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LINGUISTICS
SECTION I. THEORY OF LANGUAGE

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Acoustic measurements of the Indonesian oral monophthongs produced by Acehnese speakers

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Abstract: This study explores the characteristics of Indonesian oral monophthong vowels produced by male and female language consultants in Banda Aceh, Indonesia, as their first language. Using purposive sampling, ten Acehnese males and ten Acehnese females were selected to articulate eight target vowels: /i/, /e/, /ɛ/, /ə/, /a/, /u/, /o/, and /ɔ/. Vowel measurements were obtained through recorded word elicitation, using a word list containing the target vowels. F1 and F2 frequencies in Hertz were determined and analyzed using Praat software to assess vowel qualities and subsequently converted to the Bark scale. Vowels were plotted on the F1/F2 formant space. The findings illustrate the distinct measurements of each Indonesian monophthong vowel by male and female consultants, represented in the vowel space. Male vowels generally exhibit higher and more centralized positioning, while female vowels appear more dispersed and lower. This research contributes valuable insights for comparing vowel systems across various languages and dialects spoken in multilingual Indonesia.

Keywords: Indonesian; Acehnese; Monophthongs; Vowels; Acoustic analysis; Praat software

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Introduction

Banda Aceh, the capital city of Aceh Province, is situated at the northernmost tip of Sumatra, Indonesia. The province is home to multiple ethnic communities, each with its own distinct language and dialect. Among the prominent ethnic groups in Aceh are the Acehnese, Gayonese, Alas, Tamiang, Aneuk Jame, and Kluet (Wu, 2006). As the administrative hub of Aceh Province, Banda Aceh represents the diverse Acehnese population (Ikhsan, 2014). Many young individuals aged 20-22 predominantly speak Indonesian as their primary language in this city (Al-Auwal, 2017). The regional languages spoken within the province influence the pronunciation variations in Indonesian (Nurlaila, 2016). Investigating the vowels and consonants produced by speakers is one method to assess the extent of differences or similarities in sound production.

Moreover, Indonesia is the largest archipelago country in the world, composed of five main island groups and about 30 smaller island groups, totaling 17,508 islands, with approximately 6,000 of them inhabited. Indonesia consists of 37 provinces with 633 ethnic groups and 1,211 languages. Due to this diversity, the national language, Indonesian, serves as the lingua franca (Assapari, 2014; Paauw, 2009). In this country, despite the numerous regional languages, Indonesian is the second language for most Indonesians (Wahyuni and Widagsa, 2017). Nowadays, many young families use Indonesian as their first language when communicating with their children (Aziz and Amery, 2016), even in regions where other languages are predominant (Muliawati and Yusnida, 2022). This phenomenon is also observed in the city of Banda Aceh (Al-Auwal, 2017).

There is a dearth of published research on the acoustic characteristics of Indonesian vowels. Acoustic studies of sounds in this language have received limited attention among linguistic scholars, particularly concerning the variety spoken by Acehnese individuals born and raised in Banda Aceh. Moreover, many explanations of Indonesian sounds rely on impressionistic descriptions (e.g., Wijana, 2003; Wulandari and Nugraheni, 2019). Meanwhile, acoustic descriptions of sounds in a language offer more comprehensive and detailed findings.

Consequently, research on Indonesian sounds necessitates acoustic analysis. Unlike consonants, the vowel system is crucial to study as sound changes in vowels are often more audible (Yusuf and Pillai, 2013; Yusuf and Pillai, 2016). Accordingly, the research question is formulated as follows: “What are the characteristics of the Indonesian oral monophthong vowels produced by Acehnese male and female speakers?”

It is hoped that this research will serve as a foundational reference for further exploration of the Indonesian vowel system and documentation and comparisons with other related languages. Documentation is crucial for researchers interested in language studies (Himmelmann, 2006) because languages are dynamic (De Bot, 2008); they evolve rapidly due to the dynamism of their speakers. Additionally, the results can facilitate comparative examinations of the acoustic characteristics of sounds in the numerous languages spoken in Indonesia. The findings from this study can also be applied in clinical settings to enhance the quality of life for individuals, particularly Indonesian speakers with speech and hearing impairments (Anggraeni et al., 2023).

Literature Review

The acoustics of the vowels

This research aims to describe the Indonesian oral monophthong vowels produced by Acehnese male and female speakers in Banda Aceh using the acoustic phonetics approach. Acoustic phonetics is a field of study that involves instruments for analyzing the physical features of language sound waves (Ladefoged, 2006). Acoustic analysis is a primary method for studying sound (Fromkin, Rodman, and Hyams, 2003) and utilizes software to process data (Boersma, 2013). Speech sounds consist of several components, including formant, pitch, and intensity, which can be used for voice recognition and identifying individual characteristics (Heryono, 2019). In vowel studies, typically only formants F1 through F2 are investigated because higher formants have less energy and impact on perception (Hossain et al., 2007). Due to speaker characteristics, F3 and F4 provide more contrast than F1 and F2, making higher formants less efficient for conveying phonetic information than lower formants. Therefore, the first two formants of vowels are the most commonly used acoustic indicators (Jacobi, 2009). The first formant (F1) reflects the vertical position of the tongue and the openness of the mouth, related to the degree of constriction, whereas the second formant (F2) indicates the length of the front cavity and represents the front-to-back dimensions (Jacobi, 2009).

With relatively unrestricted airflow, vowel sounds are created, whereas consonant sounds are often voiced and primarily articulated through vocal tract closure or obstruction (Yule, 2014). Vowels are frictionless syllabic sounds produced by a free airflow down the middle of the vocal tract, typically with a convex tongue shape (Ogden, 2009). The positioning of the tongue influences the form through which the airflow must pass to produce vowel sounds (Roach, 2009).

Vowel articulation involves three primary qualities: height, backness, and rounding (Rogers, 2013). Height refers to the tongue's vertical position relative to the roof of the mouth or jaw aperture. Vowel sounds are categorized into three height types: closed vowels (/i:/), mid vowels (/e/, /ə/, /ɜ:/), and open vowels (/æ/) (Kelly, 2001; Zhang and Hu, 2018). Backness, as explained by Hayes (2009), relates to the horizontal tongue position in the mouth, influencing the frontness or backness of vowels. The mouth's shape, including lip position (rounded, spread, or neutral), also affects vowel quality (Kelly, 2001). Vowel classification by phoneticians considers tongue height and lip rounding (Roach, 2009). Additionally, vowels are classified into monophthongs and diphthongs (McMahon, 2002; Zhang and Hu, 2018).

A monophthong is a vowel sound produced with a single articulatory gesture, remaining constant without gliding (Zhang and Hu, 2018), which is known as a pure

vowel (Almurashi, 2016; Roach, 2009). For instance, in words like 'apple' (/ˈæpəl/), 'set' (/sɛt/), and 'tip' (/tɪp/), the vowels are monophthongs (Ladefoged and Disner, 2012; Zhang and Hu, 2018). Monophthongs are characterized by steady-state vowels, where articulation remains unchanged throughout their production. Tongue height, tongue progression, lip rounding, and tension are sufficient to describe monophthong vowels (Fromkin, Rodman, and Hyams, 2003; Zhang and Hu, 2018). Indonesian is identified with six pure vowels: /a/, /i/, /u/, /e/, /ɛ/, and /o/ (Wahyuni and Widagsa, 2017; Wulandari and Nugraheni, 2019). A diphthong is characterized by a sequence of vowels pronounced with varying vowel qualities (Ladefoged, 2006). As the vocal tract arrangement changes over time during the production of diphthongs, the acoustic pattern of these sounds also changes. Therefore, the first and second formants of diphthongs are anticipated to be less stable than those of monophthong vowels, with diphthongs being characterized by their changing vowel quality during articulation (Lee and Lim, 2000). Indonesian contains four diphthongs: /aɪ/, /aʊ/, /oɪ/ (Alwi et al., 2003), and /eɪ/ (Chaer, 2009).

Indonesian monophthong vowels

In Indonesian, there are six pure vowels, namely /a/, /i/, /u/, /e/, /ɛ/, and /o/ (Wahyuni and Widagsa, 2017; Wulandari and Nugraheni, 2019). Indonesian vowels can be distinguished based on parameters related to tongue position and the part of the tongue involved during vowel formation (Chaer, 2009). These parameters categorize vowels into: 1) high vowels, namely: /i/ and /u/

2) medium vowels, namely: /e/, /ə/, and /o/

3) low vowels, namely: /a/

Based on the front and rear parameters of the tongue, it is divided into:

1) front vowels, namely: /i/ and /e/

2) middle vowels, namely: /ə/ and /a/

3) back vowels, namely: /u/ and /o/

The Indonesian vowels are distinguished through minimal pairs, which refer to the ability to change the form and meaning of words by replacing one or more phonemes within word pairs (Setyadi and Wasisto, 2018). The existence of minimal pairs of vowels in Indonesian relates to several factors: (a) the functional role of phonemes in minimal pairs, (b) the consistency of speech and phoneme symbols, (c) the identification of phoneme types and quantities, (d) phonemes as a cause of meaning differences or contrasts between words, and (e) the formation of antonyms. Examples of minimal pairs of Indonesian vowel phonemes are shown in Table 1: /a/, /i/, /u/, /ə/, /ɛ/, and /o/.

Table 1. Minimal Pairs of Indonesian Monophthong Vowels[1]

No.	Minimal Pairs	Words and Gloss	
1.	/a/ – /i/	*tari* 'dance'	*tiri* 'step mother/father/sister/brother/'
2.	/a/ – /u/	*bata* 'brick'	*batu* 'rock, stone'
3.	/a/ – /ə/	*taman* 'garden'	*teman* 'friend'
4.	/a/ – /ɛ/	*kakak* 'elder sister'	*kakek* 'grandfather'
5.	/a/ – /o/	*kata* 'word'	*kota* 'city'
6.	/i/ – /u/	*kami* 'we'	*kamu* 'you'
7.	/i/ – /ə/	*gilas* 'run over'	*gelas* 'glass'
8.	/i/ – /ɛ/	*cirit* 'diarrhea'	*ceret* 'kettle'

[1] Iskandar, D. (2022). Lecture 4: Tata bahasa Indonesia [PowerPoint slides], Universitas Syiah Kuala, Banda Aceh, Indonesia.

No.	Minimal Pairs	Words and Gloss	
9.	/i/ – /o/	*kita* ‘we’	*kota* ‘city’
10	/u/ – /ə/	*kuluk* ‘oversized hat (tall and stiff, now commonly worn by grooms at weddings)’	*Keluk* ‘something curved/arched/bent’
11.	/u/ – /ɛ/	*kalung* ‘necklace’	*kaleng* ‘can, container’
12.	/u/ – /o/	*bulu* ‘fur, feather, hair, bristle’	*bolu* ‘spongecake’
13	/ə/ – /ɛ/	emas ‘gold’	*enak* ‘delicious’
14.	/ə/ – /o/	*kelam* ‘dark’	*kolam* ‘pool’
15.	/ɛ/ – /o/	*bela* ‘defend’	*bola* ‘ball’

Some works have expanded the list of Indonesian pure vowels by adding /ɔ/ to the original six vowels (/a/, /i/, /u/, /e/, /ə/, /o/), resulting in seven Indonesian monophthongs (Candra and Sukma, 2020; Wijana, 2003). Alfata (2021) introduced an additional vowel, /e/, making a total of eight Indonesian monophthongs (/a/, /i/, /u/, /e/, /ə/, /ɛ/, /o/, /ɔ/). Finally, Chaer (2009) included /ɪ/ and /ʊ/, expanding the list to ten vowels (/a/, /ɪ/, /i/, /ʊ/, /u/, /e/, /ə/, /ɛ/, /o/, /ɔ/). These variations may stem from the informants' sources; the diverse regional languages spoken by different ethnic groups in Indonesia could influence the production of Indonesian vowels. For instance, Candra and Sukma (2020) sourced Indonesian vowel data from books authored by Javanese and Sundanese individuals, Wijana (2003) from Balinese origins, Chaer (2009) from Javanese background, while Alfata (2021) conducted research with Acehnese respondents.

Inter-speaker gender differences

The comparison of formant values in acoustic phonetic studies is a delicate task, especially when dealing with speakers of different sexes (Jacobi, 2009). Formants represent distinct frequency bands in the acoustic signal of speech that correspond to resonances in the vocal tract, providing essential information for understanding and analyzing speech sounds. One significant factor contributing to these inter-speaker differences is the varying length of the vocal tract between genders. Adult females typically possess a shorter vocal tract, measuring around 13 cm, while adult males exhibit a range of lengths, often exceeding 18 cm (Maragakis, 2008). This difference in vocal tract length has direct implications for resonance frequencies in speech production. The influence of vocal tract length on resonance frequencies is particularly noteworthy. Women, with their shorter vocal tracts, tend to have higher resonance frequencies compared to men (Flynn, 2011). This variance extends to formant frequencies, which are the acoustic resonances in speech. Formant frequencies in females are generally 10% to 15% higher than those in males, resulting in speech with greater clarity (Simpson, 2009; Wang & van Heuven, 2006). The higher formant frequencies and clearer speech production in females pose challenges when directly comparing formant values across speakers of different sexes. To address this, a normalization procedure is deemed essential. This procedure, as emphasized by Jacobi (2009), should specifically account for sex differences. By doing so, linguistic effects related to gender differences can be differentiated from biological sex effects, enabling more accurate variation analysis. The normalization method transforms the acoustic vowel space with the aim of clustering phonetically similar vowels together and distinguishing those that are phonetically dissimilar (Watson, Maclagan, and Harrington, 2000). Typically, normalization research focuses on addressing variations in vocal tract size and shape between males and females (Johnson, 2005). Consequently, in situations where the speakers being examined share the same gender, the need for normalizing vocal tract length is often minimal. This is exemplified

by the study conducted by Konopka and Pierrehumbert (2010), which explored the vowel dynamics of Mexican Heritage English and exclusively involved adult female participants. Another study by Ferragne and Pellegrino (2010) examined the vowel characteristics of speakers across 13 accents of the British Isles, with participants exclusively male. In instances where participants are of the same sex, the requirement for normalization related to vocal tract length is usually deemed unnecessary (see Yusuf et al., 2021).

Material and Methods

Descriptive qualitative research is the design of this study. Rather than breaking a phenomenon down into variables, qualitative researchers choose to focus on the phenomenon as a whole to better comprehend it (Ary et al., 2009). This research design was chosen because it is suitable for describing the vowel quality of Indonesian oral monophthongs produced by Acehnese speakers from Banda Aceh.

Language consultants

The language consultants for this research were ten Acehnese males and ten Acehnese females, who are students in the Department of English Education at Universitas Syiah Kuala, Banda Aceh. The criteria for selection included being born and raised in Banda Aceh, speaking Indonesian as their first language (even if they can speak Acehnese, it is their second language after Indonesian), being aged 20-22 years old, never having lived outside their place of residence except for short holidays to other locations, having no dental problems, no lip deformations, and no hearing impairments (Yusuf et al., 2018).

Data collection

The process of data collection and analysis largely follows the approach described by Yusuf (2013). An elicitation sheet instrument containing a word list was used for data collection. The word list (see Table 1) was designed to ensure that all target sounds were presented (Yusuf, 2013; Yusuf et al., 2022) and was created based on the six existing Indonesian pure vowels (Wahyuni and Widagsa, 2017; Wulandari and Nugraheni, 2019). Consequently, this study adds two additional monophthong vowels found in Indonesian as spoken by Acehnese speakers, namely /ɔ/ and /e/ (Alfata, 2021), resulting in a total of eight Indonesian oral monophthong vowels under investigation. The presence of /ɔ/ and /e/ in Acehnese Indonesian is predictable as these vowels are part of the Acehnese vowel system (Iskandar et al., 2020; Yusuf, 2013; Yusuf et al., 2022; Yusuf et al., 2018; Yusuf and Pillai, 2013; Yusuf and Pillai, 2016).

The language consultants were asked to produce the target words from the list by incorporating them into a carrier sentence (Pillai et al., 2010). The carrier sentence used was "ucap [...] sekali lagi," which translates to "say [the target word] one more time" (Yusuf, et al., 2021). One of the advantages of using carrier sentences is that they ensure highly comparable data (Verhoeven and van Bael, 2002). Additionally, the target words were selected to be vowels preceding and following fricatives or placed in a CVC or CV environment where C represents a stop or fricative consonant (King, 2006; Yusuf, 2013).

Table 2. Word list for the Indonesian oral monophthong vowels

Vowel	Word	Gloss
/a/	*tapi* /ta.pi/	‘but’
/i /	*tiga* /ti.ga/	‘three’
/ə/	*tepi* /tə.pi/	‘edge’
/u/	*tugu* /tu.gu/	‘monument’
/ɔ/	*topi* /tɔ.pi/	‘hat’
/e/	*teko* /te.ko/	‘teapot’
/ɛ/	*teh* /tɛh/	‘tea’
/o/	*toke* /to.ke/	‘boss’

At the Department of English Education, Faculty of Teacher Training and Education, Universitas Syiah Kuala, the language consultants were observed and recorded in the Phonetics Lab. Each consultant read the carrier sentence five times

for each vowel to produce 40 tokens. Approximately 10 minutes were required for each consultant to elicit all the target words. The recordings were then stored in WAV file format using PRAAT software, which offers a variety of custom and conventional processing options, including neural networks and articulatory synthesis.

Data analysis

The recorded data saved in WAV file format were then transcribed using the TextGrid feature in the PRAAT program. To achieve maximum flexibility in the analysis of the sounds, the first two formants of each target vowel were measured. The midpoint of each monophthong shown in the spectrogram was measured at its F1 and F2 in Hertz (Ladefoged, 2003). Subsequently, following previous studies (Masykar et al., 2021; Yusuf, 2013; Yusuf et al., 2018; Yusuf et al., 2021), the data were transferred to Microsoft Excel, and the measurements in Hertz were converted to the Bark scale using the formula proposed by Zwicker and Terhardt (1980: 1254).

The vowel charts were created to display the positions of vowel production in the vowel space. These charts were constructed using Microsoft Excel, building upon the foundation established by Deterding (2003). The data results were further represented through charts and descriptions. Given the inclusion of data from both male and female speakers and considering this study as the initial investigation into the acoustic phonetics of Indonesian vowels, the integration of results is intentionally avoided. This study provides separate presentations of vowel characteristics for males and females. This approach enhances the utility of the results for future research endeavors related to the subject matter. Consequently, the findings are presented individually within designated vowel spaces for each gender.

Findings

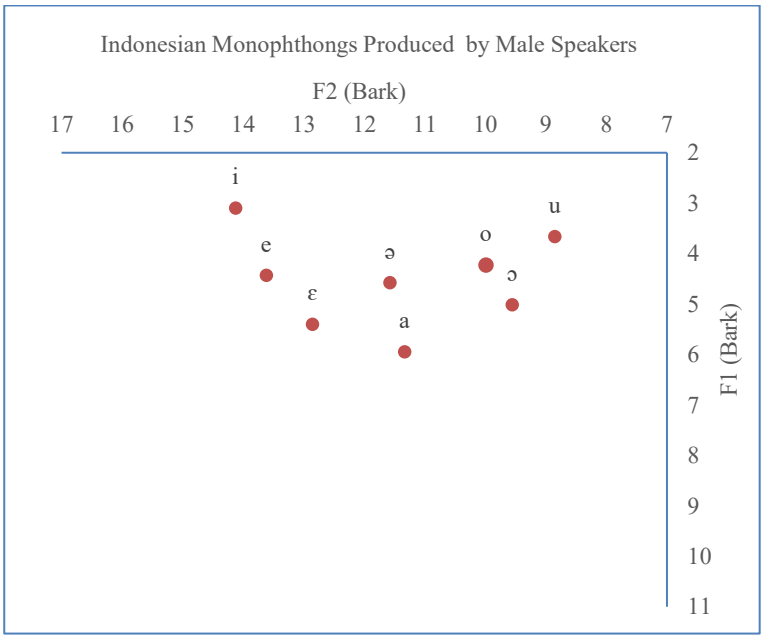
The average vowel length and formant frequencies for F1 and F2 produced by the male language consultants are shown in Table 3.

Figure 1 illustrates the plots of Indonesian oral monophthongs in the vowel space for the male language consultants.

Table 3. F1 and F2 average values for Indonesian oral monophthongs produced by the male language consultants

Vowel	Target Word	Male Language Consultants				
		Ave. Duration (sec)	Ave. F1(Hz)	Ave. F2(Hz)	Ave. F1(Bark)	Ave. F2(Bark)
/i/	*tiga*	669	831	1756	3.10	14.13
/e/	*teko*	603	466	2173	4.43	13.62
/ɛ/	*teh*	1127	578	1927	5.40	12.86
/ə/	*tepi*	456	482	1591	4.58	11.58
/a/	*tapi*	638	646	1533	5.95	11.34
/u/	*tugu*	635	380	1065	3.66	8.86
/o/	*toke*	870	443	1261	4.23	9.99
/ɔ/	*topi*	577	534	1177	5.02	9.56

Figure 1. Scatter plot of formant average values for Indonesian oral monophthong vowels produced by the male language consultants



The positions of /i/, /e/, and /ɛ/depict their positions are front vowels, with /i/ positioned as the highest front vowel. Moreover, /ə/ and /a/ are categorized as central vowels, with /a/ produced as the lowest vowel. Furthermore, /u/, /o/, and /ɔ/ are back vowels, with /u/ being the most back of them all.

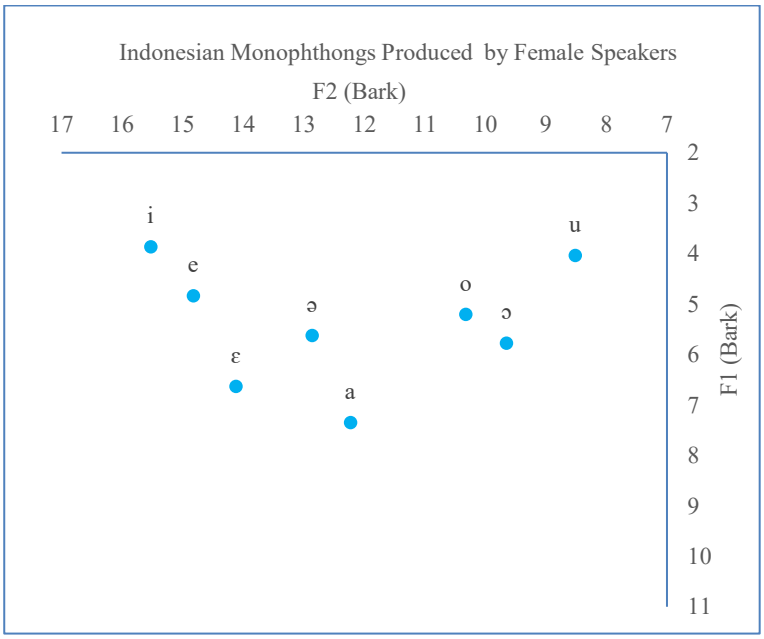
Moreover, The average vowel length and formant frequencies for F1 and F2 produced by the female language consultants are shown in Table 4.

Figure 2 illustrates the plots of Indonesian oral monophthongs in the vowel space for the female language consultants.

Table 4. F1 and F2 average values for Indonesian oral monophthongs produced by the female language consultants

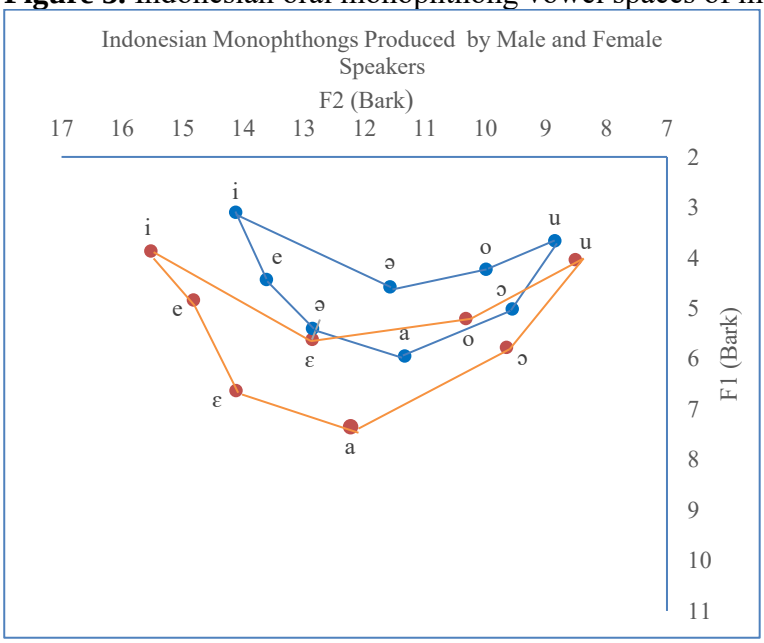
Vowel	Target Word	Female Language Consultants				
		Ave. Duration (sec)	Ave. F1(Hz)	Ave. F2(Hz)	Ave. F1(Bark)	Ave. F2(Bark)
/i/	*tiga*	771	403	2966	3.86	15.53
/e/	*teko*	754	513	2636	4.84	14.82
/ɛ/	*teh*	1109	733	2355	6.63	14.12
/ə/	*tepi*	497	605	1936	5.62	12.86
/a/	*tapi*	721	831	1756	7.35	12.23
/u/	*tugu*	900	422	1011	4.04	8.52
/o/	*toke*	1373	556	1324	5.20	10.32
/ɔ/	*topi*	684	624	1194	5.77	9.65

Figure 2. Scatter plot of formant average values for Indonesian oral monophthong vowels produced by the female language consultants



Similar to the male language consultants, the female language consultants also produced /i/, /e/, and /ɛ/ as front vowels, with /i/ positioned as the highest front vowel. Moreover, /ə/ and /a/ are categorized as central vowels, with /a/ produced as the lowest vowel. Additionally, /u/, /o/, and /ɔ/ are back vowels, with /u/ being the farthest back of them all. Hence, based on the vowel placements in Figures 1 and 2, female vowel production is more spread and lower in the vowel space compared to males. Meanwhile, the vowels of the males are positioned higher and quite centrally in the vowel space (see Figure 3).

Figure 3. Indonesian oral monophthong vowel spaces of male and female language consultants



The following subsections outline the acoustic properties of Indonesian vowels as articulated by Acehnese speakers, categorized by tongue positions: front, central, and back vowels.

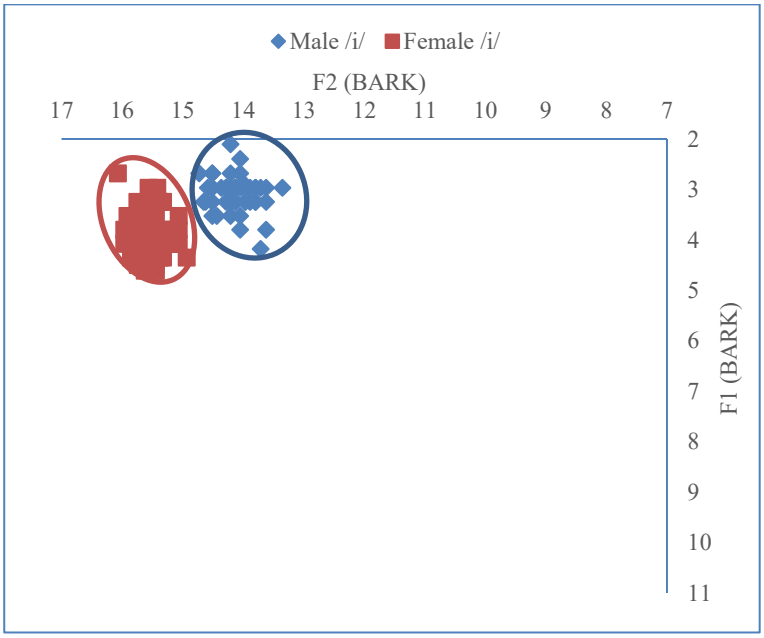
Front vowels

The front vowels in Indonesian are /i/, /e/, and /ɛ/. Their measurements and characteristics are explained below.

The production of /i/ in *tiga* /ti.ga/

The average value of F1 for the vowel /i/ in *tiga* 'three' is 831 Hz for the male language consultants and 403 Hz for the female language consultants. The males have an average F2 of 1756 Hz, whereas the females have an average F2 of 2966 Hz. The females generated the vowel /a/ lower and more fronted than the males, as illustrated in Figure 4. The distribution of male /i/ and female /i/ is presented in Figure 4.

Figure 4. Scatter plot of Indonesian /i/ from *tiga* produced by the male and female language consultants



The production of /e/ in *teko* /te.ko/

The average value of F1 for /e/ in *teko* 'teapot' is 466 Hz for the male language consultants and 513 Hz for the female language consultants. The males have an average F2 of 2173 Hz, whereas the females have an average F2 of 2636 Hz. As shown in Figure 5, the vowel /e/ is produced lower and more fronted by the females than the males.

The production of /ɛ/ in *teh* /tɛh/

For the vowel /ɛ/ in *teh* 'tea', female language consultants produce /ɛ/ lower and more fronted compared to male language consultants. The average F1 value for males is 578 Hz, while for females it is 733 Hz. The average F2 value is 1927 Hz for males and 2355 Hz for females. Figure 6 shows the distribution of /ɛ/ for both male and female speakers.

Figure 5. Scatter plot of Indonesian /e/ from *teko* produced by the male and female language consultants

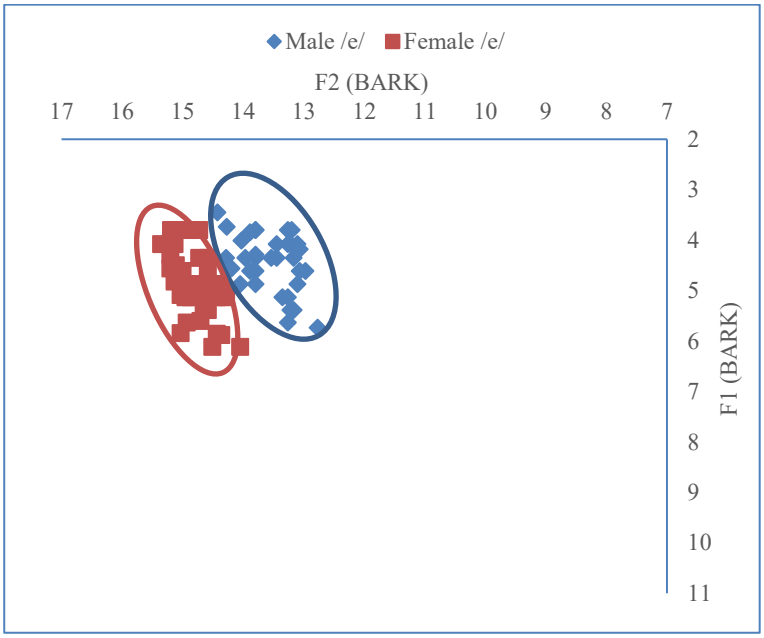
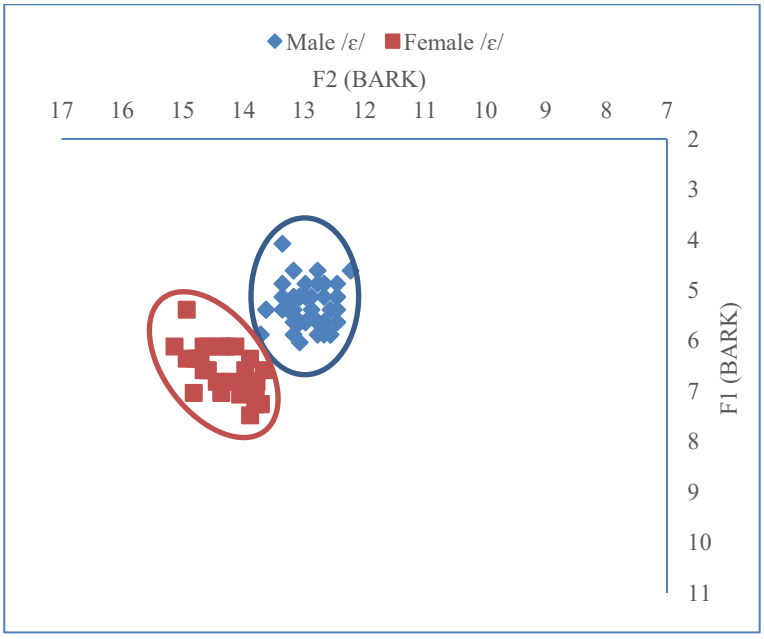


Figure 6. Scatter plot of Indonesian /ɛ/ from *teh* produced by the male and female language consultants



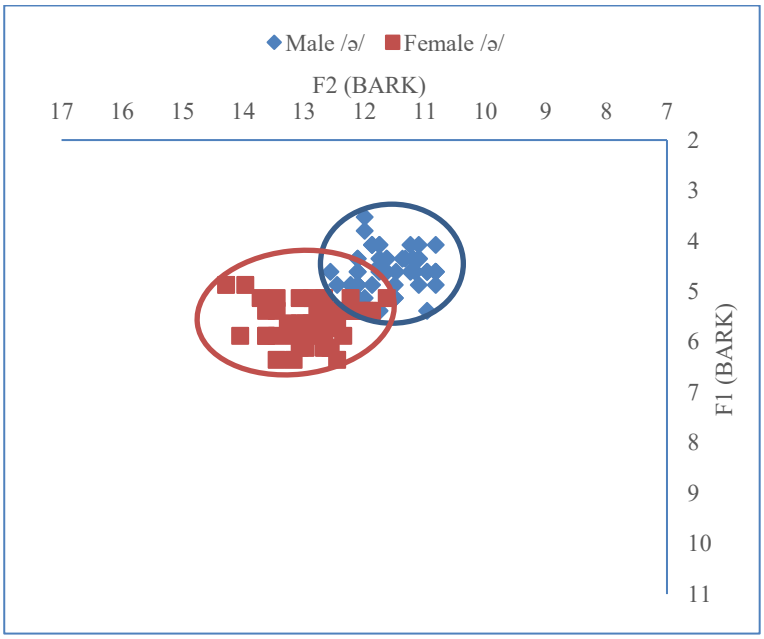
Central vowels

The central vowels in Indonesian are /ə/ and /a/. Their measurements and characteristics are explained below.

The production of /ə/ in *tepi* /tə.pi/

The analysis of the vowel /ə/ in *tepi* 'edge' revealed that the average value of F1 for the male language consultants is 482 Hz and for the female language consultants 605 Hz. The average value of F2 for males is 1591 Hz, whereas the average value for females is 1936 Hz. As shown in Figure 7, the vowel /ə/ was produced higher and further back by the males compared to the females.

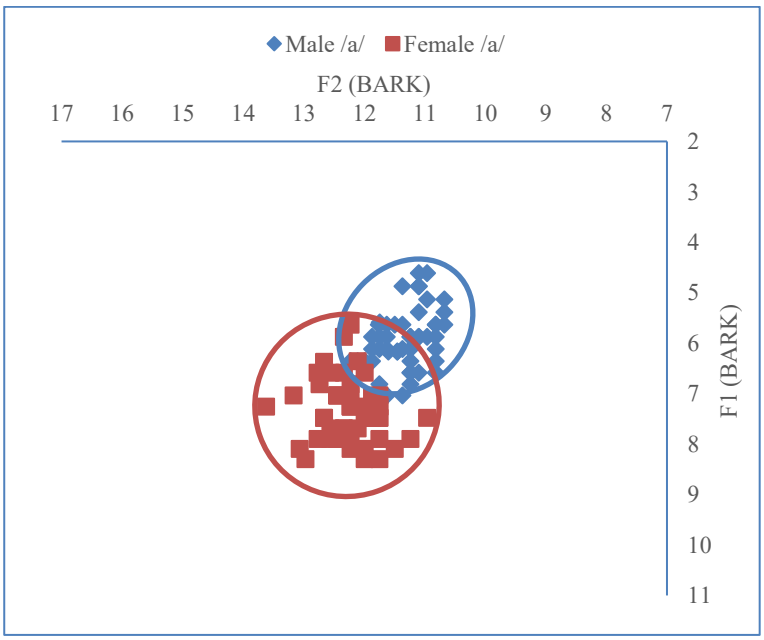
Figure 7. Scatter plot of Indonesian /ə/ from *tepi* produced by the male and female language consultants.



The production of /a/ in *tapi* /ta.pi/

The average value of F1 for /a/ in *tapi* 'but' is 646 Hz for male language consultants and 831 Hz for female language consultants. The males have an average F2 of 1533 Hz, whereas females have an average F2 of 1756 Hz. Female language consultants generated the vowel /a/ lower and more fronted than male language consultants, as illustrated in Figure 8.

Figure 8. Scatter plot of Indonesian /a/ from *tapi* produced by the male and female language consultants



Back vowels

The central vowels in Indonesian are /u/, /o/, and /ɔ/. Their measurements and characteristics are explained below.

The production of /u/ in *tugu* /tu.gu/

The average F1 value for the vowel /u/ in *tugu* 'monument' is 380 Hz for male language consultants and 422 Hz for female language consultants. The average F2 value for males is 1065 Hz, while for females it is 1011 Hz. Females produce a lower and slightly more back-positioned /u/ vowel compared to males, as illustrated in Figure 9, which shows the distribution of /u/ for both male and female speakers.

The production of /o/ in *toke* /to.ke/

The average value of F1 for /o/ in *toke* 'boss' is 443 Hz for the male language consultants and 556 Hz for the female language consultants. The average F2 value for males is 1261 Hz, while for females it is 1324 Hz. As illustrated in Figure 10, females produce the vowel /o/ lower and more fronted than males. Figure 10 shows the distribution of /o/ for both male and female speakers.

Figure 9. Scatter plot of Indonesian /u/ from *tugu* produced by the male and female language consultants

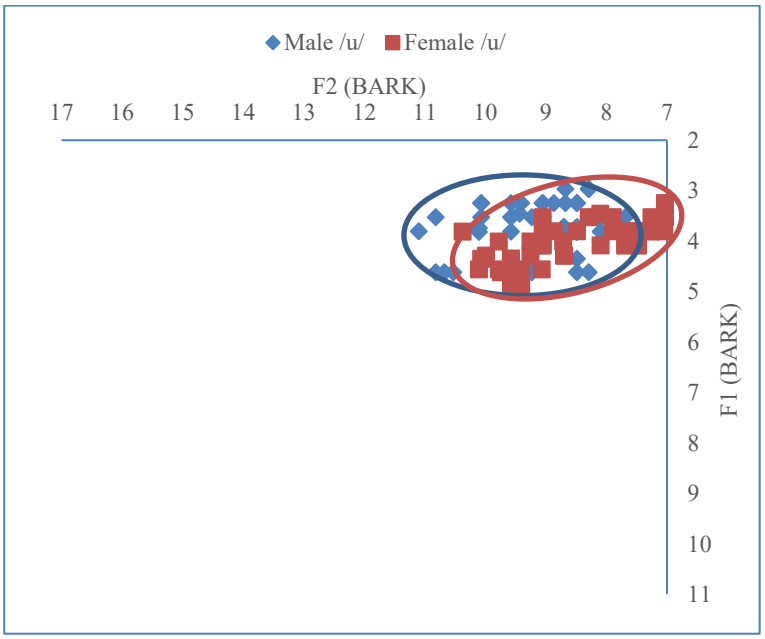
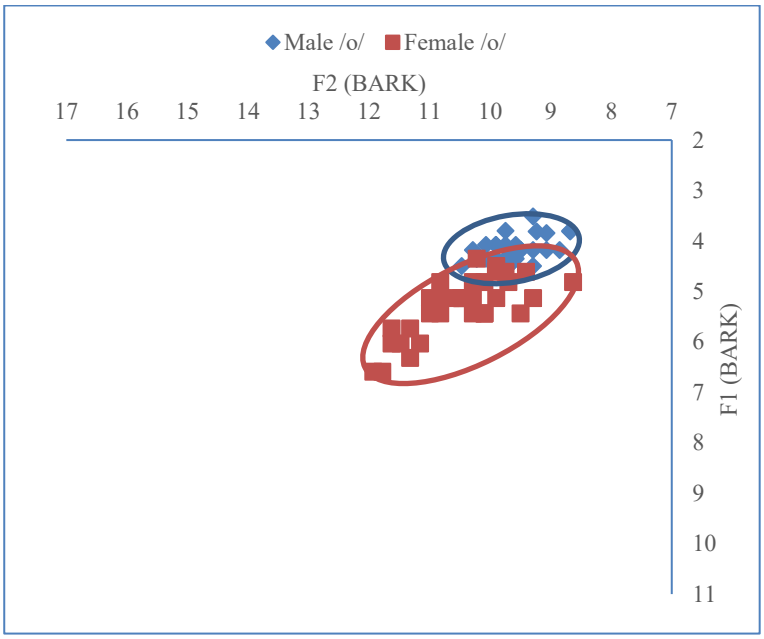


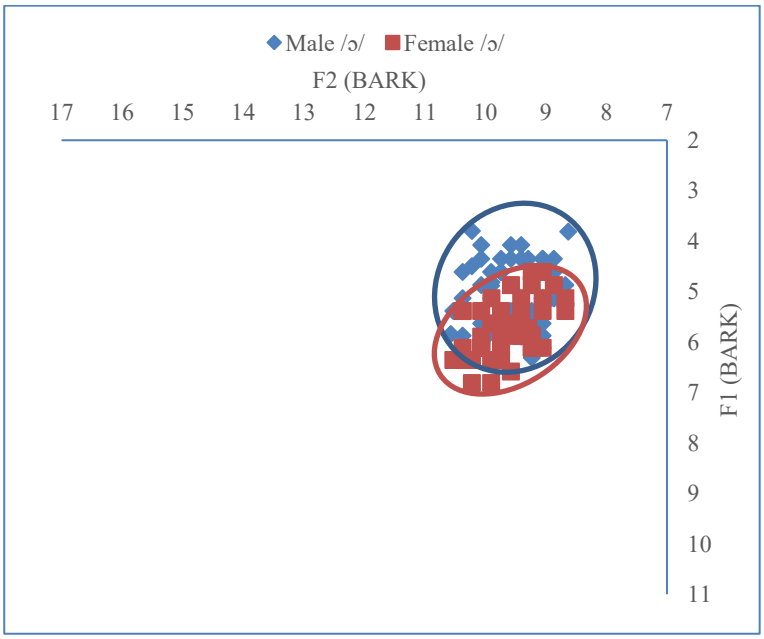
Figure 10. Scatter plot of Indonesian /o/ from *toke* produced by the male and female language consultants



The production of /ɔ/ in *topi* /tɔ.pi/

For /ɔ/ in *topi* 'hat', the average value of F1 for the male language consultants is 534 Hz, and for the female language consultants, 624 Hz. The average value of F2 for males is 1177 Hz, while the average value for females is 1194 Hz. The females generate the vowel /ɔ/which is almost identical to the males, but it is lower and slightly more fronted than the males, as seen in Figure 11.

Figure 11. Scatter plot of Indonesian /ɔ/ from *topi* produced by the male and female language consultants



Discussion

The acoustic analysis of Indonesian monophthong vowels among Acehnese speakers in Banda Aceh sheds light on vowel characteristics within this linguistic context, drawing upon insights from previous studies. Acoustic phonetics, as highlighted by Ladefoged (2006), serves as a foundational tool for analyzing speech sounds, including vowels. Our investigation centered on formants F1 and F2, echoing the emphasis on these formants' importance in vowel production (Jacobi, 2009).

The findings of this study align with the categorization of Indonesian vowels based on tongue position (front, central, back), as discussed by Wahyuni and Widagsa (2017) and Wulandari and Nugraheni (2019). The observed formant frequency variations showed how articulatory features influence vowel characteristics in Indonesian. Notably, the findings echo the research of Heryono (2019), Setyadi and Wasisto (2018) on Indonesian vowel systems, and Yusuf et al. (2018; 2022) on varieties of Acehnese vowel systems, reinforcing the functional role of phonemes in these languages. The distinctions in vowel production among Acehnese speakers further resonate with Yusuf and Pillai's (2013; 2016) work on phonetic variability across genders. Accordingly, gender-related differences in vowel production, such as resonance frequencies and formant values, are consistent with existing literature (Simpson, 2009; Wang & van Heuven, 2006). The observed variance in vocal tract length between males and females, as described by Maragakis (2008), illustrates the importance of normalization techniques in acoustic phonetic studies, as discussed by Jacobi (2009).

Hence, this study contributes to the broader understanding of Indonesian vowel characteristics, emphasizing the relationship between formant analysis, vowel categorization, and gender-related differences in speech production. By integrating findings from a range of studies, including those of Heryono (2019), Setyadi and Wasisto (2018), Wulandari and Nugraheni (2019), and Yusuf et al. (2018; 2022), this study accentuates the significance of acoustic phonetics in describing vowel dynamics within different linguistic contexts.

Conclusion

Both female and male language consultants produced vowels with different qualities. Based on the vowel placements, the vowel production by the female language consultants is more spread and lower in the vowel space compared to males. Meanwhile, the vowels of the males are positioned higher and quite centrally in the vowel space. These findings suggest distinct vowel qualities between female and male language consultants. Female vowels are lower and more spread out in the vowel space, whereas male vowels are higher and centrally positioned. This difference indicates gender-based variations in vowel articulation and placement within the acoustic vowel space.

The study has several limitations. Firstly, the sample size may be small, impacting the generalizability of the findings to broader populations. Secondly, external factors not accounted for in the study could influence outcomes. These limitations suggest caution in interpreting and applying the study's findings beyond its specific context and parameters. Diphthongs and consonants are also found in the Indonesian sound system. Therefore, future acoustic phonetics research on these sounds is deeply encouraged. Other data sets (i.e., from spontaneous speech) are also urged to be conducted. Indonesia is also a country of hundreds of ethnic groups and languages, so comparative studies on varieties of Indonesian sounds are also worthwhile.

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