Analysis of Aroma Compounds in Trapping Solvents of Smoke from Tian Op, a Traditional, Thai, Scented Candle

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ABSTRACT

To study the composition of "Tian Op" smoke, gas chromatography-olfactometry, aroma extract dilution analysis (AEDA) and gas chromatography-mass spectrometry (GC-MS) were applied to identify the potent odorants in smoked flavoring using three trapping solvents: propylene glycol, glycerol and water. Based on the results of AEDA-calculated odor-activity values, the predominant odorants in the Tian Op flavoring were vinyl ketones (C_5-C_9), n-aldehydes (C_5-C_{11}), (E)-2-unsaturated aldehydes (C_8-C_{11}) and ω-1-unsaturated aldehydes (C_8 and C_9). These components were found in the highest quantities when propylene glycol was used as the trapping solvent, followed by glycerol and water, respectively.
Key words: Tian Op, beeswax, candle, smoke, aroma, aroma extract dilution analysis (AEDA)

INTRODUCTION

The most important and unique characteristics of Thai desserts are their flavor and appearance. Jasmine (*Jusminum adenophyllum*), Pandanus leaves (*Pandanus amaryllifolius* Roxb.) and Tian Op are widely used to enhance and feather odor in many Thai desserts. Tian Op is well known as the traditional scented candle in Thailand that has been used for fumigation. The main ingredients of Tian Op are beeswax, benzoin (*Styrax benzoin* Dryand), kaffir lime (*Citrus hystrix* DC.) peel, sandalwood (*Santalum album*), and Borneo camphor (*Pogostemon calslin* Benth). Each ingredient is believed to add to the aromatic complexity of the smoke emitted from the Tian Op candle when it is burned. Depending upon the type and quantity to be processed, the dessert is 'smoked' in a closed container for 30-60 min for three to five times until the desired flavor is achieved. Some potential drawbacks in the traditional Tian Op smoking process are that flavor quality and intensity may not be the same for every piece of dessert within the smoking chamber and, furthermore, sometimes a black carbonaceous residue is deposited on the surface of the dessert.

Limited studies have been conduced on the volatile components of the ingredients of Tian Op. The main components of beeswax are nonvolatile high-molecular-weight waxes, including 14% hydrocarbons, 35% monoesters, 14% diesters, 3% triesters, 4% hydroxy monoesters, 8% hydroxyl polyesters, 1% acid esters, 2% acid polyesters, 12% free acids, 1% free alcohols and 6% unidentified compounds (Tulloch, 1980).

Ferber and Nursten (1977) reported that *p*-cymene, limonene, *cis-* and *trans*-linalool oxide, a-terpineol, guaiacol, phenol, a cresol, octanal, nonanal, decanal and benzaldehyde were the major

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volatile components of molten (65°C) beeswax. Benzoin is the resin of the styrax tree (*Styrax benzoin*, Dryand) and contains coniferyl cinnamate, sumaresiloic acid, benzoic acid, cinnamic acid, stylene, vanillin and benzaldehyde as its main chemical components (Lawless, 1995). (Z)-α-santalol and (Z)-β-santalol are the main volatile components of sandalwood essential oil (Howes *et al*., 2004). Kaffir lime peel oil is composed of 2.5% α-pinene, 0.25% camphene, 30.6% β-pinene, 22.6% sabinene, 1.4% myrcene, 29.2% limonene, 1.3% cineol, 0.1% g-terpinene, 0.1% *p*-cymene, 0.1% terpinolene, 0.6% *trans*-sabinene hydrate, 4.2% cintronellal, 0.6% copaene, 0.5% linalool, 0.5% β-cubebene, 4.2% terpinen-4-ol, 0.3% caryophyllene, 0.2% citronellyl acetate 0.2% α-terpineol, 0.1% geraneol, 0.4% citronellol, 0.3% δ-cadinene, 0.1% geraneol, 0.1% nerolidol and 0.3% elemol (Lawrence *et al*., 1971).

In order to study the components in smoke and to develop an alternative Tian Op flavoring, the trapping solvents were investigated. Attaviroj (2003) determined the optimum compositions of solvent solutions used to trap smoke from bagasse and coconut husk. It was found that a 5% propylene glycol solution was a suitable trapping medium because the quantities of phenolics, carbonyls, furans, polycyclic aromatic hydrocarbons and acid compounds in the trapped solution were higher than those quantities obtained using glycerol or water.

Propylene glycol, also known by the systematic name of propane-1,2-diol, has two hydrophilic alcoholic hydroxyl groups (OH⁻). It is an organic compound (a diol alcohol), and is usually a tasteless, odorless, colorless, clear, oily liquid that is hygroscopic and miscible with water, acetone and chloroform. It is manufactured by the hydration of propylene oxide. Propylene glycol is generally recognized as safe (GRAS) by the USA Food and Drug Administration (FDA) for use as a direct food additive under the conditions prescribed. It is approved by the FDA for certain indirect food additive uses. Propylene glycol has a wide range of practical applications and is a component in: anti-freeze, coolants, aircraft de-icing fluid; heat transfer and hydraulic fluids, solvents; food items, flavors, fragrances, cosmetics and personal care products, pharmaceuticals intermediate chemical substances, plasticizers; and thermoset plastic formulations (Greenwood and Earnshaw, 1997).

A method of producing a liquid smoke from wood tar was developed for use in food processing using propylene glycol as a trapping solvent. The liquid smoke product that was produced contained neither detectable amounts of 3,4-benzopyrene nor components of the heavy, essentially water-insoluble material that settled out of an aqueous condensation of wood smoke. Most of these components are soluble in propylene glycol (Dainius *et al.,* 2006).

Glycerol, also well known as glycerin and glycerine, is a colorless, odorless, hygroscopic, sweet-tasting, viscous liquid. Glycerol is a sugar alcohol with three hydrophilic alcoholic hydroxyl groups (OH⁻) that are responsible for its solubility in water. It is produced from dihydroxyacetone phosphate (DHAP) by the enzyme, glycerol three-phosphate dehydrogenase (Gpd p) in the cytoplasm of the eukaryotic cell during glycolysis. When referring to its function in living organisms, the term glycerol is preferred. Glycerol is an important component of triglycerides (i.e. fats and oils) and of phospholipids. It is a three-carbon substance that forms the backbone of fatty acids in fats (Greenwood and Earnshaw, 1997).

The objective of this study was to apply gas chromatography-olfactometry and aroma extract dilution analysis as identification methods for the intensity of odorants using three different solvents, i.e. propylene glycol, glycerol and water as trapping solvents of Tian Op smoke to choose a suitable trapping solvent for making liquid smoke.

MATERIALS AND METHODS

Chemicals

Unless otherwise stated, all chemicals and reagents were obtained from Sigma-Aldrich Co. (St. Louis, MO). 1-nonen-3-ol was purchased from Lancaster (Windham, NH) and 1-decen-3-ol, 7-octen-1-ol, 8-nonen-1-ol and 9-decen-1-ol were obtained from TCI America (Portland. OR). Propylene glycol and glycerol was purchased from Merk (Darmstadt,Germany) 2-acetyl-1-pyrroline was synthesized using the procedure described by Fuganti *et al*. (2007). 1-hepten-3-one, 1-nonen-3-one, 1-decen-3-one, 7-octenal, 8-nonenal, 9-decenal and (*E*)-2-undecenal were synthesized from their corresponding alcohols by oxidation with pyridinium chlorochromate using a published procedure (Corey and Suggs, 1975). (*Z*)-2-nonenal was synthesized from (*Z*)-2-nonen-1-ol (Bedoukian Research Inc., Danbury, CT) by oxidation with Dess-Martin periodinane (0.3 M in dichloromethane; Aldrich Chemical, Co.) following the procedure described by Meyer and Schreiber (1994).

Beeswax was obtained from the Sayun Bee Farm (Chiang Mai, Thailand). Composition and properties reported by the supplier were: yellow color, a saponification value of 87-110 mg KOH/g, an acid value of 17-24 mg KOH/g, an ester value of 70-86 mg KOH/kg, a melting point of 62-65°C, and impurities of 0.1%. Kaffir lime fruits were purchased from a local market (Pathumtani, Thailand) and the peel was immediately removed and dried for 36 h at 35°C in a tray dryer to a moisture content of 12%. The dried peel was milled, sieved through a 0.25 mesh sieve and stored in a desiccator until needed. Benzoin was purchased from a local market in Bangkok, Thailand (originating from Chiang Kwang, Laos). Sandalwood, originating from the Chumporn province in Thailand, was obtained from the Thai Public Health Ministry (Bangkok, Thailand), then milled, sieved through a 0.25 mesh, and stored in a desiccator until needed.

Preparation of Tian Op candle

Tian Op candle was made from beeswax (24.25 g), benzoin (0.25 g), dried kaffir lime peel (0.25 g), sandalwood (0.25 g) and benzoin (0.25 g). Beeswax was heated by placing in a stainless steel pot until it was soft and pliable. The other ingredients were thoroughly blended with the softened beeswax and then the mixture was rolled into a flat sheet (0.3 cm thick x 15 cm width). A cotton wick (Songkhla, Thailand) was then placed on the sheet and the candle was formed by rolling the sheet into a cylindrical shape. At least 1.5 cm of the wick was left exposed from each end of the candle. The Tian Op candle was then bent into a semicircular shape.

Smoking process

The smoke was generated from manual burning of the candle for 30 s, then drawn by pump at a rate of 50 mL/min into a 100 mL flask containing trapping solvent (30 g). An internal standard solution (100 μL in 1,000 ppm) was added to the liquid smoke. For this investigation, three different trapping solvents were used: propylene glycol, glycerol and odorless water. All samples were kept at -60°C until analysis. The chemical compounds of the three different solutions were analyzed.

Isolation of volatile compounds

The solution from each smoke trapping (30g) was shaken with hexane (15 mL):diethyl ether (15 mL) for 30 min. The solvent layer was separated using a separating funnel. The sample was reextracted twice with the hexane:diethyl ether mixture (2×10 mL) and the mixed solvent extract layer was collected, dried by anhydrous sodium sulfate and then concentrated to about 1 mL using a gentle stream of nitrogen. Smoke extractions were kept at -60°C until analysis.

Aroma extract dilution analysis (AEDA)

Stepwise dilutions (1:3) were prepared with diethyl ether. Each dilution was kept in a 2-mL amber vial equipped with a PTFE-lined screw cap at -70°C until analysis. The gas chromatography-olfactometry (GCO) system consisted of a 6890 GC (Agilent Technologies Inc., Palo Alto, CA) equipped with a flame ionization detector (FID), an on-column injector and an olfactory detection port (DATU Technology Transfer, Geneva, NY). Each aroma extract was injected by cool on-column mode (+3°C temperature tracking mode) into a polar capillary column (DB-Wax®, 30 m × 0.25 mm i.d.; 0.25 μm film; Restek, Bellefonte, PA) or a non-polar column (HP®-5MS, 30 m × 0.32 mm i.d.; 0.32 μm film; Restek Bellefonte, PA). Column effluent was split 1:1 between the FID and the olfactory detection port using deactivated fused silica tubing, with both detector temperatures held at 250°C. The GC oven temperature was programmed from 35 to 225°C at a rate of 10°C/min with initial and final hold times of 5 and 15 min, respectively. Helium was used as a carrier gas at a constant flow rate of 2.2 mL/min. Other conditions of GCO and AEDA have been previously described.

Gas chromatography-mass spectrometry

Chemical compounds in solutions were analyzed using a gas chromatograph-mass spectrometer (GC-MS), equipped with an automatic injector and an FID. A 1 μL aliquot was injected in splitless mode passing though the DB-5 and DB-wax column (30m length × 0.25 mm i.d. × 0.25 μm film thickness). The carrier gas was helium at a constant flow rate of 1.0 mL/min. Injector and detector temperatures were 250°C. The initial oven temperature of the HP-5 column was raised from 35 to 280°C at 4°C/min and then maintained for 43 min at 280°C. The initial oven temperature of the DB-wax column was raised from 35 to 230°C at 4°C/min and then maintained for 30 min at 230°C. The mass spectrometer detector (MSD) conditions were: capillary direct

interface temperature 250°C, ionization energy 70 eV, mass range 33-350 a.m.u., electron multiplier voltage 2094.1 V and scan rate 1.4 scan/s.

Compound identification

Compound identification was based on matching retention indices (in two different GC column phases) and mass spectra of the unknown samples with those of authentic standards. A homologous series of *n*-alkanes was used for the determination of retention indices.

Quantitative analysis

The concentration of a selected positively identified odorant was based on its area response ratio [extracted ion chromatogram area of compound/extracted ion (m/z 128) chromatogram area of the internal standard (2-methyl-3-heptanone)]. Determinations were performed in triplicate. Concentrations were expressed in mg/kg (ppb) on a wet basis.

RESULTS AND DISCUSSION

AEDA

Smoke flavorings were determined for the aroma-active components by aroma extraction dilution analysis (AEDA). The flavor dilution (FD) factors are illustrated in Table 1. Pentanal, 1-penten-3-one, hexanal, 1-hexen-3-one, heptanal, 1-hepten-3-one, (Z)-4-heptenal, octanal, 1-octen-3-one, 7-octenal, nonanal, 1-nonen-3-one, (E)-2-octenal, 8-nonenal, decanal, (E)-2-nonenal, (Z)-2-nonenal, (E,Z)-2,6-nonadienal, undecanal, (E)-2-decenal, dodecanal, (E)-2-undecenal, 2-methoxyphenol and vanillin were detected in the smoked "num dok mai" and "gleep lum duan" (Watcharananun, 2009). Based on FD factors (Table 1) and calculated odor-activity values (Table 2), the predominant odorants in the Tian Op flavored desserts were vinyl ketones (C_5-C_9), *n*-aldehydes (C_5-C_{11}), (E)-2-unsaturated aldehydes (C_8-C_{11}) and ω-1-unsaturated aldehydes (C_8 and C_9) (Watcharananun, 2009). FD factors of

pentanal, 1-penten-3-one, hexanal, 1-hexen-3-one, heptanal, 1-hepten-3-one, (Z)-4-heptenal, octanal, 1-octen-3-one, nonanal, 1-nonen-3-one, (E)-2-octenal, 8-nonenal, decanal, (E)-2-nonenal, (Z)-

2-nonenal, undecanal, (E)-2-decenal, (E)-2-undecenal and 2-methoxyphenol were detected in propylene glycol at higher values than those of glycerol and water.

Table 1 Potent odorants in liquid smoke in propylene glycol, glycerol and water.

No.	Compound	Odor [a]	RI [b]		FD-factor [c]		
			Wax	HP5	Pro	Gly	Water
2	Pentanal	painty	980	701	3	nd[d]	nd
3	1-Penten-3-one	plastic, pungent	1021	680	3	nd	nd
4	Unknown	potato	1042	- -	3	3	3
5	Hexanal	green, cut-grass	1081	799	27	3	nd
6	1-Hexen-3-one	plastic, pungent	1096	777	2187	nd	nd
7	Unknown	potato, sweet	1158	- -	27	27	3
9	Heptanal	melon, citrus, orange	1181	902	27	3	nd
11	1-Hepten-3-one	plastic, pungent	1196	876	2187	nd	nd
12	(Z)-4-Heptenal	stale, crabby	1240	901	27	nd	nd
13	Styrene	plastic	1241	895	81	27	27
14	Octanal	orange oil	1282	1002	729	81	nd
15	1-Octen-3-one	mushroom	1296	976	729	nd	nd
17	(E)-2-Heptenal	pungent, fruity	1333	956	27	27	9
18	2-Acetyl-1-pyrroline [e]	rice	1340	921	9	9	3
19	7-Octenal	fresh, melon	1354	996	81	81	9
20	Nonanal	pungent, green	1388	1104	27	nd	nd
21	1-Nonen-3-one	mushroom, pungent	1398	1078	243	nd	nd
22	(E)-2-Octenal	fresh, melon, green	1436	1058	243	nd	nd
23	8-Nonenal	stale, fatty, plastic	1445	1095	27	nd	nd
25	Decanal	pungent, green, soapy	1495	1208	9	nd	nd
26	(E)-2-Nonenal	hay, stale	1507	1151	729	243	nd
27	(Z)-2-Nonenal	hay, stale, fatty	1535	1162	729	243	nd
28	(E,Z)-2,6-Nonadienal	cucumber	1587	1155	27	27	3
29	Undecanal	green, pungent	1600	1303	27	nd	nd
30	(E)-2-Decenal	pungent, soapy	1641	1264	27	3	nd
32	Dodecanal	green, pungent, soapy	1701	1404	3	nd	nd
33	Unknown	hay, fatty	1735	- -	9	3	3
34	(E)-2-Undecenal	cilantro, green, soapy	1754	1366	81	9	nd
36	2-Methoxyphenol [Guaiacol]	smoky	1862	1090	243	81	9
38	(Z)-α-Santalol [f]	incense, woody, cedar	2350	1674	9	9	9
39	(Z)-β-Santalol [g]	incense, woody, fragrant	2434	1716	9	9	9
40	Vanillin	vanilla	2576	1404	81	81	81

[a] Odor quality as perceived during GCO. [b] Retention indices were calculated from GCO data; WAX, DB-wax column. [c] Flavor dilution (FD) factor determined on DB-wax column. [d] nd, not detected. [e] Compound was tentatively identified on the basis of comparison of its odor property and retention indices with a reference compound. [f] and [g] Each compound was identified on the basis of mass spectra and retention indices determined for (Z)-·-santalol or (Z)-,-santalol in authentic sandalwood oil and by comparison to literature (Gorsch,1993).

The majority of the above-mentioned potent odorants were most likely produced from the oxidative reactions of myricyl palmitate in beeswax, which is responsible for the formation of ketones, n-aldehydes (C_5-C_{11}), and (E)-2-unsaturated aldehydes (C_8-C_{11}) (Parliament $et\ al.$, 1989). At higher temperature, the saturated fatty acids undergo oxidative decomposition. It is believed that the oxidative mechanism involves the formation of monohydroperoxides and that oxygen attack occurred at ketone, n-aldehyde (C_5-C_{11}), and (E)-2-unsaturated aldehyde (C_8-C_{11}) sites in the fatty acid chain (Parliament $et\ al.$, 1989). The aldehydes (hexanal, octanal, nonanal and (E)-2-nonenal) were typical scission products of monohydroperoxides in beeswax. The carbon-carbon bond of palmitate hydroperoxides was the most vulnerable to cleavage under moderate conditions of autoxidation, while scission at the carbon-oxygen linkage was favored under stress conditions, such as heat. Vinyl ketones (1-hepten-3-one, 1-octen-3-one and 1-nonen-3-one), along with aldehydes (hexanal, octanal, nonanal and (E)-2-nonenal) were reported as being primarily responsible for the off-odor associated with thermally oxidized polyethylene (Bravo $et\ al.$, 1992). 7-Octenal was previously reported as a volatile decomposition product of thermally oxidized triolein (May $et\ al.$, 1983). Sanders $et\ al.$ (2005) reported that 8-nonenal contributed a "plastic" off-odor to high-density polyethylene packaging. In addition to the above, some odorants may have originated from other ingredients of the Tian Op candle, such as vanillin from benzoin (Lawless, 1995) and (Z)-α-santalol and (Z)-β-santalol from sandalwood (Howes $et\ al.$ 2004). Likewise, guaiacol might have been derived from the pyrolysis of any of the lignin-containing ingredients (e.g. cotton wick, sandalwood, etc.) (Cadwallader, 2007). Most aroma compounds have a low polarity or are non polar and propylene glycol ((CH_2)$_n$(OH)$_2$) has lower polarity than glycerol (C_3H_5(OH)$_3$) and water (H_2O). Propylene

glycol has two separate hydroxyl groups (-OH), while glycerol has three hydrophilic alcoholic hydroxyl groups (OH$^-$). The low polarity of propylene glycol is near the polarity of the C_7-C_{18} aldehydes, alkenes, and alkanes in Tian Op smoke, so that propylene glycol can trap these compounds better than glycerol and water (Mcmurry, 1989). The aldehydes found in smoke had low polarity because R-groups of aldehydes contained non-polar hydrocarbons at the point of attachment to the carbonyl group. The longer the R-group is, the greater the non-polarity of the compounds becomes. For this reason, the C_7- C_{17} aldehydes that have a long chain R-group are less soluble in water and are more soluble in a lower- polarity solvent, such as propylene glycol (Mcmurry, 1989).

Quantitative analysis

From the analysis of the Tian Op smoke flavorings trapped in propylene glycol, glycerol and water, it was found that most compounds were hydrocarbons and oxygenated compounds. Three trapped solvents, propylene glycol, glycerol, and odorless water were used to trap the smoke because they were safe, stable, and colorless (Reineccius, 1994). The amounts of each chemical compound identified in these solvents are presented in Table 2. A greater number of chemical compounds was found when propylene glycol was used as the solvent compared with glycerol and odorless water. Most of the compounds found in all solvents were aldehydes, followed by unsaturated aldehydes, and vinyl ketones. The aldehyde-trapping ability of the solvents used was not the same. The odorless water could not trap any aldehydes, but glycerol could trap three aldehydes (heptanal, octanal, and nonanal) and at low concentration propylene glycol could trap several aldehydes. The vinyl ketones, despite being present in relatively low quantities, had the highest odor-activity values (OAVs) in propylene glycol. Likewise, some other odorants that were present

at low levels but above the minimum odor-detection thresholds, e.g. 8-nonenal, had relatively high OAVs. Eight compounds found at high levels, i.e. n-aldehydes and (*E*)-2-unsaturated aldehydes, had particularly high OAVs. Based on OAV principles, such compounds should have the greatest impact on the overall aroma of the smoked flavoring.

Branched alkanes, α-1,ω-1-alkadienes, unsaturated aldehydes, and vinyl ketones were minor volatile constituents identified in all solvents used. It was previously demonstrated that the chemical structures of the volatile compounds were affected by the structure of fatty acid and the involvement of oxygen in the breakdown reactions of alkoxy radicals. Monohydroperoxides were the

Table 2 Concentrations and odor-activity values (OAV) of selected volatile components of liquid smoke in propylene glycol, glycerol and water.

Compound	Concn (ug/kg)			Odor threshold (ug/kg)[a]	OAV		
	Propylene Glycol	Glycerol	Water		Propylene Glycol	Glycerol	Water
1-Penten-3-one	80 (±25%)	nd	nd	1.3 [A]	61.54	nd	nd
1-Hexen-3-one	36 (±39%)	nd	nd	0.024 [B]	1500.00	nd	nd
1-Hepten-3-one	27.4(±14%)	8.9 (±27%)	nd	0.04 [C2]	685.00	222.50	nd
1-Octen-3-one	143 (±19%)	nd	nd	0.005 [C]	28600.00	nd	nd
1-Nonen-3-one	117.2 (±7%)	nd	nd	0.008 [D]	14650.00	nd	nd
Pentanal	2160 (±15%)	709 (±84%)	nd	12 [E]	180.00	59.08	nd
Hexanal	1243 (±21%)	284 (±17%)	nd	4.5 [A]	276.22	63.11	nd
Heptanal	2460 (±69%)	228 (±51%)	nd	3 [A]	820.00	76.00	nd
Octanal	5693 (±55%)	1354 (±62%)	nd	0.7 [E]	8132.85	1934.28	nd
Nonanal	3894 (±76%)	184 (±84%)	nd	1 [A]	3894.00	184.00	nd
Decanal	5190 (±92%)	nd	nd	2 [E]	2595.00	nd	nd
Undecanal	9030 (±55%)	nd	nd	5 [F]	1806.00	nd	nd
Dodecanal	6180 (±86%)	nd	nd	2 [G]	3090.00	nd	nd
(*E*)-2-Octenal	88.83 (±74%)	3.28 (±21%)	nd	3 [A]	29.61	1.09	nd
(*E*)-2-Nonenal	621 (±32%)	21.3 (38%)	nd	0.08 [A]	7762.50	266.25	nd
(*E*)-2-Decenal	450 (±32%)	113 (±17%)	0.93 (±44%)	0.3 [A]	1500.00	376.67	3.10
(*E*)-2-Undecenal	319 (±17%)	6.92 (±35%)	nd	(150) [H]	2.13	0.05	nd
7-Octenal	79.3(±27%)	59.2 (±10%)	nd	(0.51) [I]	155.49	116.08	nd
8-Nonenal	22.6 (±45%)	nd	nd	(1.6) [I]	14.13	nd	nd
Vanillin	1249 (±90%)	1135 (±53%)	1250 (±90%)	25 [J]	49.96	45.40	50.00
2-Pentanone	474 (±15%)	274 (±39%)	nd	2300 [K]	0.21	0.12	nd
2-Hexanone	438 (±59%)	105 (±43%)	nd	930 [K]	0.47	0.11	nd
2-Heptanone	476 (±48%)	148 (±49%)	nd	140 [E]	3.40	1.06	nd
2-Octanone	441 (±55%)	157 (±67%)	nd	50 [E]	8.82	3.14	nd
2-Nonanone	236 (±49%)	107 (±27%)	nd	200 [E]	1.18	0.54	nd

Threshold references (waiting for number assignment):
[A] = Guadagni *et al*. (1972), [B] = Buttery *et al*. (1978), [C2] = Buettner and Schieberle (2001), [C] = Buttery *et al*. (1990), [D] = Ott *et al*. (1997), [E] = Buttery *et al*. (1988), [F] = Guadagni *et al*. (1963), [G] = Boelens and Gemert (1987), [H] = Meijboom (1964), [I] = Meijboom and Jongenotter (1981), [J] = Semmelroch *et al*. (1995), [K] = Siek *et al*. (1969), [a] Orthonasal odor threshold in water or in oil (italics). Reference is provided in brackets.

primary detectable products of thermal oxidized saturated fats. In addition, aldehydes, unsaturated aldehydes, and vinyl ketones that were minor volatile constituents identified from beewax were reported as major degradation products of the thermal degradation of tristearin in air (Selke *et al.*, 1975).

The results indicated that propylene glycol was the most suitable solvent for trapping smoke from Tian Op because several active aroma compounds could be detected from this solvent.

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