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RESEARCH ARTICLE

VOLATILE ESTERS AND SULFUR COMPOUNDS IN DURIANS & A SUGGESTED APPROACH TO ENHANCING ECONOMIC VALUE OF DURIANS

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ABSTRACT

Durio zibethinus, more commonly known as Durian or the 'king of fruits' by locals is a Southeast Asian tropical fruit. Smell is a crucial factor in durian acceptance amongst consumers as many are unable to accept the pungent onion-like odour liberated by durians. Due to the controversial aroma of durians, chemical compounds reportedly contributing to the durian smell- volatile esters and sulfur compounds have been widely discussed in the literature. This review article seeks to consolidate the literature which have identified volatile esters and sulfur-containing compounds in durians from Malaysia, Indonesia and Thailand, and studies shedding light on how the economic value of durians can be enhanced. Literature review was conducted using databases Scopus and ScienceDirect and a total of 18 articles were reviewed. In light of the rising demand for durians, factors, namely aroma, flavour and colour, in which consumers consider in the purchase of durians are further looked at, to explore the potential of enhancing favourable traits of durians and increasing its economic value and sales in the global market. By knowing the chemical compounds involved or influencing each factor, further studies can be conducted to explore methods such as breeding of new durian cultivars and metabolic or gene modification for phenotypic manifestation of favourable traits attractive to consumers.

KEYWORDS

Breeding, Flavour, Odour, Aroma, Fragrance

1. INTRODUCTION

A flight was delayed as a heated argument ensued where passengers complained about an odour likened to rotten onions, which would make flying unbearable. Later a batch of fruits, arguably the world's smelliest fruit- Durian, was removed from the flight [1]. There are an estimated 27 species of *Durio* worldwide but *Durio zibethinus* remains the most popular. Originating from the Malay Peninsula, Durian or *Durio zibethinus* belongs to the family of *Bombacaceae*, is well known by locals as the 'king of fruits'. Recently, it was reported that chinese consumers bought up 80,000 durians within 60 seconds upon its commencement of sales on Alibaba's Tmall platform. It was also announced that a 3 billion *yuan* deal was closed between Alibaba and the Thai government [2]. Growth in durian sales in the global market is remarkable seeing exports from major producers such as Indonesia, Malaysia and Thailand. Despite its controversial aroma, durians have been proven a valuable commodity of trade and governments in South East Asia have been looking to expand their durian industry.

The smell of durians has two distinct tones: a fruity and onion-like odour, due to the presence of volatile esters and sulphur-containing compounds [3]. Smell is a crucial factor in durian acceptance amongst consumers as many are unable to accept the pungent onion-like odour liberated by durians. Studies have been done to investigate characterisation of volatiles in durians, storage and retention of volatiles in durians, opportunities in the durian biomass industry, and sensory properties and biochemical metabolites in durians [3-17].

To date, there are many publications discussing the identities and contributory role of volatile esters and sulfur-containing compounds in the aroma, liberated by the durian fruit. Studies have been conducted with durian cultivars from various South-East Asian countries such as Malaysia, Indonesia and Thailand. In order to gather and consolidate data from all available studies that have discussed the chemical names of these esters and sulfur-containing compounds, their respective aromatic contributions, the specific aroma of different durian cultivars, a literature review was conducted. To consider how the economic value of durians can be enhanced, studies discussing aromatic contributions of esters and sulfur-containing compounds in the lai cultivars (used in durian hybridisation), the metabolomics of compounds contributing to aroma, colour and flavour, are also reviewed.

2. MATERIALS AND METHODS

The literature review was conducted using two databases: Scopus and ScienceDirect. This review focuses on the volatile esters and sulfur compounds. Key terms "Durian", "Durio", "Esters", "Sulfurs", "Volatility", "Volatile", "Flavours", "Fragrance", "Aroma" and "Odour" were included in the search strategy. A filter was applied to search for articles with these key terms appearing in the title, abstract or keywords. A total of 30 and 10 articles were found on Scopus and ScienceDirect respectively. Only English articles (including both abstract and the full text) indexed in the two databases were utilised. There were no changes in the number of articles with the language filter applied.

2.1 Inclusion Criteria

Articles discussing esters and sulfur compounds in durians were shortlisted for review. Relevant articles were also selected from the bibliography of the articles for discussion.

2.2 Exclusion Criteria

Articles discussing fermentation, wine or alcoholic fermentation, volatile compounds in other fruits, storage of durians and retention of volatiles, development of tools for quantitation of chemical compounds in durians, were not considered for this literature review.

A total of 18 articles were considered for final review [3-11, 18-26]. A flowchart reporting the steps taken to select articles for review, is shown below in Figure 1.

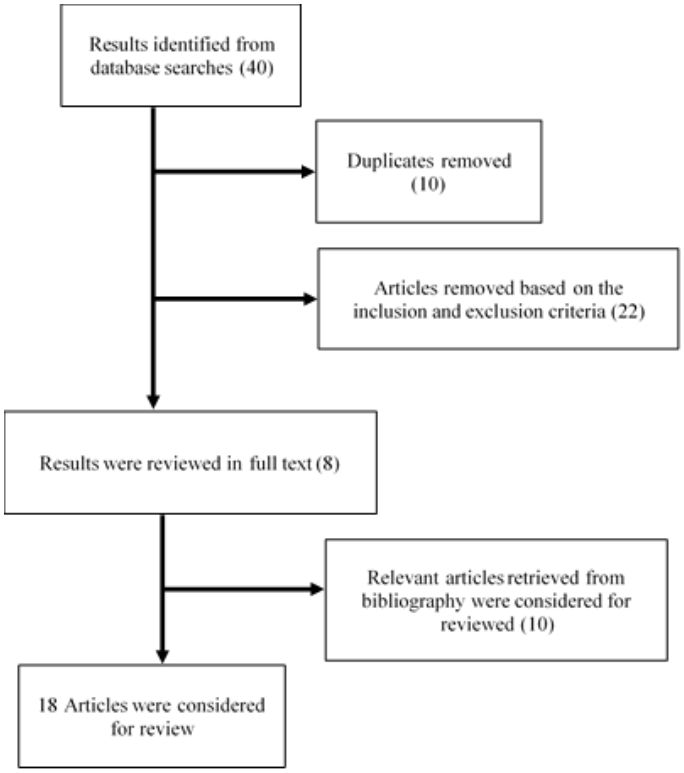

Figure 1: Flowchart of included literature for review

3.RESULTS

A total of 9 papers have been consolidated in Table. 1 summarising the esters and sulfur compounds identified in each study.

3.1 Esters and sulfur compounds found in durians

Table 1: Esters and Sulfur Compounds Identified in Studies

Authors, Year	Volatile Compounds Found in Durians	Country of Origin
[3]	Sulfur compounds: ● Hydrogen sulphide ● Methanethiol ● Ethanethiol ● Propanethiol ● Dimethylthioether ● Diethylthioether ● Diethyldisulphide Ester compounds: ● Methyl acetate ● Ethyl acetate ● Methyl propionate ● Ethyl propionate ● *n*-Propyl propionate ● Ethyl *iso*-butyrate ● Ethyl butyrate ● Methyl α-methylbutyrate ● Ethyl α-methylbutyrate ● *n*-Propyl α-methylbutyrate ● Ethyl iso-valerate ● Ethyl methacrylate ● Ethyl benzene	Unknown durian cultivar from Singapore and Malaysia
[4]	Sulfur compounds: ● Hydrogen sulfide ● Diethyl disulfide	Unknown

	● Ethyl propyl disulfide ● Ethyl methyl trisulfide ● Diethyl trisulfide ● Ethyl propyl trisulfide ● Diethyl tetrasulfide Ester compounds: ● Ethyl-2-methylbutanoate ● Ethyl acetate	
[5]	Sulfur compounds: ● S-ethyl thioacetate ● Methyl ethyl disulfide ● 1-hydroxy-2-methylthioethane ● Methyl 2-methylthioacetate ● Dimethyl sulfone ● Diethyl disulfide ● S-ethyl thiobutyrate ● Ethyl 2-(methylthio)acetate ● 2-isopropyl-4-methylthiazole ● S-isopropyl 3-(methylthio)- 2-butenoate ● 3,5-dimethyl-1,2,4-trithiolane (I) ● 3,5-dimethyl-1,2,4-trithiolane (II) ● S-methyl thiohexanoate ● 5-methyl-4-mercapto-2-hexanone ● Benzothiazole ● 3,4-dithia-2-ethylthiohexane ● S-methyl thiooctanoate ● 3,5-dimethyltetrathiane Ester compounds: ● Ethyl 2-methylbutanoate ● Ethyl acetate ● Ethyl hexanoate ● Propyl 2-methylbutanoate ● Ethyl caprylate ● Ethyl hexadecanoate ● Methyl propanoate ● Methyl 2-methylbutanoate ● Hexadecanyl propanoate	Unknown durian cultivar from Indonesia
[6]	Sulfur compounds: ● S-Ethyl thioacetate ● Methyl ethyl disulphide ● Ethyl vinyl disulphide ● Diethyl disulphide ● Methyl propyl disulphide ● 1,1-Bis(methylthio)ethane ● Dimethyl trisulphide ● 3-(Ethylthio)butan-l-ol ● Ethylpropyl disulphide ● 1-(Ethylthio)-1-(methylthio)ethane ● Ethyl methyl trisulphide ● S-Ethyl 2-methylbutanethioate ● 3-(Ethylthio)-2-methylbutan-l-ol (2 isomers) ● 3-(Propylthio)butan-1-ol ● Di-isopropyl disulphide ● Dipropyl disulphide ● Butyl ethyl disulphide ● 1-(Methylthio)-1-(propylthio)ethane ● 3,5-Dimethyl-1,2,4-trithiolane (2 isomers) ● 3-Methyl-1,2,4-trithiane ● 3-(Methyldithio)butan-1-ol ● Diethyl trisulphide ● 1-(Ethyldithio)-1-(methylthio)methane ● 2-Ethyl-3-(ethylthio)butan-1-ol (2 isomers) ● 3-Ethyl-5-methyl-l,2,4-trithiolane (2 isomers) ● 3-(Ethyldithio)butan-1-ol	Unknown durian cultivar from Indonesia

	● Ethyl isopropyl trisulphide ● Ethyl propyl trisulphide ● 1-(Ethylthio)-l-(methyldithio)ethane ● 1-(Ethyldithio)-1-(methylthio)ethane ● 1-(Ethyldithio)-1-(ethylthio)methane ● 3-(Ethyldithio)-2-methylbutan-l-ol ● 3-(Propyldithio)-butan-l-ol ● Di-isopropyl trisulphide ● lsopropyl propyl trisulphide ● Dipropyl trisulphide ● 1-(Ethyldithio)-1-(ethylthio)ethane ● 1-(Methylthio)-1-(propyldithio)-ethane ● 3,6-Dimethyl-1,2,4,5-tetrathiane ● 1-(Ethyldithio)-1-(ethylthio)propane ● 1-(Ethylthio)-1-(propyldithio)ethane ● 1-(Ethyldithio)-1-(propylthio)ethane ● 1-(Ethylthio)-1-(propyldithio)ethane Ester compounds: ● Ethyl (E,Z,Z)-deca-2,4,7-trienoate ● Ethyl (E,E,Z)-deca-2,4,7-trienoate ● Ethyl (Z,Z)-deca-3,6-dienoate ● Ethyl (Z,Z)-deca-2,4-dienoate ● Ethyl (E,Z)-deca-2,4-dienoate ● Ethyl (E,E)-deca-2,4-dienoate	
[7]	Sulfur compounds: ● Ethanethiol ● Propanethiol ● S-Ethyl thioacetate ● Ethyl methyl disulphide ● S-Propyl thioacetate ● Methyl hexanoate ● Diethyl disulphide ● Methyl propyl disulphide ● S-Propyl thiopropionoate ● Ethyl propyl disulphide ● 1-(Ethylthio)ethanethiol ● Diethyl trisulphide ● Ethyl propyl trisulphide ● *trans*-3,5-Dimethyl-1,2,4-trithiolane ● *cis*-3,5-Dimethyl-l,2,4-trithiolane Ester compounds: ● Ethyl acetate ● Methyl propanoate ● Ethyl propanoate ● Ethyl 2-methylpropanoate ● Propyl acetate ● Methyl butanoate ● Methyl 2-methylbutanoate ● Propyl propanoate ● Ethyl butanoate ● Propyl 2-methylpropanoate ● Ethyl 2-methylbutanoate ● Ethyl 3-methylbutanoate ● Butyl acetate ● Diethyl carbonate ● Propyl butanoate ● Propyl 2-methylbutanoate ● Ethyl pentanoate ● Butyl propanoate ● Ethyl (E)-but-2-enoate ● Ethyl hexanoate ● Ethyl(E)-2-methylbut-2-enoate ● Ethyl heptanoate ● Ethyl 2-hydroxypropanoate ● Methyl Octanoate ● Ethyl octanoate	Clones no. 15, 28, 74 durian cultivars from Malaysia

	● Ethyl (methylthio)acetate ● Methyl 3-hydroxybutanoate ● Ethyl 3-hydroxybutanoate ● Ethyl decanoate ● y-Butyrolactone ● Ethyl dodecanoate	
[8]	Sulfur compounds: ● Hydrogen sulfide ● Ethylene sulfide ● Sulfur dioxide ● Methanethiol ● Ethanethiol ● Propanethiol ● Butanethiol ● Ethanethioate, *S*-ethyl ● Ethanethioate, *S*-(2-methylbutyl) ● Carbon disulfide ● Diethyl disulfide ● Dipropyl disulfide ● Methyl ethyl disulfide ● Ethyl propyl disulfide ● Butyl ethyl disulfide ● Dipropyl trisulfide ● *Trans*-3,5-dimethyl-1,2,4-trithiolane ● *Cis*-3,5-dimethyl-1,2,4-trithiolane Ester compounds: ● Methyl acetate ● Ethyl acetate ● Butyl acetate ● Methyl propanoate ● Ethyl propanoate ● Propyl propanoate ● Butyl propanoate ● Pentyl propanoate ● Methyl-2-methylpropanoate ● Ethyl-2-methylpropanoate ● Propyl-2-methylpropanoate ● Ethyl-(*S*)-2-hydroxypropanoate ● Ethyl-2-methyl-2-propenoate ● Methyl butanoate ● Ethyl butanoate ● Propyl butanoate ● Ethyl-2-butanoate ● Ethyl DL-3-hydroxybutanoate ● Methyl-2-methylbutanoate ● Ethyl-2-methylbutanoate ● Ethyl-3-methylbutanoate ● Ethyl (*E*)-2-methyl-2-butenoate ● Propyl-2-methylbutanoate ● Butyl-2-methylbutanoate ● 2-methylpropyl-2-methylbutanoate ● Methyl-2-ethyl acrylate ● Propyl (*E*)-2-methyl-2-butenoate ● Diethyl butanediaote ● Ethyl pentanoate ● Ethyl-2-methylpentanoate ● Methyl-3-methyl-2-oxo-pentanoate ● Methyl-4-2-oxo-pentanoate ● Methyl hexanoate ● Ethyl hexanoate ● Propyl hexanoate ● Ethyl-3-hydroxyhexanoate ● Ethyl heptanoate ● Propyl heptanoate ● Methyl octanoate ● Ethyl octanoate	Unknown durian cultivar from Malaysia

	● Propyl octanoate ● Ethyl (*Z*)-4-octenoate ● Ethyl nonanoate ● Ethyl decanoate ● Ethyl dodecanoate ● Methyl hexadecanoate ● Ethyl hexadecanoate ● Dimethyl carbonate ● Diethyl carbonate	
[9]	Sulfur compounds: ● Ethanethiol ● 1-Propanethiol ● Methyl propyl sulphide ● Methyl ethyl disulphide ● Diethyl disulphide ● Methyl propyl disulphide ● Ethyl propyl disulphide ● Dipropyl disulphide ● 1-Methylethyl propyl disulphide ● Diethyl trisulphide ● 3,5-Dimethyl-1,2,4-Trithiolane (isomer 1) ● 3,5-Dimethyl-1,2,4-Trithiolane (isomer 2) ● Dipropyl trisulphide ● 1,1-Bis(ethylthio)-ethane Ester compounds: ● Ethyl acetate ● Methyl propionate ● Ethyl propanoate ● Ethyl 2-methylpropanoate ● Methyl butanoate ● Methyl 2-methylbutanoate ● Ethyl butanoate ● Propyl propanoate ● Propyl 2-methylpropanoate ● Ethyl 2-methyl butanoate ● Ethyl 3-methylbutanoate ● Propyl butanoate ● Propyl 2-methylbutanoate ● Ethyl but-2-enoate ● Methyl hexanoate ● Ethyl hexanoate ● Propyl hexanoate ● Ethyl heptanoate ● Methyl octanoate ● Ethyl octanoate ● Ethyl 3-hydroxybutanoate ● Ethyl decanoate	D2, D24, D101, MDUR78 and Chuk durian cultivars from Malaysia
[10]	Sulfur compounds: ● Ethanethiol ● Propanethiol ● 1-(methylthio)-propane ● *S*-ethyl ethanethioate ● *S*-propyl ethanethioate ● Diethyl disulfide ● Methyl propyl disulfide ● Ethyl propyl disulfide ● 1-(ethylthio)-1-(methylthio)-ethane ● Dipropyl disulfide ● Diethyl trisulfide ● Ethyl propyl trisulfide ● 3,5-dimethyl-1,2,4-trithiolane ● 3,5-dimethyl-1,2,4-trithiolane ● Dipropyl trisulfide ● 1,1-bis(ethylthio)-ethane Ester compounds:	D2, D24, D101 durian cultivars from Malaysia

	● Ethyl acetate ● Methyl propanoate ● Ethyl propanoate ● Ethyl-2-methylpropanoate ● Propyl acetate ● Methyl butanoate ● Methyl-2-methylbutanoate ● Ethyl butanoate ● Propyl propanoate ● Ethyl-2-methylbutanoate ● Ethyl-3-methylbutanoate ● Propyl butanoate ● Propyl-2-methylbutanoate ● Propyl-3-methylbutanoate ● Ethyl-2-butenoate ● Methyl hexanoate ● 3-methylbutyl propanoate ● Ethyl hexanoate ● Propyl hexanoate ● Ethyl heptanoate ● Methyl octanoate ● Ethyl octanoate	
[11]	Sulfur compounds: ● Ethanethiol ● Methanethiol ● Ethyl (2*S*)-2-methylbutanoate ● Hydrogen sulfide ● Propane-1-thiol ● Ethane-1,1-dithiol ● Methyl (2*S*)-2-methylbutanoate ● 1-(ethylsulfanyl)ethane-1-thiol ● 2(*5*)-ethyl-4-hydroxy-5(2)-methylfuran-3(2*H*)-one ● Diethyl trisulfide ● 1-(methylsulfanyl)ethane-1-thiol ● 1-(ethyldisulfanyl)-1-(ethylsulfanyl)ethane ● 1-(ethylsulfanyl)propane-1-thiol ● 3-methylbut-2-ene-1-thiol Ester compounds: ● Ethyl butanoate ● Ethyl-2-methylpropanoate ● Ethyl cinnamate	'Monthong' durian cultivar from Thailand

3.2 Chemical contribution of esters and sulfur compounds to durian aroma

The strong smell of durians is favoured only by a limited group of consumers and it has presented as an issue in the transportation of durians when it is marketed in other parts of the world. Many are turned away by the onion-like odour of durians, which have been reported to be due to sulfur-containing compounds present in durians [5]. Hence to enhance the favourability of durians, plant breeders have started to look at the cultivation of new breeds of the fruit. To breed new cultivars however, selection has to be based on the characteristics of fruits that breeders would like to see manifesting in the new durian cultivar. One paper, namely the Belgis et al study sheds lights on how characterisation of cultivars can aid selection of candidates for future breeding of new durian cultivars [18]. This will be elaborated in the subsequent subsections.

3.2.1 Sulfur compounds

Belgis et al has looked at the characterisation of volatiles and aroma of several lai (*Durio kutejensis*) and durian (*Durio zibethinus*) in Indonesia [18]. Both being of the Durio species, lai has a milder aroma than durians. A total of six lai cultivars ("Batuah", "Merah", "Mahakam", "Kutai", "Gincu" and "Mas") and four durian cultivars ("Mahatari", "Sukarno", "Ajimah" and "Hejo") were harvested and analysed. By Solid Phase Micro Extraction (SPME)/Gas Chromatography-Mass Spectrometry (GC-MS) analysis, a total of 8 sulfurs were identified in lai while 12 sulfurs were identified in durians. Belgis et al reported that sulfur compounds causing the pungent durian smell such as propanethiol, bis(ethylthio)methane, 3-mercapto-2-methyl propanol, 1,1-bis(methylthio)-ethane, and 1,1-bis(ethylthio)-ethane were not found in the lai cultivars sampled. It is reported that this might be a reason why lai has a milder smell than durians. 3,5-dimethyl-1,2,4-trithiolane, reported to contribute to the durian stink, was found in "Mas" lai, but not other lai cultivars. Belgis et al cited Burdock that some sulfur compounds are reported to be responsible for the sulfur stink in durian aroma [19].

3 papers are consolidated in Table. 2 summarising the sulfur compounds found and their contribution to aromatic nuances in durian cultivars [10, 11, 18].

Table 2: Aromatic Contribution of Sulfur Compounds and Cultivars They Are Found in [10, 11, 18]

Sulfur compounds	**Contribution to aromatic nuances**
3-mercapto-2-methyl propanol	Stinky, sulfury, durian-like aroma
Bis(ethylthio)methane	Stinky, sulfury, durian-like aroma
1,1-bis(methylthio)-ethane	Stinky, sulfury, durian-like aroma
Ethanethiol	Rotten onion, rubber odour
Propanethiol	Rotten, durian/ Cabbage, sweet onion-like odour
S-ethyl ethanethioate	Alliaceous coffee odour
Diethyl disulfide	Sulfury, roasty, cabbage-like odour
Methyl propyl disulfide	Powerful penetrating sulfuraceous onion-like odour
Dipropyl disulfide	Pungent sulfur-like onion and garlic odour
Diethyl trisulfide	Sweet and alliaceous odour/ fried shallot
Ethyl propyl trisulfide	Alliaceous, roasted, rubbery odour
3,5-dimethyl-1,2,4-trithiolane	Sulfury, heavy, cocoa odour
3,5-dimethyl-1,2,4-trithiolane	Sulfury, onion odour
Dipropyl trisulfide	Powerful diffusive garlic odour
1,1-bis(ethylthio)-ethane	Burnt, rubbery, alliaceous odour
1-(ethylsulfanyl)ethane-1-thiol	Roasted onion
Methanethiol	Rotten cabbage
Ethane-1,1-dithiol	sulfury , durian
Methyl (2*S*)-2-methylbutanoate	Fruity
1-(methylsulfanyl)ethane-1-thiol	Roasted onion
1-(ethylsulfanyl)propane-1-thiol	Roasted onion
3-methylbut-2-ene-1-thiol	Skunky
1-(ethyldisulfanyl)-1-(ethylsulfanyl)ethane	Sulfury, onion
Hydrogen sulfide	Rotten egg

3.2.2 Esters

Esters are reported to be responsible for the fruity smell of durians [3]. Studies report that different esters contribute different aroma nuances. Esters and their aromatic nuances from 6 studies done are consolidated in Table. 3 and 4 for lai and durian cultivars respectively.

Table 3: Esters and their Aromatic Nuances in Lai Cultivars [5, 18, 19]

Esters	**Contribution to aroma nuances**
Propyl-2-methyl butanoate	Fruity, sweet and pineapple aroma
Propyl propanoate	Fruity, apple and banana-like aroma
Ethyl-2-butenoate	Fruity, rum with caramel aroma

Ethyl octanoate	Fruity and floral aroma
Ethyl-2-methyl butanoate	Stinky aroma

Table 4: Esters and their Aromatic Nuances in Durian Cultivars [5, 6, 10, 11, 19]

Esters	**Contribution to aroma nuances**
Ethyl (2*S*)-2-methylbutanoate	Fruity
Ethyl-2-methylpropanoate	Fruity
Ethyl cinnamate	Honey
Ethyl acetate	Pleasant, ethereal, fruity, brandy-like odour
Methyl propanoate	Fruity odour reminiscent of rum
Ethyl-2-methylpropanoate	Fruity aromatic odour
Propyl acetate	Fruity, pear and raspberry-like odour
Methyl butanoate	Apple-like odour
Methyl-2-methylbutanoate	Sweet fruity, apple-like odour
Ethyl butanoate	Fruity odour with pineapple undertone
Propyl propanoate	Complex fruity odour reminiscent of apple banana
Ethyl-2-methylbutanoate	Powerful, green, fruity, apple-like odour
Ethyl-3-methylbutanoate	Fruity odour reminiscent of apple
Propyl butanoate	Pineapple and apricot-like odour
Propyl-3-methylbutanoate	Fruity odour
Methyl hexanoate	Ether-like odour reminiscent of pineapple
3-methylbutyl propanoate	Pineapple-apricot like odour
Ethyl hexanoate	Powerful fruity odour with pineapple-banana note
Propyl hexanoate	Ether-like odour reminiscent of pineapple
Ethyl heptanoate	Fruity odour reminiscent of cognac, wine-like brandy odour
Methyl octanoate	Powerful winey, fruity, orange-like odour
Ethyl octanoate	Pleasant, fruity, floral odour with wine apricot note

3.2.3 Characteristic Aroma of Durian and Lai Cultivars

Belgis et al reported on the characterisation of lai and durian cultivars in Indonesia by Quantitative Descriptive Analysis (QDA), a method used to characterise aroma through evaluation of sensory properties and subsequent description of these sensory attributes by categories, highlights the type of aroma of each cultivar and identifies chemical compounds possibly influencing these aroma nuances in durian and lai cultivars (as summarised in Table 6 and Table 7) [18]. By identifying the characteristic aroma of the different durian and lai cultivar, it will better inform decisions on breeding and the potential traits that might arise in the new breeds of durian fruits.

Table 5: Characteristic Aroma in Durian Cultivars

Durians	**Characteristic aroma**	**Chemical contribution**
Matahari	Strongest sulfury and fruity aroma amongst durians used in study	Contains highest amount of sulfurs including ● diethyl disulfide, ● ethyl propyl disulfide, ● 1,1-bis(methylthio)-ethane,

		● 1,1-bis(ethylthio)-ethane, ● 3-mercapto-2-methyl propanol
Ajimah	Strongest alcohol and sweet aroma	-
Sukarno	Strongest green and sweet aroma	-
Hejo	Mildest alcohol and sulfury aroma among studied durian	-

Table 6: Characteristic Aroma in Lai Cultivars

Lai	**Characteristic aroma**	**Chemical contribution**
Merah	Strongest fruity aroma amongst lai cultivars used in study	-
Gincu & Kutai	Medium sweet and fruity aroma	-
Mahakam	Mildest fruity aroma	-
Mas	Strong beany, green, floral and nutty aroma	-
Batuah	Mild alcohol and sulfur aroma; Characterised by pleasant fruity and sweet aroma which is likely favoured by consumers.	Likely due to the presence of highest ester ethyl-2-butenoate

3.3 Enhancing Economic Value of Durians: Modifying Aroma, Color, Flavor

The sweet fruity smell of fruits is what attracts consumers but despite having a fruity aroma, the unique sulfur or onion-like odour of the durian fruit turns some consumers away. Smell is a critical factor in influencing consumer decisions. As mentioned in the previous sections, the onion-like odour of durian fruits is unacceptable to many consumers in the market. Apart from sensory attributes, the colour and appearance of durians- often used as a judge of aesthetics and quality- affect consumer decisions [20]. Durians with darker colours are usually less attractive to consumers [21]. Taste of the durian fruit is also an important factor of consideration. As such, these criteria in which consumers use to assess the favourability of durians are important to be looked in order to be improved upon, to increase the economic value of the fruit.

3.3.1 Aroma

Metabolomics of durians reported that amino acids leucine and cysteine are important precursors that contribute to the aroma of fruits, where leucine is responsible for volatile esters while cysteine is responsible for sulfur-containing aroma production [23]. Difference in amounts of the 2 amino acids present in Chanee and Mon Thong durian cultivars reported in a study by Pinsorn et al could possibly account for the difference in aroma volatiles [22].

3.3.2 Colour

Lai cultivars, which have a orange and red colour, are more visually attractive than durian cultivars, which have pale yellowish colour. Association between the yellow and orange colours of durians and lai, and β-Carotene has been established in earlier studies [20, 24].

3.3.3 Flavour

2 cultivars Chanee and Mon Thong durian cultivars from Thailand by Pinsorn et al. The study revealed that metabolites glutamate, citrate, ν-glutamylcysteine, and glutathione, present in durian pulps from both cultivars are taste-related compounds. Amino acids highly abundant in both cultivars, such as alanine, aspartate and glutamate are likely responsible for the flavour of the durian pulps [22]. Another study found that amino acids alanine, proline, phenylalanine and isoleucine are likely to have contributed to the bitter taste in durians sampled [20, 25]. The sweet taste is one of the most important traits in fruits, which is influenced by the sugar content (i.e. sucrose, glucose, fructose, maltose) present. By QDA, lai cultivars from Indonesia were found to have higher sweetness than durian cultivars [20].

4. DISCUSSION

To select candidates for breeding, the analysis of the characteristics of different cultivars could be studied and based on these characteristics' breeders would like to see manifesting in new breeds of durian, they can select accordingly the pair of cultivars. Belgis et al suggested that "Batuah" lai, which has a fruity and sweet aroma, and "Hejo" durian, with the mildest sulfur aroma of all 4 durian cultivars, can be used to produce new cultivars, likely with a milder aroma [18]. Cross breeding has been conducted in previous experiments and their genetic diversity has been studied at the molecular level. By using plant breeding techniques, it is believed that durian cultivars of better quality can be produced [26]. Metabolomics is also important in highlighting important contributors to aroma and flavour of durian fruits. In combination with studies such as those of Belgis et al where they had identified volatile esters and sulfur compounds and their aromatic contribution, further studies can be conducted to investigate how certain metabolites or precursors and their eventual product formation can be manipulated to change the aromatic nuances in durians [20]. Metabolites resulting in the formation of sulfur compounds such as 3,5-dimethyl 1,2,4-trithiolane, diethyl disulfide, 3-mercapto-2-methyl propanol, bis(ethylthio)methane, 1,1-bis(methylthio)-ethane, and 1,1-bis(ethylthio)-ethane, which contributes to the pungent durian odour, may be further studied to look at possible inhibition of pathways leading to the formation of such sulfur compounds. Since research has been conducted on the durian genome, the identification of important metabolites and precursors can potentially enable genetic modification of the durian genome to enhance favourable traits in durians [23]. The genes coding for metabolites and precursors can be manipulated, perhaps modifying amounts of esters formed to enhance the fruity aroma, amounts of β-Carotene produced to enhance the colour of durian cultivars, amounts of sugars and amino acids produced to change the flavour nuances of durians, and remove unfavourable traits such as the onion-like odour disliked by many consumers. Since dark colours are visually less attractive to consumers, molecules resulting in the dark colour of the durian pulp and methods to lighten the colour by modifying such molecules merits further studies. Price differentiation amongst different durian cultivars exist and are influenced by demand as some cultivars are preferred by consumers over others. With the improvement of durian cultivars to be acceptable by more consumers, a general increase in demand will follow and as such, the economic value of the durians can be increased.

5.CONCLUSION

In conclusion, considering that the aroma of durians is unbearable to many, and its smell being an issue in air travel, further studies can analyses consumer preferences in relation to the aromatic contributions of specific esters and sulfur-containing compounds in durians. This would allow understanding of the science behind the appeals or rejection of the fruit. Future material science research, in relation to esters and sulfur-containing compounds identified to contribute to smell, can be conducted to mitigate issues regarding diffusion of the durian aroma. With this, the probability of durian batches removed from air travel will be minimised, reducing losses and thereby also expanding the market of durians

amongst individual consumers who adopt air travel transport. Considering that studies report lai cultivars as good candidates for durian hybridisation, it highlights the possibility of other *Durio* cultivars as potential choices for durian hybrid production. Further research is recommended to explore new combinations for breeding and the aromatic profiles of new hybrids produced. Players in the durian industry should look at enhancing factors taste, appearance and aroma according to consumer preferences to leverage on the rising demands for durians. This is the recommended approach to increasing the economic value of durians.

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