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Characterization of active-aroma wheel in contemporary coffee processes via gas chromatography–olfactometry, and sensory perspective

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ABSTRACT

This research is to study the difference in chemical changes during fermentation, between the new fermentation processes. Aroma descriptors and sensorial assessments can be effectively used to tailor made fermentation processes. Coffee cherries (*Coffea arabica* L. var. Catimor) were treated with three different processes as followed: 1) Dry process (control), 2) Semi-carbonic maceration process (SCM): Carbon dioxide gas was injected to replace oxygen, and 3) Yeast process: coffee cherries were fermented by commercial yeast strain *Saccharomyces cerevisiae var cerevisiae*. SCM and Yeast processes were both incubated at 17±1°C until mucilage of pulped coffee and pectin layer reached to 4.2-4.3 of pH value. Low air temperatures (20-33 °C), low relative humidity (25-60%) to dry coffee samples to the desired 12.5% moisture content was used. The chemical component of the intact mucilage during fermentation was analyzed. The active-aroma attributes of roasted coffee were qualified and intensified by gas chromatography–olfactometry, categorized as followed: Enzymatic, Sugar browning, Dry distillation and Aromatic, and translated into an active-aroma wheel. The quality cup scores were evaluated by certified Q arabica graders, according to the standard of the Specialty Coffee Association. Results shows that, when compared to Control, SCM and Yeast process had a greater potential when it comes to increasing active-aroma attributes (twenty, twenty-nine, and twenty-two active-aroma attributes respectively). The fermentation process of SCM and Yeast process changes the post fermentation chemical composition of coffee cherry, a decrease in pH value, and an increase in acidity and ethanol. Both processes resulted in an improvement in aromatic attributes of roasted coffee, in both types and intensities. In line with the cup quality's final scores of 81.50, and 82.83 (specialty coffee), respectively, both processes scored higher than the Dry process (79.42 cup score), with coffee from Yeast process scoring the highest in significant difference.

Key words: Coffee; active-aroma wheel; semi-carbonic maceration process; yeast process; gas chromatography-olfactometry.

1 INTRODUCTION

To the best of our knowledge, edaphoclimatic conditions, planting altitudes, soil, the microbiome of plants and fruits, genotypes, and postharvest processing are factors determinants of the chemical and sensory quality of the coffee (Brioschi et al., 2020; Chindapan; Soydok; Devahastin, 2019; De Bruyn et al., 2017; Pereira et al., 2021; Martinez et al., 2021; Veloso et al., 2020). The flavors of coffee are a direct result from the green beans' production process, from harvest to storage (De Bruyn et al., 2017). Not only the process of coffee cherries (Pereira et al., 2020), the genetic variety of the plant (Bertrand et al., 2006), and natural coffee microbiota (De Bruyn et al., 2017) has an effect on coffee fermentation, but coffee quality can also be optimized with the application of microorganism's starters that modify taste and texture (Pereira et al., 2021; Martinez et al., 2021; Pereira et al., 2017; Bertrand et al., 2006; Evangelista et al., 2015; Bressani et al., 2020). The different forms of coffee processing are rapidly evolving towards specialty coffee. A new trend is to study assisted fermentation by using microorganisms as starter strains, enzymes treatment, and recently Carbonic process (Gudi, 2017; Jitjaroen, 2021), Yeast process (Fundira; Duez; Sieczkowski, 2020), and Coffivino process (Jitjaroen, 2021).

Carbonic maceration is a winemaking technique, exploiting the adaptability of intact grape berries to an oxygen-deprived medium enriched with carbon dioxide. This adaptation is reflected almost instantly inside each berry by the transition from a respiratory to fermentative anaerobic metabolism (Tesniere; Flanzy, 2011). The berries absorbed carbon dioxide gases and began oxygen free and indigenous microorganism that breaks down the sugars and lowers the acidity in the berries. The final product has a richer flavor and superior aromatic qualities (Etaio et al., 2016) with a higher content of phenolic compounds (Navarro et al., 2000), which are desirable to consumers. This method has been adopted in many countries around the globe and has highly increased the value of coffee beans on the international market (Gudi, 2017).

Semi Carbonic Maceration (SCM) is a similar technique to the Carbonic Maceration. But it creates a carbon dioxide-concentrated atmosphere for a short amount of time inside the fermentation tank. There are two ways to create carbon dioxide gas. When the coffee cherries, at the bottom of the fermentation tank, are being squished or torn, causing nutrients to leak. Natural microorganisms from coffee cherries will feed on those leaking nutrients, creating alcohol and carbon dioxide. These gases will combine with the added carbon dioxide, creating a carbon dioxide-rich atmosphere inside the fermentation tank, leading to a complex biochemical reaction (Robinson, 2006; Liu et al., 2014; Jitjaroen, 2021).

Fermentation in coffee is often referred to as biochemical reaction leading to the removal of the mucilage from the bean. In fact, lots of microorganisms are present at this key step of the coffee processing and can impact the process. Similarly, in coffee, the benefits of processing or fermenting cherries with selected coffee yeasts have been observed. These selected yeasts can be applied for any processing technique, be it whole fruit, wet or honey processing (Fundira; Duez; Sieczkowski, 2020). The selected yeast strain prevailed over indigenous microbiota, and the production of specific aroma compounds increased (Pereira et al., 2014; 2015). The final product was evaluated as a high-quality coffee. It has been observed that coffee producers stand to gain a lot from a controlled fermentation (Fundira; Duez; Sieczkowski, 2020).

Carbonic maceration and Yeast processes are widely used to produce wine with novel characteristics. These techniques observations help the demucilagination process; limit the formation of some undesirable compounds, and benefit from the biochemical metabolism that contributes to the aroma development. Currently, there are only a few scientific studies on both processes. Therefore, the aim of this research is to study the difference between these processes on coffee quality. In order to understand whether chemical changes during fermentation, aroma descriptors and sensorial evaluation, can be effectively used to designed fermentation processes. This would help to develop a new technique for those who desire to step into the world of specialty coffee.

2 MATERIAL AND METHODS

2.1 Coffee cherry preparation

Arabica coffee (*Coffea arabica* L. var. Catimor) cherries, from the 2021 crop was harvested by hand, in a coffee farm, in the northern part of Thailand. The village is called Nam Pan, situated in Na Rai Luang sub district, Song Khwae district, Nan province, at an altitude of 790 m above sea level (19.17°N, 100.41°E). The coffee cherries were separated by the method of water separation. Defected and dried coffee cherries have a lighter mass than healthy coffee cherries, causing them to float, allowing the team to manually remove them. Thirty-five kg of coffee cherry (40% of the tank capacity) were filled in 75 L plastic tanks for each variable fermentation. The sulfur dioxide solution, 75 ppm, was added to each tank.

2.2 Process condition

2.2.1 Fermentation condition

Triplicate samples of three processes were studied: 1) Dry process (control) 2) Semi Carbonic Maceration process (SCM): Carbon dioxide (99.9% purity) was flushed to remove atmosphere air for 20 sec. until the inside relative pressure of the tank has reached 1 bar (modified from Brioschi et al., 2020), until the volume capacity reached to 60% of the tank.; 3) Yeast process: yeast strain *Saccharomyces cerevisiae var cerevisiae*, which was rehydrated for 30 min at 35 °C and was added to the must at 0.03% wt/wt (modified from Jitjaroen; Bouphun; Panjai, 2013) was added under the initial *yeast cell concentration* of 10^{10} cell.g^{-1} by using the Bucket inoculation method (Bressani et al., 2021) and covered with air loc k. They were incubated at 17±1 °C until mucilage of pulped coffee and pectin layer reached to 4.2-4.3 of pH value. The coffee cherry samples were dried with the use of low air temperature, low relative humidity method.

2.2.2 Dehydration condition

The temperature, relative humidity (RH), and air velocity of this LTLH drying method were set at 20-33 °C, 25-60%, and 7.0 m.s^{-1} respectively with a pre-set air circulation system (modified from Ondier; Siebenmorgen; Mauromoustakos, 2010). Temperature (York, Thailand) and low relative humidity were controlled gradiently at 20±1 °C, 25±1 °C, and 30±1 °C. in relation to the RH value of 60±1%, 40±1%, and 25±1%, combined with a humidifier (Modern kool, DY-30, China). The drying air, at set temperature and RH, was circulated from the air conditioning unit through perforations at the bottom of each basket containing the coffee cherry samples and back to the air conditioning unit. Temperature and RH of the drying air over the dehydration period were recorded. Each basket was weighed twice daily (Sunford, KAH5000S, Thailand). The drying rate curve were documented throughout the drying process, by using hot air oven method (Association of Official Analytical Chemists - AOAC, 2000), until the desire moisture content (<12%) of the coffee beans were achieved (De Pereira et al., 2019). At the end of each drying experiment, the final moisture content of each coffee sample was determined. These samples were packed in high-strength polyethylene bag, and stored at 25 °C prior to the quality assessment. Each treatment of this coffee drying experiment were triplicated.

2.3 Analytical methods

2.3.1 Coffee mucilage determinations

The mucilage of pulped coffee and pectin layer bean during fermentation were controlled before and after the fermentation. The mucilage was precipitated by using the centrifuge (Laboratory Centrifuge; SE11073, China) at speed 4,000 rpm for 10 min. The following properties of the supernatant was analyzed: pH value by pH meter (Docu-pH; Sartorius, Germany), titratable acidity by titration (expressed as citric acid) (Reta et al., 2017) with slight modifications, total soluble solids by hand refractometer (Atago; N-1α/ 0-32 °Brix, Japan), ethanol content by Ebulliometer (Dujardin-Salleron, Paris), and total solids content by hot air oven method (Memmert, Germany) (AOAC, 2000). The cherries were then hulled and sorted to obtain the perfect green beans.

2.3.2 Gas chromatography-olfactometry (GC-O) analysis

The green coffee beans were roasted using a coffee roaster (Probat-Werke, Germany) at a medium roasting profile. 3.0 g of freshly grounded coffee were weighed into a screw-capped headspace vial and extracted using headspace–solid phase microextraction (HS-SPME) with SPME fiber; 100 µm (PDMS, Fused Silica) and extracted at 90 °C for 30 min without stirring. Aroma compounds were separated with an HP-5MS capillary column (30 m x 0.25 mm, 0.25 µm) (J&W, USA), with oven temperature from 180 to 230 °C for 26 min.

A gas chromatography was performed on an Agilent gas chromatograph (7890A; Agilent Technologies, Germany) and connected to an olfactory detection port (Perkin Elmer, USA). The aroma descriptors, intensity (1=low intensity, 2=medium intensity, 3=high intensity) and frequency were described by the specialized panelist with the duplicate in each sample.

2.4 Sensory evaluation

The sensory analysis, for roasted and brewed coffee, laid down by the Specialty Coffee Association (Lingle, 2011; Specialty Coffee Association - SCA, 2021) was performed by six certified Q Arabica graders. The fermented green coffee was roasted to a level corresponding to Lightness (L) 30-31 by a roaster (Probat-Werke, Germany). Then one hundred grams of green bean from each sample were roasted. For the sensory evaluation, three cups of each sample were tasted, with one session of sensory analysis for each repetition.

The evaluated sensory attributes were grouped into subjective and objective categories. The subjective attributes were fragrance/aroma, flavor, acidity, body, balance, after taste and overall impression. They were scored according to their qualities on a scale of 6 to 10 points, with 0.25-point increments. The objective category includes uniformity, sweetness, and clean cup. The objective attributes were scored on a scale from 0 to 10 points, with 2 points awarded for each cup that presented satisfactory levels of each attribute. The sum of all these evaluated attributes is the total score (SCA, 2021). In addition to these evaluations, the panelists were also asked to describe the unique characteristics of the samples' fragrances, aromas and flavors.

2.5 Statistical analysis

The assay was carried out in a Completely Randomized Design for Physico-chemical composition, Balance Incomplete Block Design for sensory evaluation, with three replications and three conditions of fermentation. The results are expressed as means ± SD. Significant differences between treatment samples for all parameters were determined using a one-way ANOVA. A Duncan's Multiple Range Test was conducted to establish the differences among mean values. Statistical analyses were carried out using SPSS 22.0. The threshold p-value chosen for statistical significance was $p \leq 0.05$ (Ritthiruangdej, 2018).

3 RESULT

3.1 Fermentation characteristics

Results shows, that the SCM process and the Yeast process affect the chemical qualities of mucilage, such as pH, acidity, total soluble solids, and alcohol content with statistical significance ($p \leq 0.05$) (Figure 1).

After ending the fermentation of the SCM process and the Yeast process, the mucilage of every sample saw a decrease in pH value, from 5.1±0.02 to 4.35±0.13, and 4.27±0.05, relating to an increase in acidic value from 0.49±0.25% to 0.85±0.06, and 0.66±0.08% respectively. Furthermore, after the fermentation, the mucilage from every sample has seen a decrease in total soluble solids, from 22.34±0.24 °Brix to 21.37±0.44 and 18.94±0.74 °Brix, relating to the increase in alcoholic content of 0.80±0.05 and 3.15±0.05% v/v respectively. This proves that different fermentation methods will result in different changes in the fermentation of the mucilage of pulped coffee and pectin layer.

3.2 GC-O assessment

The resulting aromas were in the form of single aroma component, which were later grouped and displayed in the form of an active-aroma wheel (Table 1; Figure 2-4).

The difference in process can affect the creation of aromatic category and intensity of roasted coffee. By using the Dry process, SCM, and Yeast process, the processors will be able to develop twenty, twenty-nine, and twenty-two different aromatic attributes, respectively.

Twenty types of aromas were found in samples of roasted coffee, developed by using the dry process, which consists of nine types from the Enzymatic category (pineapple, lemon, mango, apricot, peach, cherry, blueberry, prune, pandan), six types from the Sugar browning category (roasted almond, roasted black sesame, jelly, roasted coffee, honey (detected twice), vanilla), three types from the Dry distillation category (wood, oak, dry leaves), and two aromas from the Aromatic category (salted meat, medicinal).

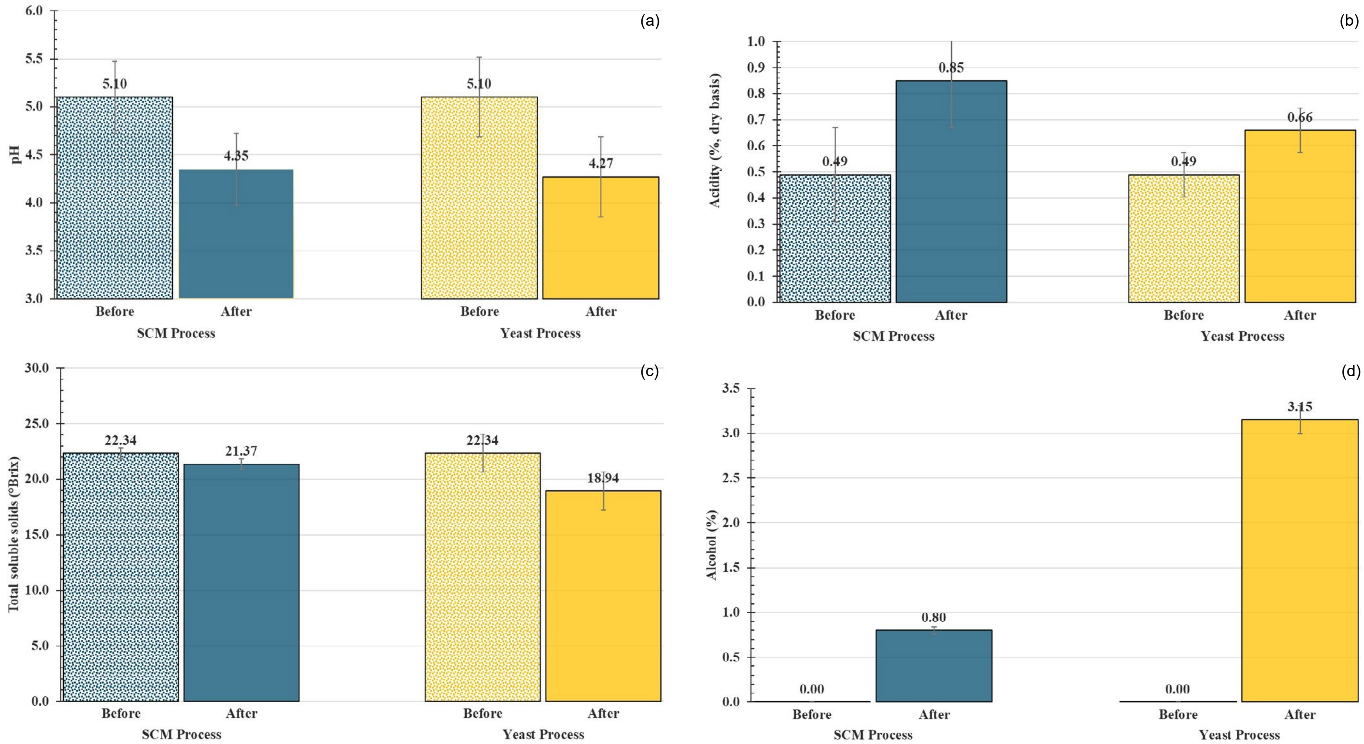

Figure 1: Chemical composition changes of the mucilage of pulped coffee and pectin layer before and after Semi-carbonic maceration, and Yeast process: (a) pH value; (b) acidity; (c) total soluble solids; (d) alcohol content.

Twenty-nine types of aromas were found in samples of roasted coffee, developed by using the SCM process, which consists of twelve types from the Enzymatic category (green apple, lemon, pineapple, apricot, peach, raspberry, red grape, blueberry, potato, cucumber, cos lettuce, pandan), eight types from the Sugar browning category (roasted almond, roasted white sesame, caramel, roasted coffee, honey (detected twice), honey lemon, vanilla, white chocolate), five types from the Dry distillation category (wood (detected 3 times), oak, cinnamon, nutmeg, clove), and three aromas from the Aromatic category (salted meat, salted shrimp paste, earth).

Twenty-two of aromas were found in samples of roasted coffee, developed by using the Yeast process, which consists of nine types from the Enzymatic category (green apple, pineapple, lemon, mango, orange, apricot, peach, cucumber, pandan), eight types from the Sugar browning category (roasted almond, roasted white sesame, sesame oil (detected twice), caramel, roasted coffee, honey (detected twice), honey lemon, vanilla), two types from the Dry distillation category (oak, wood), and three aromas from the Aromatic category (Greek yogurt, salted meat, salted shrimp paste).

By comparing the influence of semi-carbonic maceration and yeast techniques on coffee aromatic and sensory properties to the traditional techniques, the study shows that fermenting coffee by using SCM or Yeast process leads to a more positive development of coffee aromas, both in the number of types and intensities, than using traditional Dry process. Types and intensity of each aromatic category varies depending on the process. For the Enzymatic category, when treated using the SCM process, is able to create more aromas from the berries and leguminous groups. And, if fermented by using the Yeast process, the enzymatic category can create more aromas from the citrus group. While the Sugar browning category can develop more chocolate (only with the SCM process), nutty and caramel aromas, if fermented using the SCM or the Yeast process. When fermented using SCM process, the Dry distillation category, can create more aromas from the spice family. At the same time, the Yeast process can help reduce the woody smell from the Dry distillation category. Furthermore, it has been discovered that if treated using the dry process, coffee tend to process medicinal aromas from the aromatic category, which is an undesirable smell, where else coffee using the SCM or the Yeast process do not carry smells from the medicinal group. Additionally, fermentation through Yeast process result in additional yogurt scent.

3.3 Cup quality assessment

Coffee from all three processes, Dry process, SCM process, and Yeast process, have been evaluated as very good (7.08-7.58) in terms of acidity, body, and balance, with significant difference among the treatments. The cup quality results revealed the attributes of uniformity, clean cup and sweetness had the maximum notes for all treatments quantified by all the tasters (score of 10.00). SCM and Yeast process scored more than dry process in every attribute. The Yeast process has statistically significant higher scores than SCM in three categories; aftertaste, flavor, and overall. Results show that different processes uniquely affect the sensory quality of coffee (Table 2, Figure 5).

All three processes have been scored "very good" (7.00-7.75) in terms of fragrance, aftertaste and overall, with a significant difference of SCM and Yeast process, both, receiving higher scores than dry process. This is in line with GC-O's aroma attributes, which shows that both the SCM and the Yeast processes possesses more types of aromas, with some types having higher intensity than coffee from the dry process, leading to a more complex end-product, which is most likely the reason for both processes to have earned the final score of 81.50, and 82.83 respectively, with Yeast process resulting in the more superior final product. Both scores are categorized as Specialty Coffee. On the other hand, coffee from the Dry process scored only 79.42, which is categorized as "not specialty coffee". The study proves that by using SCM and/or Yeast process, it is able to improve the final cup quality score by 2.08 and 3.41 points, respectively.

Table 1: The average aromatic intensity of different roasted coffee: Dry process; Semi-carbonic maceration process; Yeast process, examined by gas chromatography-olfactory.

Aroma category		Aroma attributes	Level of aroma intensity[1]					
			RT[2]	Dry process	RT	SCM process	RT	Yeast process
ENZYMATIC								
Fruity	Citrus	Green apple		-	8.07	2	13.00	2
		Pineapple	11.25	3	16.81	3	12.07	3
		Lemon	10.71	2	11.23	2	12.23	2
		Mango	17.60	3	-	-	14.03	2
		Orange		-	-	-	22.97	1
	Berry	Apricot	11.60	3	9.55	1	8.91, 9.77	1, 2
		Peach	12.00	3	9.83	2	9.19	3
		Cherry	12.84	3		-	-	-
		Raspberry		-	16.68	2	-	-
		Red grape		-	16.32	1	-	-
		Blueberry	13.55	2	16.57	2	-	-
		Prune	13.39	3	-	-	-	-
Herby	Leguminous	Potato		-	7.66	3	-	-
		Cucumber		-	6.94	3	6.23	3
		Cos lettuce		-	7.10	3	-	-
		Pandan	5.44	3	6.86	3	6.15	3
		Total intensity		25		27		22
SUGAR BROWNING								
Nutty	Nut	Roasted almond	4.23	3	4.20	3	4.27	3
	Malt	Roasted white sesame		-	5.85	3	6.48	3
		Roasted black sesame	6.01	3		-		-
		Sesame oil		-	5.02	3	4.98, 6.66	2, 3
Caramelly	Candy	Jelly		3		-		-
		Caramel		-		2		2
		Roasted coffee		1		1		2
	Syrup	Honey	8.32, 12.15	3, 3	11.62, 15.02	3, 3	11.24, 13.28	2, 3
		Honey lemon			14.27	2	14.82	2
Chocolaty	Vanilla	Vanilla	4.44	3	4.46	3	4.46	3
	Chocolate	White chocolate		-	4.28	3		-
		Total intensity		19		26		25

Continue...

Table 1: Continuation.

Aroma category		Aroma attributes	Level of aroma intensity[1]					
			RT[2]	Dry process	RT	SCM process	RT	Yeast process
DRY DISTILLATION								
Resinous	Turpeny	Wood	6.76	3	5.44, 7.23, 24.13	3, 3, 3	18.95	1
		Oak	4.73	2	4.72	3	5.22	3
		Dry leaves	6.95	3		-		-
	Warming	Cinnamon		-	4.42	3		-
		Nutmeg		-	7.88	3		-
	Pungent	Clove		-	4.50	3		-
		Total intensity		8		21		4
AROMATIC								
		Greek yogurt		-		-	16.18	2
		Salted meat	4.50	2	4.62	3	4.66	3
		Salted shrimp Paste		-	5.52	3	5.44	3
		Earth		-	6.79	3		-
		Medicinal	5.35	3		-		-
		Total intensity		5		9		8
Total intensity				57		83		59
Relative factor				1		1.456		1.035

[1] 1= low intensity, 2=medium intensity, 3= high intensity [2] RT= Retention time.

Figure 2: Active-aroma wheel of roasted coffee from Dry process, examined by gas chromatography-olfactory.

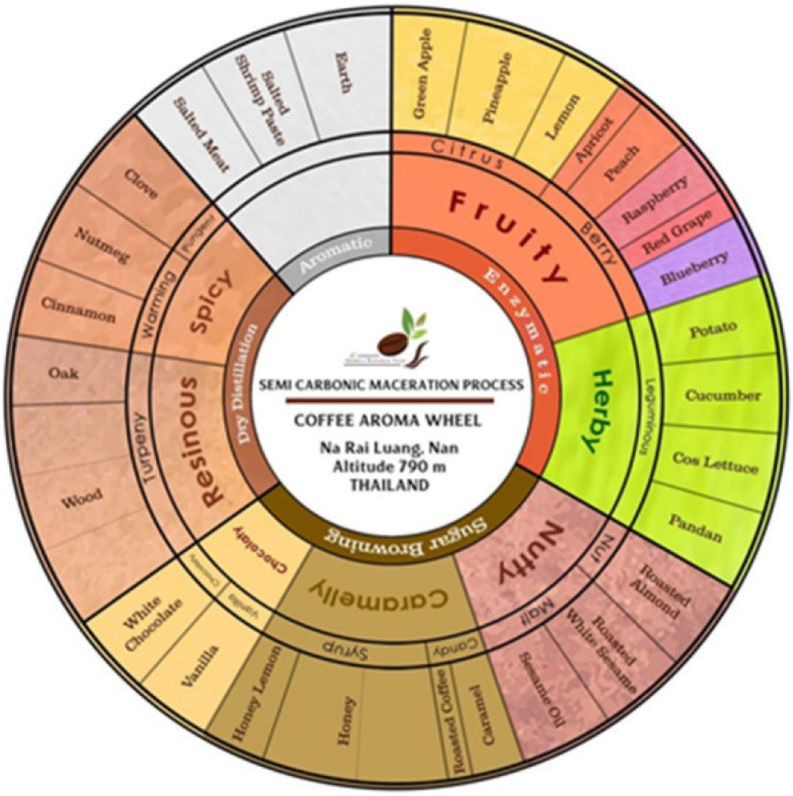

Figure 3: Active-aroma wheel of roasted coffee from Semi-carbonic maceration process, examined by gas chromatography-olfactory.

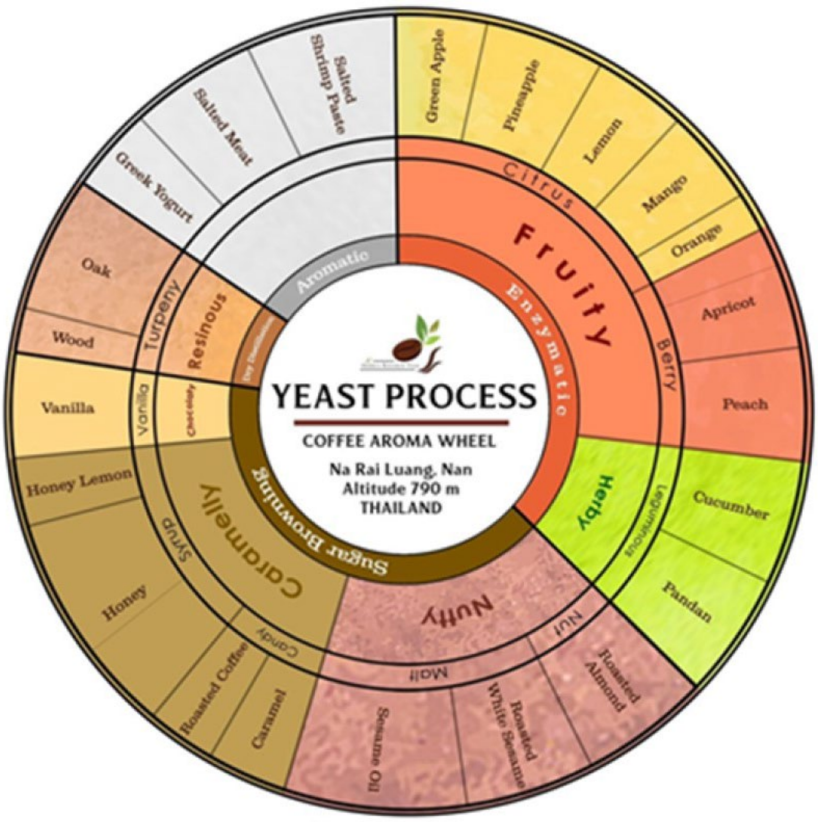

Figure 4: Active-aroma wheel of roasted coffee from Yeast process, examined by gas chromatography-olfactory.

Table 2: Cupping scores of the brewed coffee from different process a) Dry process; (b) Semi-carbonic maceration process; (c) Yeast process, evaluated by certified Q Arabica graders.

Cupping descriptors	Dry process	SCM process	Yeast process
Fragrance/Aroma	7.00 ± 0.00^{b}	7.58 ± 0.29^{a}	7.67 ± 0.29^{a}
Flavor	7.00 ± 0.00^{b}	7.25 ± 0.25^{b}	7.75 ± 0.25^{a}
Aftertaste	7.00 ± 0.00^{b}	7.17 ± 0.14^{b}	7.42 ± 0.14^{a}
Acidity	7.17 ± 0.29^{ns}	7.25 ± 0.25	7.58 ± 0.14
Body	7.08 ± 0.14^{ns}	7.42 ± 0.29	7.42 ± 0.14
Balance	7.08 ± 0.14^{ns}	7.50 ± 0.25	7.42 ± 0.14
Overall	7.08 ± 0.14^{c}	7.33 ± 0.14a^{b}	7.58 ± 0.14^{a}
Final score	79.42 ± 0.72^{c}	81.50 ± 0.25^{b}	82.83 ± 0.58^{a}
Fragrance/aroma attributes	tamarind, vanilla, cocoa, earthy, woody, salted fish	green guava, peanut, ripe and sweet fruit, ripe mango, dry yellow fruit, unripe mango, cocoa, spice, vanilla	Yellow flower, floral, pink guava, salacca, cherry, red apple, ripe fruit, hazelnut honey, nutmeg

Mean±SD (N=6), ($p \leq 0.05$).
Different superscript letters within the same row represent significant difference among processes.
ns superscript letter with in the same row represent not significant difference among processes.

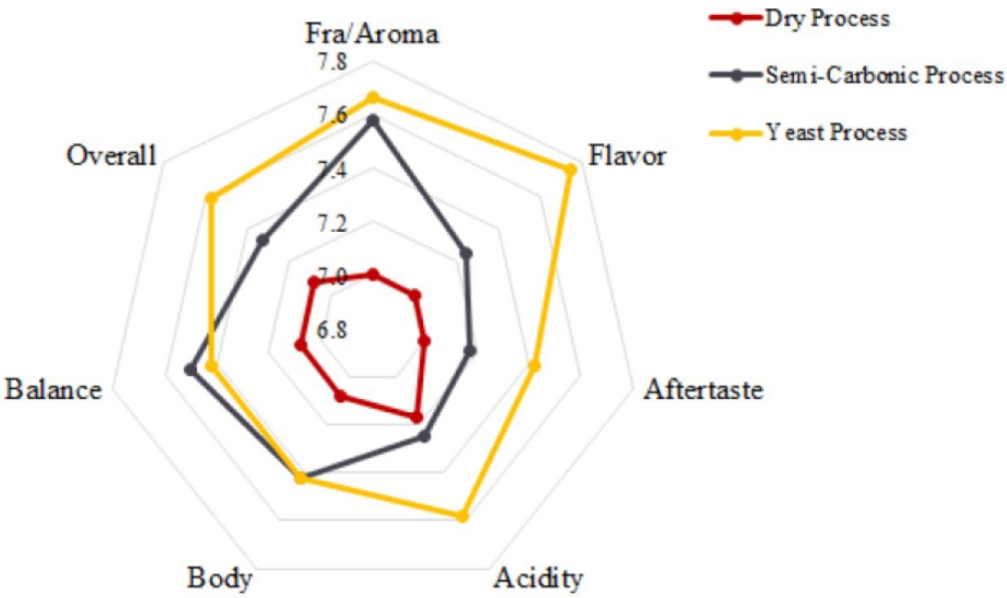

Figure 5: Spider graphical presentation of the quantitative descriptive sensory profiling analysis of brewed coffee from different processes: a) Dry process; (b) SCM process; (c) Yeast process, evaluated by certified Q Arabica graders.

3.4 Integrated GC-O and cupping attributes

The approximate twenty to twenty-two aroma attributes in the study were determined by GC-O to have a characteristic coffee-like odor, in each process. Thus, the samples were confirmed the odor impact as a whole by certified Q Arabica graders. The fragrance/aroma and flavor of samples were included: six attributes of tamarind, vanilla, cocoa, earthy, woody and salted fish on Dry process; nine attributes of green guava, peanut, ripe and sweet fruit, ripe mango, dry yellow fruit, unripe mango, cocoa, spice and vanilla on SCM; ten attributes of yellow flower, floral, pink guava, salacca, cherry, red apple, ripe fruit, hazelnut honey and nutmeg on Yeast process.

However, it can be observed that there some differences between the aroma attributes detected from the GC-O and the ones identified during the cupping process. For example, GC-O instrument has detected the aroma of mango from the dry process sample, but not from the SCM process. On the other hand, during the cupping process, the aroma of mango was found in the SCM process samples but not in the dry process samples.

Though over hundreds of volatiles have been identified from different processes, but only a few compounds with high odor active values play a major role in coffee flavor quality which would be further investigated.

4 DISCUSSION

4.1 Fermentation characteristics

The coffee parchment is being wrapped by a layer of mucilage, naturally created once the coffee cherry has ripened (Haile; Kang, 2019; 2020). The mucilage is a clear layer of gel in the middle of the coffee cherry (mesocarp), which consists of glucose, protein, starch, fiber, carbohydrates, oils and pectin (Meenakshi; Jagan, 2007; Haile; Kang, 2019; 2020). It is a nutritional source for microorganisms. The compounds of coffee cherry mucilage vary depending on a number of factors, such as variety, and coffee cherry ripeness. The more mucilage, the better the resulting coffee tastes, and aromas will be (Meenakshi; Jagan, 2007).

Due to the dense phase CO_2, created during both fermentation processes, the resulting chemical changes involve a decrease in cytoplasm pH, explosive cell rupture, modification of a cell's membrane, inactivation of key enzymes and extraction of intracellular substances (Gunes; Blum; Hotchkiss, 2005; Liu et al., 2014). The pH value is key in determining the end point of the fermentation process, in order to prevent coffee from over fermenting to the point in which the microorganisms involved during the fermentation create undesirable aroma substances, causing a drop in coffee qualities (Haile; Kang, 2019).

A previous research supports this set of data, explaining that complex changes occurred during the SCM fermentation process including converting a small amount of sugar into alcohol. For example, during the wine production, the SCM process would be able to produce 1.5–2 % v/v alcohol, generally the wine would be fermented at 30-32 °C for 5-8 days, or at 15 °C for 20 days (Tesniere; Flanzy, 2011). However, during the fermentation of coffee, SCM in this study, when used with pulped coffee beans fermented at 17 °C until mucilage of pulped coffee reached to 4.35 of pH value, this took for approximately 3 days, was only able to create a small amount of alcohol, 0.8 % v/v.

At the same time, yeast has the ability to create a high amount of alcohol resulting in a low soluble solid and an increase in acidity, which is optimal for the process of digesting mucilage into new precursors for the green bean coffee through the growth of yeast and/or endogenous enzymes of coffee (Avallone et al., 2001). The process metabolites sugar into carbon dioxide gas as well as creates more acidic, alcoholic and volatile compounds (Haile; Kang, 2019; Silva et al., 2014; Evangelista et al., 2014).

According to researches and observations, the fermentation of SCM and Yeast process helps dissolve intact mucilage on coffee beans, which helps lessens the stickiness on coffee beans. Due to the reduction in degree of polymerization as well as in degree of methyl and acetate esterification releases some bound water into free water and enhances the moisture permeability in the plant tissue. Since free water has higher dielectric properties than bound water, the efficiency of drying is increased, leading to better product quality (Liu et al., 2014), including further developing coffee aromatic precursors (Vaast et al., 2006). A good process will create good sensory quality (Haile; Kang, 2019).

4.2 GC-O assessment

There are more than 2,600 aromatic substances (Ohloff, 1978) and more than 1,000 types of them are highly significant for the sensorial perception (Sunarharum et al., 2014), as well as the display of the unique aromatic attributes in food.

GC-O can be used to provide important information about the character of the odor associated with the different molecules contained within an odor sample. Thus, it allows for more information on odor quality. This technique is particularly suited to the analysis of odors due to the use of human nose, which is far more sensitive than an instrumental detector: the human nose is sometimes able to detect the presence of odors where the chromatogram doesn't show any peak (Capelli et al., 2019).

The Specialty Coffee industry has divided coffee aromas into 4 categories; 1) The Enzymatic category, which represents aromas created from the bio-chemical reactions of enzymes during the growth of coffee cherries on the coffee tree, a genetic result of the different coffee varieties, and can be further developed during the fermentation process. Aromas from this category, such as floral, fruity, and herbal, are most prominent as a light-roasted coffee. 2) The Sugar browning category, created from the caramelization and Millard reaction of single-molecule sugar inside coffee beans. The aromas of caramel, nuts, and chocolates are the most striking as a medium roasted coffee. 3) The Dry distillation category holds the resinous, spicy and carbony, characteristic of coffee. Coffee bean contains abundance of fibers within its cells. As coffee roasting is a very intense process, immense heat can burn the fibrous materials of the seed. Therefore, any chemical compounds that can be produced through above reactions are more likely to have resinous, spicy and carbony aromas. This category of aromas is most striking as a dark-roast coffee. 4) The Aromatic category is created through the natural chemical changes inside coffee beans. They can be found under special conditions such as the humidity of tropical forests, which causes coffee to generate earthy and smoky scent. Each of the aromatic categories contains both good and bad scents, which will be created through the chemical reaction during the roasting process and the aromatic intensities will be determined by the level of roasting (Bandara, 2014).

Concurring with previous research, which shows that the Carbonic maceration exposes intact grape berries to an oxygen-deprived environment, allowing enzymatic fermentation to occur within the berries, typically resulting in richly aromatic wines with a fruity bouquet and palate softness (Tesniere; Flanzy, 2011). The differences in microbial populations in Carbonic maceration result in sensory descriptors of spicy note and prevail complexity (Guzzon et al., 2020). Furthermore, the concentration of esters in the wine made by Carbonic maceration was higher than that in the wine made by classical white and red-winemaking techniques as found in Muscat Hamburg wine (Zhang et al., 2019). In coffee processing there is a relationship between the microbial load, the sensory and chemical profile of coffee submitted to Carbonic maceration, this was also observed in wine fermentation, indicating a change in the sensory profile in line with the microbial community (Lai et al., 2019).

Recent research on the yeast process supports, the theory of a starter culture fermentation during on-farm wet process, using one selected strain isolated from green coffee beans. At the end of the fermentation, the selected yeast strain prevailed over indigenous microbiota, and the production of specific aroma compounds increased (Pereira et al., 2020). Coffee that has been fermented by using the yeast strain CCMA 0543 possesses the flavors of banana, cashew nut, and the acidity of citrus fruits. While fermenting with the yeast strain CCMA 0544D will result in flavors of apples and cherries. On the other hand, the yeast strain CCMA 0543 will produce caramel flavors (Martinez et al., 2017). Furthermore, yeast strains *Candida parapsilosis* UFLA YCN448 and *S. cerevisiae* UFLA YCN727 produces special aroma of caramel, herbs and fruits in coffee processed by the Dry method (Evangelista, 2014).

4.3 Cup quality assessment

Sensory analysis is one of the most important techniques to judge the quality of coffee (Silva et al., 2014). The assessment is carried out by certified Q Arabica graders, using the cupping protocol set by the Specialty Coffee Association (Ethiopian Commodity Exchange, 2015; SCA, 2021). The results agreed with former research on the evaluation of inoculating two varieties of coffee (Ouro Amarelo and Mundo Novo) by combining Semi-dry method with three yeast strains (*S. cerevisiae* CCMA 0200 and CCMA 0543 and *Torulaspora delbrueckii* CCMA 0684, respectively) (Ribeiro et al., 2017).

The results of this study agree with previous studies, the various strategies employed during coffee fermentation encourages of numerous bio-chemical reactions, leading to a change in sensorial, chemical, and microorganism qualities. By using different time and temperature, the Carbonic maceration technique was able to provide higher quality sensory experience. The combination of 38 ^{o}C and 120 hours resulted in a total score of 85 points (Zhang et al., 2019). The combination of Wash process and Yeast process greatly affects the quality of aromas and flavors in coffee. 39% of consumers enjoyed coffee fermented by using the yeast strain CY3079 (Kwak; Jeong; Kim, 2018).

The same goes for the combination of Semi-dry process and yeast starter culture by direct inoculation and bucket inoculation, all treatments were performed empirically, without any type of control under environmental conditions, the ambient temperature ranged from 14.6 to 28.2 °C for 16 hrs. The sensorial results showed that no significant difference has been observed between treatments and inoculation methods. Coffee from all the treatments achieved scores above 80, which indicates good quality (Martinez et al., 2017). Similarly, Lallemand has been extensively researching on the impact of selected yeast on coffee processing. The average cup quality score of coffee using the Lalcafé yeast, has seen an average increase of two points (Fundira; Duez; Sieczkowski, 2020). Ultimately, the highest sensory evaluation is connected closely with the aroma compounds presented (Zhang et al., 2019).

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4.4 Integrated GC-O and cupping attributes

The aroma analysis through GC-O and the cupping process can be effectively integrated, however, the types of aroma detected might differ depending on various factors such as aromatic intensities, sample extraction processes, and the abilities of the cuppers. On one hand, the application of GC-MS-O method resulted in the determination of aroma-active compounds based on human odor receptors (Delahunty; Eyres; Dufour, 2006). This technique doesn't provide any information about the odor concentration of the sample. Since it operates a separation of the sample in its single components, the olfactory properties of the sample as a whole are not considered (Capelli et al., 2019). On the other hand, the cupping process belongs to the category of sensory descriptive analysis, it is one of the most powerful, sophisticated and most extensive tools used in sensory science, which provides a complete description of the sensory characteristics of food products (Varela; Ares, 2012). The cupping method depends on the human ability to perceive complex aromas created from various combinations of substances.

The previous study shows the aroma impact of fruits was due to the interaction between compounds. For example: Lychee was the interaction between compounds with floral (cis-rose oxide, 2-phenylethanol), citrus-fruity (geraniol, â-damascenone, linalool, isobutyl acetate), nutty-woody (2-acetyl-2-thiazoline, guaiacol, γ-nonalactone), plastic-green (2-nonenal, linalool oxide), and sweet (Furaneol) aromas with phenylacetic, isovaleric, and hydrocinnamic acids providing complexity to its aroma (Peter; Ong; Terry, 1998). The aroma of "Yulu" peach was contributed significantly between compounds of hexanal, 3-methylbutanal, (E)-2-hexen-1-ol, 3MHA, (E, E)-2,4-decadienal, 2-methylpropanal, γ-decalactone, 2-methylbutanal, theaspirane, and δ-decalactone (Niu et al., 2021).

5 CONCLUSIONS

The goal of this research was to create active-aroma wheels in three different coffee processes (Dry process, SCM-process, and Yeast process) by using gas chromatography–olfactometry, and sensory perspective. The aromas are then categorized into Enzymatic, Sugar browning, Dry distillation and Aromatic, and later translated into an active-aroma wheel, which would be highly beneficial for the future development of the specialty coffee industry.

This research shows that coffee from SCM and Yeast processes had greater potential in terms of active-aroma attributes than the ones from dry process. Coffee that has been treated by either the SCM process or the Yeast process resulted in a final score of above 80 points, which qualified all of them as specialty coffee, with coffee from Yeast process scoring the highest. The average final cup scores have been increased from the dry process by 2.08 and 3.41 respectively. Comparative active-aroma compounds of roasted coffee in each process by GC-O method and the identification of aroma descriptor by olfactory method can be further subjected to investigation. This systematic study can improve the active-aroma map of modern coffee process, and provide data support for the quality identification and traceability of the coffee process in the future.

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7 AUTHORS' CONTRIBUTION

WJ wrote the manuscript, supervised and performed the experiment, DC performed the experiment and conducted all statistical analyses, and LP performed the experiment, co-work the manuscript, reviewed and approved the final version of the work.

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