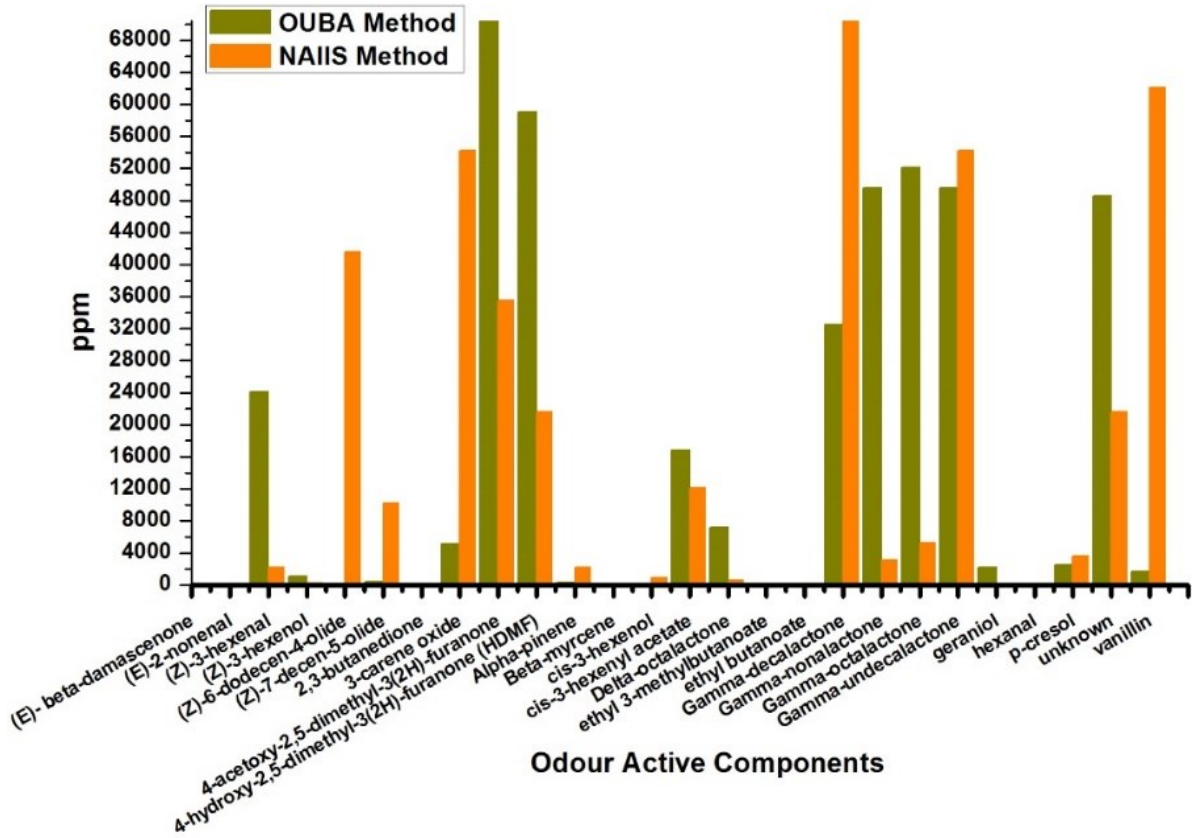



**Fig. 5.** The FD factor for Banganapalli mango compared using OUBA and NAIIS analyses.

OUBA and NAIIS methods gave FD factors for all 28 odor-active components of Malgova mango, where the percent error is zero. For Alphonso mango, the OUBA method determined the FD factor for 27 components, and the NAIIS method determined the FD factor for 22 components out of 28, which leads to a percent error of 3.57% and 21.42%, respectively. The OUBA method determined the FD factor for 26 components, and the NAIIS method determined the FD factor for 27 components out of 28, which leads to a percent error of 7.14% and 3.57%, respectively, for Senthuram mango. Similarly, for Banganapalli mango, the OUBA method determined the FD factor for 28 components, and the NAIIS method determined the FD factor for 27 components out of 28, which leads to a percent error of 0% and 3.57%, respectively. Therefore, the average percent error for determining the odor active component using OUBA and NAIIS are 2.66% and 7.14% based on the FD factor.

## CONCLUSIONS

Odor uproot blend analysis (OUBA) and NAIIS (natural aroma instantaneous input to the sniffing port) identify 25 odor-active components and three unknown components of top four categories of South Indian mangoes. The odor-active components such as γ-undecalactone, cis-3-hexenol, cis-3-hexenyl acetate, β-myrcene, 2,3-butanedione, β-myrcene, (E)-β-damascenone, and hexanal can be utilized to differentiate between these four categories of South Indian mangoes. These identified odor-active components can be used to design an odor sensor specially for these categories of mangoes, which can be implemented in automated systems in mango export and related product production factories. Further, it will also be helpful to identify the ripening stages of all these categories of mangoes so that mango fruit can be delivered on time for consumers and avoid fruit wastage, which is essential for human beings who need it.

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