J. Hortl. Sci.
Vol. 12(2) : 109-117, 2017

Original Research Paper

Seasonal influence on volatile aroma constituents of two banana cultivars (Grand Naine and Nendran) under Kerala conditions

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ABSTRACT

Banana is a tropical fruit with a pleasant flavour, widely consumed throughout the world. Volatile aroma compounds are responsible for olfactory flavor of banana. However, the development of aroma flavors is affected by the atmospheric temperatures during fruit growth period. In order to get good quality fruits in terms of aroma it is essential to understand the optimum temperature for maximum aroma production. The approach used in this study was to alter the dates of harvest to understand the optimum temperature required for maximum production of volatile compounds under Kerala conditions. The results revealed that with increased temperature volatile aroma compounds decreased in cvs. Grand Naine and Nendran. Total volatile compounds were higher in cv. Grand Naine compared to cv. Nendran. Cultivar Nendran recorded increased concentrations of esters, alcohols and decreased aldehydes, ketones, hydrocarbons and acids at high temperatures. Phenols and other constituents did not show much variation with respect to the temperature variation in both the cultivars. Among esters, Isoamyl butanoate and 3-Methylbutyl-3-methylbutyrate esters were the most abundant in both the cultivars. Ketones, especially 4-Methyl-1-penten-3-one was higher in cv. Nendran whereas esters were lower compared to cv. Grand Naine. Total area of aroma constituents in cultivars Grand Naine and Nendran were high in October followed by February with mean atmospheric temperature of 30.5°C and 32.6°C respectively. In case of cv. Nendran, total area of esters and alcohols were maximum at high temperature (34.5°C) but in cv. Grand Naine, esters and alcohols decreased with high temperature. Results indicated that fruits harvested in October were better in terms of volatile aroma quantity in both the cultivars due to lower atmospherictemperature. Seasonal variations affected the two cultivars differentially in terms of percentage of groups of volatile compounds.

Key words: Banana, volatile compounds, atmospheric temperature, SPME, GC-MS

INTRODUCTION

Banana (*Musa* spp.) is one of the most widely distributed and consumed fruits in the world. It is grown extensively in tropical and subtropical regions and is an economically important fruit crop (Selli *et al*, 2012). The fruit aroma is one of the most important factors, which determines the consumer acceptability and the quality of bananas. More than 350 aroma compounds have been identified in bananas. Most of the components are esters, alcohols, and carbonyl compounds (Berger, 1991). The biosynthetic pathways for production of aroma compounds involved β-oxidation, hydroxyacid cleavage (leading to lactones), and lipoxygenase to form aldehydes, ketones, acids, alcohols, lactones, and esters from lipids (Heath and

Reineccius, 1986; Dixon and Hewett, 2000). Esters of acetate and butyrate have been reported to play an important role in the aroma of fully ripe banana fruit; however, isoamyl acetate and isobutyl acetate have generally been regarded as the key characteristic compound in the aroma of banana fruit (Marriot, 1980; El Hadi *et al,* 2013). Other researchers have also investigated aroma compounds of banana. The concentrations of acetates and butanoates increased during ripening of banana fruit (Jayanty *et al,* 2002). In addition, isoamyl alcohol, isoamyl acetate, butyl acetate, and elemicine were detected by olfactometric analyses as characteristics of banana odor (Boudhrioua *et al,* 2003). Volatile esters, such as 3-methylbutyl-acetate and 2-methylbutyl-acetate, also contribute to the characteristic banana flavor of the fruits. Fatty acids are major precursors of aroma volatiles in most fruit (Sanz *et al,* 1997).

Aroma volatiles are affected by abiotic factors such as temperature and humidity (Takabayashi *et al,* 1994; Gouinguene and Turlings, 2002). High temperatures influence the biosynthesis of volatiles in banana fruit at the transcriptional level and confirm the findings that high temperatures cause stress in banana fruit during ripening. In banana, high temperature resulted in elevated levels of ethanol, ethyl acetate and other acetate esters. Higher expression level of Ban BCAT was found in pulp which correlated well to volatile production in banana fruit, indicating the role of Ban BCAT in regulating the formation of branched aroma compounds during banana fruit ripening (Yang *et al,* 2011). Wills and McGlasson (1971) concluded that volatile concentrations increase as temperature increases, although production rate is reduced above 32°C. High temperature can cause a dramatic increase in the production of off-flavour aroma compounds during the storage of fruits (Liu and Yang, 2002; Petracek *et al,* 2002).

The main objective of this study was to investigate the effect of seasonal temperature during fruit growth period on the volatile aroma quality of Banana fruits of cvs. Grand Naine and Nendran under Kerala conditions.

MATERIAL AND METHODS

Effect of seasonal temperature on volatile aroma constituents in banana varieties [cv. Grand Naine (GN), and Nendran] grown in Kerala region were studied. Fruit samples were collected at full maturity stage at quarterly intervals during the period October 2013 to February 2015 from Kerala region along with the data on temperature from shooting to harvest period **(Table 1)**. Harvested fruits were ripened at room temperature. The room temperature during fruit ripening period was recorded and is given in **Table 2**. Volatile aroma constituents were analyzed in the Fruit Biochemistry laboratory of ICAR-IIHR, Bengaluru, by headspace-solid phase micro-extraction (HS-SPME) technique using capillary GC and GC-MS/MS.

Table 1. Mean maximum temperature (°C) from shooting to harvest period

		Months of Harvest				
Region	Varieties	2013-Oct	2014-Feb	2014-Jun	2014-Oct	2015-Feb
Kerala	Grand Naine	33.3	34.5	33.8	30.5	32.6
	Nendran	33.3	34.5	33.8	30.5	32.6

Table 2. Mean room temperature (°C) from harvest to ripe period

		Months of Harvest				
Region	Varieties	2013-Oct	2014-Feb	2014-Jun	2014-Oct	2015-Feb
Kerala	Grand Naine	28.0	27.2	30.5	29.5	29.4
	Nendran	28.0	27.2	30.5	29.5	30.0

SPME Extraction of Volatiles

Earlier studies have reported the extraction and analysis of head space volatiles of banana fruits by using SPME fiber (Facundo *et al,* 2012; Pino and Febles, 2013). SPME fiber device coated with DVB/CAR/PDMS (50/30 µm, highly crossed linked) was first conditioned at 250°C for 2 hours. The extraction process for head space volatiles from fresh banana fruit pulp was followed as described by (Facundo *et al,* 2013) with slight modification. A known quantity (50 g) of fresh cut ripe banana fruits was macerated to slurry by using a pre-chilled homogenizer, the slurry was transferred with 100 ml of double distilled water and 0.5 g of solid NaCl to the 250 mL flasks with silicon rubber caps. The flasks with slurry were kept on a magnetic stirrer after an incubation period of 20 minutes. The solid phase micro-extraction fibre was inserted into the flask through the silicon rubber stopper and was allowed to adsorb all the volatiles for 2 hrs with continuous stirring. Later the fibre was removed and injected into a gas chromatography-mass spectrometry for separation and identification of compounds.

~~Gas Chromatography and~~ Gas Chromatography-Mass Spectrometry analysis

Subsequently, The SPME device was injected into the injector port for GC analysis and was remained in the inlet for 15 min. The GC/MS analysis was carried out using a Varian-3800 Gas Chromatograph coupled to a Varian-4000 Ion-Trap mass spectrometer. The MS column VF-5MS (Factor four) (Varian, USA) fused-silica capillary column of 30 m x 0.25 mm id, 0.25 mm film thickness was used for the analysis. The injector temperature was set at 250ºC and all injections were made initially in split (1:20) mode for 0.5 min followed by split-less. The detector temperature was 270°C, and the temperature programmes for column was as follows: 40°C for 3 min at an increment 3°C/min to 190°C, hold for 1 min, then 5°C/min to 220°C and maintaining the constant temperature for 5 min.

The mass spectrometer was operated in the external electron ionization mode with the carrier gas helium 1 ml/min; injector temperature, 250°C; trap temperature 180°C, ion source-heating at 190°C, transfer line temperature 260°C, EI-mode was 70 eV, with full scan-range 50-350 amu was used. The total volatile production was estimated by the sum of all GC peak areas in the chromatogram and individual compounds was quantified as relative percent area and the compounds were identified by comparing the retention index which was determined by using homologous series of n-alkanes (C_5 to C_{32}) as standard (Kovats, 1965) and comparing the spectra using two spectral libraries available as Wiley and NIST-2007.

RESULTS AND DISCUSSION

More than 50 major volatile compounds were identified in both the cultivars irrespective of the seasons **(Table 3)**. The results revealed that with increased temperature, the quantity of volatile aroma compounds decreased in cvs. Grand Naine and Nendran. Total area of aroma constituents in cultivars Grand Naine and Nendran were high in October month followed by February with mean atmospheric temperature of 30.5ºC and 32.6ºC respectively **(Table 4)**. The various groups of aroma compounds found in banana cultivars were esters, alcohols, aldehydes, ketones, acids, phenols, hydrocarbons and few others **(Table 3)**.

Table 3. Volatile components identified in banana cvs. Grand Naine and Nendran by gas chromatography–mass spectrometry analysis

Volatile components	KI	2013-October		2014-February		2014-June		2014-October		2015-February	
		Grand Naine	Nendran	Grand Naine	Nendran	Grand Naine	Nendran	Grand Naine	Nendran	Grand Naine	Nendran
		(%)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Esters											
Ethyl Acetate	614	0.17	0.52	0.07	0.68	0.18	0.51	0.18	0.22	0.04	0.22
Ethyl butanoate	799	0.06	-	0.08	-	0.06	-	0.11	-	0.14	-
Methyl 2-propenoate	812	-	7.45	-	8.53	-	7.99	-	4.45	-	4.92
1-Butyl acetate	813	0.05	-	0.02	-	0.27	-	0.12	-	0.03	-

Volatile components	KI	2013-October		2014-February		2014-June		2014-October		2015-February	
		Grand Naine	Nendran	Grand Naine	Nendran	Grand Naine	Nendran	Grand Naine	Nendran	Grand Naine	Nendran
		(%)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)3-
Methyl-2-butenyl formate	867	-	0.12	-	0.26	-	0.22	-	0.32	-	0.13
Isoamyl acetate	876	0.09	0.05	0.09	0.24	0.04	0.07	0.13	4.54	0.04	0.92
Propyl butanoate	897	0.63	0.13	0.91	1.21	0.68	0.79	1.46	0.26	1.65	0.43
Propyl pivalate	899	0.29	2.82	0.12	3.80	0.11	3.52	0.03	0.83	0.08	0.74
Isopentyl acrylate	910	0.89	1.82	1.73	2.56	0.93	0.76	0.30	0.84	0.39	1.78
Propyl isovalerate	949	-	0.15	-	0.71	-	0.54	-	0.19	-	0.32
1-Butyl butyrate	994	1.22	0.55	2.94	1.62	1.27	0.51	1.14	0.40	0.06	1.06
2-Methylpropyl 3-methylbutyrate	1003	0.51	0.25	0.91	1.41	0.46	1.02	0.67	0.99	0.24	0.11
1-Butyl isovalerate	1010	0.92	0.84	1.96	1.39	0.80	0.76	0.54	0.76	0.15	0.78
Isoamylbutanoate	1056	20.39	9.64	23.02	9.57	22.60	8.47	18.71	5.03	18.90	5.74
1-Pentyl butyrate	1094	2.21	1.96	2.26	0.28	2.11	0.59	4.81	0.18	4.47	0.93
3-Methylbutyl 3-methylbutyrate	1094	17.74	10.34	18.02	8.97	16.98	9.20	11.58	2.12	10.57	3.75
iso-Amyl 2-methyl butyrate	1102	0.53	9.34	0.63	10.32	0.53	9.66	0.50	3.75	0.46	4.15
1-Methylbutyl pentanoate	1118	0.06	-	0.10	-	0.06	-	0.08	-	0.23	-
Amyl valerate	1183	-	0.37	-	1.43	-	0.39	-	0.50	-	0.41
Butyl hexanoate	1186	1.03	0.50	0.16	0.15	0.95	0.76	1.22	0.06	0.38	0.34
Hexyl butyrate	1190	0.13	-	0.15	-	0.14	-	4.71	-	4.85	-
Butyl sorbate	1199	0.12	0.36	0.06	0.80	0.13	0.41	0.40	0.19	0.14	0.05
Isopentylhexanoate	1208	0.77	-	0.44	-	0.02	-	0.01	-	0.01	-
HeptyIisobutyrate	1218	1.79	0.15	0.83	0.53	1.80	0.13	1.63	0.12	3.32	0.12
cis-3-Hexenyl-α-methylbutyrate	1226	5.80	1.24	6.38	1.21	5.77	1.36	2.20	1.01	1.38	0.96
Cyclopentylpentanoate	1226	-	0.17	-	0.81	-	0.09	-	0.17	-	0.21
Hexyl 3-methylbutanoate	1245	5.56	1.80	5.99	1.37	5.81	1.37	2.03	0.83	1.18	0.28
Linalyl acetate	1256	0.12	0.35	0.02	0.38	0.10	0.16	0.13	0.16	0.27	0.17
4-Pentenyl hexanoate	1272	3.49	-	1.01	-	3.50	-	2.75	-	3.50	-
Heptylbutanoate	1282	3.17	0.17	1.78	0.13	3.13	0.44	7.28	0.12	9.52	0.15
1-Cyclohexyl pentanoate	1345	0.78	-	0.51	-	0.88	-	0.10	-	0.21	-
Isobutyl decanoate	1545	-	0.46	-	0.43	-	0.30	-	0.26	-	0.43
Ethyl dodecanoate	1597	-	0.53	-	0.67	-	0.34	-	0.26	-	0.72
Isoamyllaurate	1844	-	2.30	-	0.86	-	0.89	-	0.74	-	0.93
Acetic acid,1,4-dimethylpent-4 -enyl esters		0.17	0.20	0.36	0.94	0.14	0.17	0.62	0.37	0.23	0.34
n-Hexyl-trans-hexen-2-oate		0.16	0.34	0.01	0.41	0.15	0.48	0.01	0.37	0.04	0.29
Alcohols											
Hexynol	778	-	0.12	-	0.16	-	0.29	-	0.14	-	0.12
2,3-Dimethyl-1-pentanol	832	0.02	-	0.02	-	0.02	-	0.03	-	0.03	-
1-Hexanol	841	0.09	1.85	0.15	2.74	0.07	1.74	0.04	0.61	0.04	0.50
1-Methyl-2-cyclohexen-1-ol	913	-	0.63	-	0.78	-	0.84	-	0.18	-	0.21
(3E,6E)-3,6-Nonadien-1-ol	1175	-	0.38	-	0.24	-	0.25	-	0.47	-	0.82
Citronellol	1223	0.47	-	0.22	-	0.45	-	0.29	-	0.41	-
10-Undecyn-1-ol	1355	1.00	-	0.16	-	0.83	-	0.66	-	0.22	-
(8E,10E)-8,10-Dodecadien-1-ol	1473	0.95	-	1.28	-	2.01	-	7.14	-	3.45	-
1-Dodecanol	1473	-	0.15	-	1.22	-	0.40	-	0.42	-	0.72

Volatile components	KI	2013-October		2014-February		2014-June		2014-October		2015-February	
		Grand Naine	Nendran	Grand Naine	Nendran	Grand Naine	Nendran	Grand Naine	Nendran	Grand Naine	Nendran
		(%)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)1-
Tridecanol	1569	0.14	-	0.15	-	0.22	-	0.03	-	0.13	-
(3Z,6Z)-Dodeca-3,6-dien-1-ol		0.46	-	0.17	-	0.44	-	0.95	-	0.65	-
(E)-5-Decen-2-ol		-	0.89	-	1.78	-	1.15	-	0.25	-	0.35
Aldehydes and Ketones											
3-Methylbutanal	654	0.25	1.12	0.34	1.40	0.26	1.31	0.11	1.67	0.06	2.06
4-Methyl-1-penten-3-one	680	0.18	11.82	0.24	6.15	0.20	12.31	1.31	22.57	0.76	15.47
(E)-2-Hexenal	848	0.55	-	0.05	-	0.65	-	0.16	-	1.02	-
2-Heptanone	891	0.12	-	0.11	-	0.11	-	0.09	-	0.03	-
Pulegone	1176	1.24	0.27	1.21	1.43	1.32	0.94	1.16	0.03	0.94	0.08
1-(3-Cyclohexen-1-yl)-2,2-dimethyl-1-propanone	1212	0.84	0.07	0.67	0.04	0.86	0.06	1.45	1.57	1.48	1.14
6-Dodecanone	1350	-	0.15	-	1.45	-	1.54	-	2.20	-	1.80
Dodecanal	1409	0.44	-	0.33	-	0.44	-	0.33	-	0.29	-
7-Tridecanone	1449	0.41	0.24	0.02	0.27	0.13	0.51	0.02	1.15	0.16	1.54
trans-β-Ionone	1482	-	1.02	-	0.68	-	0.66	-	0.81	-	1.45
2-Tetradecanone	1597	-	0.80	-	0.53	-	1.01	-	2.20	-	2.42
(9Z)-9,17-Octadecadienal	1997	0.09	5.35	0.03	0.61	0.03	3.07	0.03	1.00	0.02	1.36
Acids											
4-Butoxybutanoic acid	1249	0.53	0.41	0.47	0.17	0.47	0.30	0.43	0.45	0.45	1.72
8-Nonenoic acid	1262	2.14	0.34	1.37	0.54	1.77	0.55	5.41	0.54	5.03	1.09
Phenols											
Eugenol	1356	0.22	0.35	0.68	0.41	1.19	0.91	0.49	0.20	2.18	0.25
Hydrocarbons											
Decane	1015	0.02	2.97	0.02	2.30	0.04	3.29	0.05	6.19	0.01	6.29
cis-1,2-Dichlorocyclohexane	1052	0.99	0.66	0.25	0.40	0.28	0.21	0.54	0.30	0.75	0.12
(±)-Dictyopterene A	1076	1.41	-	1.11	-	1.08	-	3.76	-	3.61	-
3-Hexyl-1-cyclopentene	1140	0.54	-	0.60	-	0.58	-	0.69	-	1.04	-
Naphthalene	1179	0.51	-	0.04	-	0.04	-	0.08	-	0.06	-
Tetradecane	1214	-	0.80	-	2.43	-	2.19	-	1.53	-	1.07
(5E,7E)-5,7-Dodecadiene	1230	3.39	0.32	4.10	0.22	3.10	1.10	1.32	0.41	2.92	0.29
(2E,4Z)-2,4-Dodecadiene	1230	0.42	-	0.27	-	0.29	-	0.09	-	0.26	-
(2Z)-2-Dodecen-4-yne	1239	0.36	-	0.33	-	0.18	-	0.05	-	0.90	-
(3Z)-3-Tetradecen-5-yne	1438	1.00	-	1.05	-	0.98	-	0.28	-	0.99	-
α-Selinene	1478	-	1.15	-	0.61	-	0.61	-	0.46	-	0.69
Pentadecane	1512	-	1.44	-	1.75	-	1.28	-	14.92	-	14.78
δ-Selinene	1532	-	0.79	-	0.78	-	0.69	-	0.90	-	1.27
C16 Hydrocarbon		-	1.02	-	1.75	-	0.76	-	0.86	-	1.10
Others											
2-Amyl furan	989	-	0.99	-	0.24	-	0.53	-	0.74	-	0.81
Isoelemicin	1568	0.35	2.60	0.36	1.46	0.39	3.11	0.08	1.52	0.15	1.06
2,2-Diisopropyltetrahydrofuran		2.59	0.71	1.60	0.18	1.46	0.56	2.29	0.13	2.05	1.62
cis-epoxy ocimeme		4.45	0.66	7.03	0.58	5.51	0.90	2.16	0.52	2.43	1.43

* Is the relative percentage of compounds

Esters were the most abundant volatile aroma constituents in both the cultivars compared to other group of volatiles **(Table 4)**. Among esters, Isoamyl butanoate and 3-Methylbutyl-3-methylbutyrate esters were found most abundant in both the cultivars. Similarly, esters were quantitatively the dominant group of volatiles in ripe banana fruits (Wyllie and Fellman, 2000). Esters account for about 70% of the volatile compounds and acetates and butyrates predominate (Seymour, 1993). Esters were produced from the enzymatic actions on alcohols and acyl CoA's derived from both fatty acid and amino acid metabolism (Wyllie and Fellman, 2000). Berger (1991) reported that 3-Methylbutyl acetate was considered to be the dominate banana flavor and it was the key odor-impact volatile in banana fruit followed by butanoate and 3-methylbutanoate. In our study, with increased seasonal temperature, total area of volatile aroma compounds decreased in cvs. Grand Naine and Nendran. Isoamylbutanoate (23.02%) and 3-Methylbutyl-3-methylbutyrate (18.02%) esters were the major esters found high at high temperature (34.5ºC) in cv. Grand Naine. Hexyl butyrate and Heptyl butanoate esters were found high at low temperature of 30.5ºC and 32.6ºC where as least was observed during low temperature in both the cultivars. Cultivar Nendran recorded increased concentrations of esters at high temperatures. Wills and McGlasson (1971) concluded that volatile concentrations increase as temperature increases, although production rate is reduced above 32°C. Ester concentrations and rates of production of 'Jonathan' apples increased as temperature increased. The biosynthetic pathway for the formation of volatile esters in ripening climacteric fruits is well-established (Arvanitoyannis and Mavromatis, 2009). Nogueira *et al* (2003) investigated that the ester (57.2-89.8 mg/kg) appeared to play an important role in the characteristics of the composition of volatiles of Dwarf Cavendish, Giant Cavendish and Robusta banana cultivars. Methyl-2-propenoate (8.53%) and iso-Amyl-2-methyl butyrate (10.32%) were recorded highest in cv. Nendran whereas least in cv. Grand Naine at high

Table 4. Percent change in area under curve of volatile components when compared to fruits (cvs. Grand Naine and Nendran) harvested during October 2014 which showed maximum area under curve.

Volatile components	2013-October		2014-February		2014-June		2014-October		2015-February	
	Grand Naine	Nendran	Grand Naine	Nendran	Grand Naine	Nendran	Grand Naine	Nendran	Grand Naine	Nendran
	(%)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Esters	6511854 (-48.2)	471511 (+20.5)	6275480 (-50.0)	503442 (+28.7)	6456552 (-48.6)	444040 (+13.5)	12559920	391141	11799107 (-6.1)	333602 (-14.7)
Alcohols	295804 (-83.6)	34534 (+27.8)	191349 (-89.4)	56561 (+109.4)	376514 (-79.2)	39958 (+47.9)	1808978	27013	932449 (-48.5)	28887 (+6.9)
Aldehydes and Ketones	389894 (-57.8)	178910 (-58.6)	264420 (-71.4)	102606 (-76.3)	371524 (-59.8)	183175 (-57.6)	923857	432140	897960 (-2.8)	290595 (-32.8)
Acids	251960 (-78.2)	6478 (-50.0)	163553 (-85.8)	5833 (-54.9)	208115 (-82.0)	7262 (-43.9)	1155835	12945	1034967 (-10.5)	29924 (+131.2)
Phenols	20836 (-78.4)	3012 (+18.4)	60184 (-37.6)	3347 (+31.6)	110434 (-14.6)	7821 (+207.6)	96373	2543	411324 (+326.8)	2654 (+4.4)
Hydrocarbons	818419 (-39.8)	78454 (-76.4)	691594 (-49.1)	83593 (-74.9)	609114 (-55.2)	86707 (-73.9)	1358478	332830	1989832 (+46.5)	272279 (-18.2)
Others	698792 (-21.9)	42568 (+12.3)	798430 (-10.8)	20168 (-46.8)	683019 (-23.7)	43623 (+15.1)	895284	37915	874552 (-2.3)	52358 (+38.1)
Total Area	**8987559 (-52.2)**	**815467 (-34.1)**	**8445010 (-55.1)**	**775550 (-37.3)**	**8815272 (-53.1)**	**812586 (-34.3)**	**18798725**	**1236527**	**17940191 (-4.6)**	**1010299 (-18.3)**

*Values mentioned in the parenthesis are percent reduction in volatile components over October 2014

- indicates the decrease in volatiles + indicated the increase in volatiles temperatures. In case of cv. Nendran, esters were maximum at high temperature (34.5ºC) but in cv. Grand Naine, esters decreased with high temperature. Results indicated that fruits harvested during October month followed by February were better in terms of esters volatile aroma quantity in both the cultivars due to lower growth temperature. Guactagni *et al* (1971) concluded that the 'Red Delicious' apples had maximum ester production at low temperature; it decreased at 32°C and was inhibited at 46°C indicating that temperature inhibit or inactivate enzymes responsible for producing volatiles.

Cultivar Nendran recorded increased concentrations of alcohols at high temperatures (34.5ºC) whereas least in cv. Grand Naine. Nogueira*et al* (2003) recorded that the alcoholic fractions (19.0-47.7 mg/kg) appeared to play a significant role in the sensorial characteristics of banana fruit. Variation in volatiles was affected by abiotic factors such as temperature and humidity (Vallat *et al,* 2005). In our study, 1-Hexanol followed by (E)-5-Decen-2-ol were found maximum in cv. Nendran; similarly, (8E,10E)-8,10-Dodecadien-1-ol was higher in cv. Grand Naine irrespective of the seasons **(Table 3)**. Results indicated that fruits harvested at February month followed by October were better in terms of alcohols volatile aroma quantity in both the cultivars due to lower growth temperature. Alcohol concentrations and rates of production of 'Jonathan' apples increased as temperature increased (Wills and McGlasson, 1971). Volatile production is considered to be proportional to temperature, the higher the temperature, the greater the production of volatiles (Fallik *et al,* 1997). However, the volatile aroma production seems to increase only up to a certain temperature beyond that the production decreases. Fatty acids serve as the precursor for alcohols which could be generated through lipoxygenase pathway of unsaturated linoleic and linolenic acids (Perez *et al,* 1999). In many types of fruits, through the action of lipoxygenase isozymes, linoleic and linolenic acids are degraded and produce fatty acid hydroperoxides. Hydroperoxide lyase converts these fatty acid hydroperoxides to aldehydes and oxoacids, while alcohol dehydrogenase acts on them to produce the corresponding alcohols (Sanz *et al,* 1997).

Increased temperature resulted in decreased aldehydes and ketones in cvs. Grand Naine and Nendran. Total concentrations of aldehydes and ketones were maximum in cv. Nendran **(Table 4)**. Ketones, especially 4-Methyl-1-penten-3-one followed by (9Z)-9,17-Octadecadienal and 3-Methylbutanal were higher in cv. Nendran whereas these compounds were lower in cv. Grand Naine. Total concentrations of aldehydes and ketones in cultivars Grand Naine and Nendran were high in October followed by February with mean growth temperature of 30.5ºC and 32.6ºC respectively **(Table 4)**. Hexanal concentrations of 'Cortland' and 'Mclntosh' apples had the same pattern of change, irrespective of temperature (Yahia *et al,* 1990b; Yahia *et al,* 1991).

A few hydrocarbons were also identified in the present study **(Table 4)**. Hydrocarbons were present in high proportions in cv. Nendran compared to cv. Grand Naine. Varieties of hydrocarbons have been detected in banana cultivars (Shiota, 1991). Total concentration of hydrocarbons especially, pentadecane was high in October month (14.92%) followed by February (14.78%) in cv. Nendran with mean growth temperature of 30.5ºC and 32.6ºC respectively. But in cv. Grand Naine, pentadecane was totally absent. Decane and tetradecane were also present in high proportions in cv. Nendran. Similarly, in cv. Grand Naine, hydrocarbons were high in October with mean growth temperature of 30.5ºC. The concentrations of (5E,7E)-5,7-Dodecadiene followed by (±)-Dictyopterene were maximum in cv. Grand Naine. Temperature may also affect production of specific volatiles with some compounds only being produced at certain temperatures by affecting rates of substrate supply and volatile biosynthesis. If this is so then the different biosynthetic pathways producing volatiles may be active at different rates according to temperature (Dixon and Hewett, 2000).

There were two kinds of acids namely; 4-butoxybutanoic acid and 8-nonenoic acid were found in cultivars Grand Naine and Nendran **(Table 3)**.Maximum concentrations of acids were found in cv. Grand Naine compared to cv. Nendran at low temperature where as minimum were recorded at high temperature. Fallik *et al* (1997) concluded that the high temperature (38°C) reduced volatile production in 'Golden Delicious' apples compared to low temperature. Most of the acids were probably derived from β-oxidation of fatty acids. During fruit ripening, fatty acids, more precisely acyl-CoA derivatives, are metabolized to shorter-chain acyl-CoAs by sequentially losing 2 carbons during each round of the β-oxidation cycle (Sanz *et al,* 1997). A phenol such as eugenol was present in both the cultivars and did not show much variation with respect to the temperature in both the cultivars. Other constituents such as isoelemicin were found maximum in cv. Nendran similarly cis-epoxy ocimime followed by 2,2-diisopropyltetrahydrofuran were found maximum in cv. Grand Naine. At high temperature (34.5ºC), other constituents were recorded high in cv. Grand Naine but in cv. Nendran, did not show much variation with respect to the temperature.

ACKNOWLEDGEMENT

This work was carried out under the project on "National Initiative on Climate Resilient Agriculture (NICRA)", Indian Council of Agricultural Research (ICAR), New Delhi. The authors are grateful to the Director, IIHR, Bengaluru for providing the necessary facilities.

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(*MS Received 18 August 2017, Revised 22 October 2017, Accepted 15 December 2017)*