On the Status of Bìrọ̀m Vowel Harmony

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Abstract

Platoid languages of North-Central Nigeria, including Bìrọ̀m, have been assigned to an "ATR-less zone" in which tongue root harmony is held to be absent, and the only recognized mid-vowel patterning is one of strict or liberal contrast. This classification, however, rests on typological generalization rather than on instrumental evidence. This study therefore sets out to determine the status of vowel harmony in Bìrọ̀m by examining the co-occurrence patterns of mid vowels to establish whether they constitute a harmony system and to identify the acoustic cues that characterize the behavior of that system. Fifty-five CVCV lexical items were elicited from ten adult native speakers, with each item repeated three times, yielding 1,650 tokens. The data were annotated in ELAN, measured automatically in Praat, and analyzed in RStudio and PhonR. F1, F2, B1, and CPP were measured, and the analysis was framed within the typology of ATR harmony - particularly the distinction between complete and trace (incomplete) systems. Findings show that Bìrọ̀m operates a trace ATR system in which height and tongue root interact, such that [+ATR] mid vowels do not co-occur with [-ATR] mid vowels within the root, while the high and low vowels /a i u/ remain neutral. Acoustically, [-ATR] vowels have consistently higher F1 and B1 than their [+ATR] counterparts, whereas F2 separates the back pair [o] and [ɔ] from the non-back pair [e] and [ɛ], a difference attributable to backness rather than tongue root position. These findings are consistent with articulatory explanations from previous acoustic investigations.

Keywords: *Bìrọ̀m/Bèròm; mid-height vowels; harmony; ATR; acoustics; Platoid*

1 Introduction

This paper is an acoustic investigation of the status of vowel harmony in Bìrọ̀m (mostly written as Bèròm). Bìrọ̀m is a language spoken in the highlands of Plateau State in Nigeria. The choice of Bìrọ̀m as the spelling for the language in this study is consistent with the native speakers' pronunciation; the language is assigned the ISO 639-3 code [bom]. Bìrọ̀m is an African language classified as an East Benue-Congo language (Williamson & Blench, 2000; Watters, 2018; Blench, 2019) and spoken in North-Central Nigeria, specifically in Jos South, Jos North, Barkin Ladi and Riyom in Plateau State, and in parts of Kaduna State (Gwom, 1992; Ukaegbu, 2017b). Bitrus et al. (2013) believe that the speaker population of Bìrọ̀m is over 500,000, but Eberhard et al. (2026) put the figure at over 1,000,000.

Bìrọ̀m has been reported to have seven vowels and 24 consonants. It is a register tone language with high, low, and mid tones, as well as contour tones in a few instances

(Ukaegbu, 2017a). Although Clements and Rialland (2008) report that vowel harmony is less common or absent in East Benue-Congo languages, perceptual evidence suggests that Bìrọ̀m has two mutually exclusive sets of harmonic vowels and one neutral set (Ukaegbu, 2017a). While Bìrọ̀m exhibits various syllable structure types, CV is the most common, with the syllable peak serving as the tone-bearing unit (Ukaegbu, 2017a). Typologically, Gwom (1992) observes that Bìrọ̀m shares a close affinity with the Bantu language group, though it retains some traces of Niger-Congo affixes. Bìrọ̀m employs internal morphology, particularly tone, along with affixing morphemes to mark grammatical relations (Ukaegbu, 2017a). Consequently, the language has received a measure of attention from several scholars (e.g., Blench & Dendo, 2006; Bitrus et al., 2015; Blench, 2009, 2012, 2018, 2019). Figure 1 presents the Bìrọ̀m vowel chart, adapted from Bouquiaux (1970).

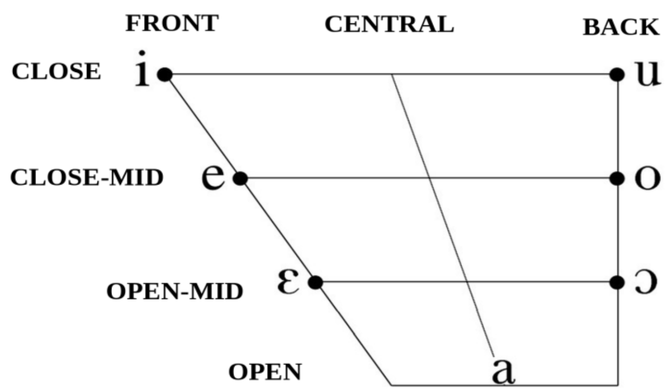

Figure 1. *Vowel inventory of the Bìrọ̀m language*

Despite this seeming progress, scarce literature exists on the sound system of Bìrọ̀m. More importantly, Clements and Rialland (2008) and Rolle et al. (2017) have argued that Platoid languages show a notable absence of ATR harmony, and that what is found instead is a strict and/or liberal contrast between mid vowels. There is, however, nothing inherent in the sound inventory of a language that determines the patterning of its vowel harmony system; this can only be ascertained empirically. Given the claim that Platoid languages generally fall within an "ATR-less zone", and that Bìrọ̀m in particular lacks ATR harmony, there is limited acoustic and empirical evidence with which to test the assumption. The present study fills this gap by providing empirical evidence that Bìrọ̀m exhibits a *trace ATR harmony system*, thereby challenging the classification of Platoid languages as lacking ATR harmony and contributing to broader typological debates on vowel harmony systems. To this end, the study pursues two objectives: to examine the co-occurrence patterns of mid vowels in order to determine whether they reflect a harmony system, and to identify the acoustic cues that provide further evidence of the behaviour of the Bìrọ̀m vowel harmony system.

2 Review of related literature

Vowel harmony is a cross-linguistic phonological phenomenon in which vowels within a specified domain systematically agree in one or more phonological features (Kenstowicz, 1994). These features may include height, backness, rounding, nasality or tongue root position ([ATR]), and the process may operate across morpheme boundaries or within lexical roots. Casali (2008, p. 496) defines vowel harmony as a system in which “vowels in some phonological domain obligatorily share the same value of a vowel feature”, while Van der Hulst (2016) characterises it as a prototypical agreement system that manifests both in static lexical patterns and in dynamic alternations during morphological combination (cf. Kaun, 2004; Casali, 2003, 2008, 2016; McCollum & Essegbey, 2020). Such agreement often results in harmonic pairings, in which vowels are organised into sets that interact predictably within phonological domains. Within this broader typology, advanced tongue root (ATR) harmony has been extensively documented, particularly in African languages, where it constitutes one of the most robust and well-studied harmony systems (Casali, 2008). Empirical studies show that ATR harmony varies significantly across languages in both scope and implementation. In Akan, for instance, a canonical ATR harmony language, harmony operates across morpheme boundaries and involves strict alternations between [+ATR] and [-ATR] vowel sets (Stewart, 1967; Hess, 1992). Similarly, Degema exhibits a well-defined ATR contrast with clear acoustic and articulatory correlates (Fulop et al., 1998). In Maa, a Nilo-Saharan language, Guion et al. (2004) demonstrate that ATR harmony is robustly encoded both acoustically and phonologically, with systematic co-occurrence restrictions across vowel sets.

However, ATR harmony is not uniform across languages. A crucial typological distinction exists between complete (dominant/recessive) harmony systems and partial or trace systems. In languages such as Igbo, harmony has been described as relatively systematic and pervasive, affecting a wide range of morphological environments (Mbah & Mbah, 2010; Akinbo et al., 2023). Yorùbá, by contrast, exhibits a more restricted harmony system in which ATR distinctions are largely confined to mid vowels and do not extend uniformly across the vowel inventory (Archangeli & Pulleyblank, 1989; Casali, 2008). This type of system illustrates partial harmony, in which only a subset of vowels participates actively in harmonic processes.

Beyond Niger-Congo, studies of Nilo-Saharan languages reveal additional variation. Reh (1996) and Guion et al. (2004), for example, show that ATR contrasts in these languages are often accompanied by differences in voice quality, suggesting that ATR may interact with laryngeal features in ways not typically observed in West African systems. Rolle et al. (2017) further propose that many languages in the Macro-Sudan Belt exhibit "trace" or "incomplete" ATR harmony, in which co-occurrence restrictions exist but do not extend to full morphological alternation or across-the-board spreading. These cross-linguistic differences highlight at least three dimensions along which ATR harmony varies. The first is the domain of application: root-controlled as against stem-to-affix spreading (Alderete & Finley, 2016; Jam, 2020), or word-internal as against morphologically conditioned harmony. The second is inventory structure and participation: full participation, as in Akan, as against restricted participation, as in the Yorùbá mid vowels alone, together with the presence of neutral vowels, which do not participate in harmony (Casali, 2003; Morton, 2012). The third is phonetic realisation and strength: strong, categorical harmony as against weak or gradient ("trace") systems (Rolle et al., 2017), and interaction with other phonetic cues such as voice quality or spectral energy.

Against this typological backdrop, the phonetic grounding of ATR harmony has been widely investigated. The first formant (F1) is consistently identified as the primary acoustic correlate of tongue root position, reflecting expansion or constriction of the pharyngeal cavity (Halle & Stevens, 1969; Archangeli & Pulleyblank, 1994). Empirical studies across multiple languages confirm that [+ATR] vowels are characterised by lower F1 values, while [-ATR] vowels exhibit higher F1 (Maddieson, 2003; Guion et al., 2004; Rolle et al., 2017). Although the second formant (F2) has also been implicated in ATR distinctions (Halle & Stevens, 1969), its role is generally considered secondary, with changes in F1 providing the most robust and consistent cue (Lindau, 1979; Hess, 1988, 1992; Larsen, 1991). In addition to formant frequencies, other acoustic parameters have been proposed. Formant bandwidth (B1), for instance, has been linked to differences in vocal tract damping and articulatory tension, with narrower bandwidths associated with [+ATR] vowels (Johnson, 2012; Stewart, 1967; Ladefoged & Maddieson, 1996), though its reliability remains debated (Kingston et al., 1997). Similarly, spectral tilt measures such as H1–H4 and voice quality parameters have been shown to play a role in certain language families, particularly in Nilo-Saharan systems (Fulop et al., 1998; Guion et al., 2004; Berkson, 2019).

First formant bandwidth is another acoustic feature that has been suggested as an additional correlate of ATR (Koffi, 2016; Tabain et al., 2024), on the basis of general acoustic principles of damping and articulatory tension. General acoustic theory shows that bandwidth reflects damping and energy loss in the vocal tract (Johnson, 2012), while studies of ATR vowels describe increased vocal tract tension and expansion for [+ATR] vowels (Stewart, 1967; Ladefoged & Maddieson, 1996). This implies that greater tension in [+ATR] vowels reduces acoustic losses, resulting in narrower bandwidths, whereas reduced tension in [-ATR] vowels leads to increased damping and wider bandwidths. However, the role of bandwidth as a reliable acoustic cue remains contested (Kingston et al., 1997). Other studies suggest that ATR contrasts may instead be reflected in spectral energy distribution, with advanced tongue root vowels exhibiting differences in higher frequency energy relative to their retracted counterparts (Halle & Stevens, 1969; Fulop et al., 1998; Guion et al., 2004). Ladefoged and Maddieson (1996, p. 301), for instance, report that in Degema [+ATR] vowels are perceived as “brighter” owing to greater energy in higher frequencies, challenging earlier claims that [-ATR] vowels are acoustically brighter (Stewart, 1967; Jacobson, 1980). Additional proposals identify harmonic amplitude differences, such as H1–H4, as primary correlates of ATR (Kingston et al., 1997), while voice quality has also been shown to play a role in certain language groups, particularly within Nilo-Saharan systems (Reh, 1996; Guion et al., 2004).

Given these accounts, the identification of consistent and cross-linguistically reliable acoustic correlates of ATR remains an open empirical question. Despite the breadth of research on ATR harmony, the empirical literature has concentrated largely on well-documented systems such as Akan, Maasai and Degema, while Platoid languages, including Bìrọ̀m, remain underrepresented. Typological accounts have suggested that Plateau languages fall within an “ATR-less zone” (Clements & Rialland, 2008; Rolle et al., 2017), but these claims have not been supported by detailed acoustic investigation. The present study therefore examines the Bìrọ̀m vowel system within the broader typology of ATR harmony, with particular attention to whether its phonological patterns reflect a trace ATR system. Within this empirical and typological context, the selection of acoustic parameters must be both theoretically grounded and methodologically robust. Among the various acoustic correlates proposed, F1 remains the most consistent and widely accepted indicator of ATR contrast. While there is general agreement on the pre-eminence of F1, other acoustic cues have been shown to contribute to the phonetic realisation of ATR, albeit with varying degrees of reliability across languages. Accordingly, this study adopts a multi-parameter approach, employing the first two formants, F1 and F2 (Fulop et al., 1998; Starwalt, 2008; Casali, 2008; Harrington, 2010; Uguru, 2019), first formant bandwidth, B1 (Dunn, 1961; Kent & Vorperian, 2018), and cepstral peak prominence, CPP (Berkson, 2019; Akinbo et al., 2023), to analyse ATR contrast in Bìrọ̀m.

3 Methodology

Stimuli consisted of 55 CVCV lexical items drawn from Roger Blench's wordlist. Tone and consonant type were not controlled for, but variations in the words were captured. Data were elicited from ten native speakers of Bìrọ̀m aged between 25 and 50 years. The speakers confirmed that they had no history of speech or hearing disorders, and each was asked to pronounce the same stimuli. The data were recorded in a quiet room with an improvised portable sound booth and a Zoom H1 digital recorder, at a sampling rate of 44.1 kHz and a bit depth of 16. Participants used the carrier phrase "you said …" before each target word, and each item was repeated three times, giving a total of 1,650 tokens.

ELAN version 6.7 (The Language Archive, 2023) and Praat version 6.2.23 (Boersma & Weenink, 2023) were used for annotation and for the extraction of acoustic measurements respectively. Using scripts written by Riebold (2013), acoustic measurements from the 1,650 tokens were automatically extracted and exported to RStudio. R version 4.3.2 and RStudio version 2023.12.1+402 were subsequently used for the descriptive statistical analysis of the acoustic measurements, while PhonR version 1.0.7 was used to carry out the statistical comparison of the mid vowels and to plot the graphs for vowel visualisation. Tokens from speakers were anonymised, and the values of the acoustic parameters were z-score normalised to reduce the effect of inter-speaker variation. To identify the specific differences between the ATR pairs of vowels, post hoc tests were carried out on subsets of each relevant vowel pair, that is, between [e, ɛ] and between [o, ɔ]. The null hypothesis in each case was that tongue root position does not affect the distribution of the acoustic parameters. The study is not concerned with comparison between individual speakers' speech patterns, but with describing the feature responsible for vowel harmony in Bìrọ̀m.

Ethical clearance to conduct this research was obtained from the Faculty of Arts Ethics Committee, University of Nigeria, Nsukka (UNN/FA/FAREC/09092023). Sufficient information about the research was made available to participants from the outset, enabling them to make an informed decision to participate voluntarily in the experimental sessions and to withdraw at will without prejudice. Participants were made to understand that aspects of the data provided that included personal information would be treated confidentially and anonymised where necessary.

4 Data presentation and analysis

Most lexical categories in Bìrọ̀m have onsets, and onsets do not participate in ATR harmony in Bìrọ̀m, as the harmonic process targets only the mid vowels. The use of CVCV lexical items in this study reflects the fact that most Bìrọ̀m words are onset-initial; lexical words with mid vowels were therefore used as the stimuli. The data are presented in broad IPA transcription with all tones marked. The items were, however, presented to the Bìrọ̀m speakers in the Bìrọ̀m writing style, which indicates neither tone nor ATR distinctions, along with the English translations. Although there were a few lexical variations, the participants confirmed their familiarity with the words, since they all spoke the Riyom variety of Bìrọ̀m. Four acoustic parameters were measured for the annotated vowels in order to detect the acoustic correlates of ATR features in Bìrọ̀m. These parameters, selected on the basis of previous empirical studies that have adopted them, were F1, F2, B1 and CPP. The data presented in (1) show vowel co-occurrence within root words having the syllable sequence consonant, vowel, consonant, vowel (CVCV).

1.	**Bìrọ̀m CVCV words**		**Gloss**
a.	*káwẹ̄*	/káwɛ̄/	‘every’
b.	*vàné*	/vàné/	‘those’
c.	*nìkjén*	/nìkjén/	‘life’
d.	*símó*	/símó/	‘want’
e.	*rìyọ́m*	/rìjɔ́m/	‘suffering’
f.	*gùbǒm*	/gùbǒm/	‘big lizard’
g.	*nùnọ̀n*	/nùnɔ̀n/	‘beak’
h.	*rúgú*	/rúgú/	‘cloth’
i.	*swírí*	/swírí/	‘ladle’
j.	*gàbík*	/gàbík/	‘spirit’
k.	*vwònòs*	/vwònòs/	‘doctor’
l.	*chẹ̀gẹ̀l*	/ʧɛ̀gɛ̀l/	‘sand’
m.	*yọ̀bọ́*	/jɔ̀bɔ́/	‘ring’
n.	*rèmó*	/rèmó/	‘now’
o.	*rẹ́mọ́*	/rɛ́mɔ́/	‘present’
p.	*bérē*	/bérē/	‘plenty’

The data presented in (1) exemplify the possible occurrences of vowels in CVCV root words in Bìrọ̀m. The high and low vowels can occur with themselves and with the mid vowels, as in 1(a)–(j). Mid vowels can also co-occur with one another, but only on the basis of their ATR specifications, as can be gleaned from the data in 1(k)–(p). This kind of harmony system shows trace patterns of harmony in words, which agrees with Ladefoged (1964). In this case there are vowel restrictions that resemble strict ATR harmony but do not demonstrate dynamic cross-height harmony. Most systems that operate trace ATR vowel harmony show a restriction on the mid vowels, whereby close-mid vowels do not co-occur with open-mid vowels and vice versa, as in *[e…ɛ] and *[ɔ…o]. This is exactly the co-occurrence pattern in Bìrọ̀m. A theoretical overview of mid-vowel sequence co-occurrence in Bìrọ̀m is given below.

e…e	o…o	ɛ…ɛ	ɛ…ɔ
o…e	e…o	ɛ…ɔ	ɔ…ɛ
*e…ɛ	*e…ɔ	*o…ɛ	*o…ɔ
*ɛ…e	*ɛ…o	*ɔ…e	*ɔ…o

In the illustration above there is a mid-height co-occurrence restriction within root words in Bìrọ̀m, with no evidence of cross-height harmony. The data in (2) illustrate this.

2. **Permissible mid-vowel co-occurrence**			**Non-permissible mid-vowel co-occurrence**
a. *chẹ̀gẹ̀l*	/ʧɛ̀gɛ̀l/	'sand'	*/ʧègɛ̀l/ or */ʧɛ̀gèl/
b. *yọ̀bọ̀*	/jɔ̀bɔ̀/	'ring'	*/jòbɔ̀/ or */jɔ̀bò/
c. *chọ̀gọ̀t*	/tʃɔ̀gɔ̀t/	'stick'	*/tʃògɔ̀t/ or */tʃɔ̀gòt/
d. *vwònòs*	/vwònòs/	'doctor'	*/vwònɔ̀s/ or */vwɔ̀nòs/
e. *rẹ́mọ́*	/rɛ́mɔ́/	'present'	*/rɛ́mó/ or */rémɔ́/
f. *bérē*	/bérē/	'plenty'	*/bérɛ̄/ or */bɛ́rē/
g. *rẹ̀hwọ́s*	/rɛ̀hwɔ́s/	'rainy season'	*/rɛ̀hwós/ or */rèhwɔ́s/

The data in (2) illustrate how trace ATR vowel harmony systems operate in Bìrọ̀m: [+ATR] mid vowels co-occur with one another and [-ATR] mid vowels co-occur with one another. The forms on the left in 2(a)–(g) are therefore possible sequences of mid-vowel co-occurrence in Bìrọ̀m, while those on the right are impossible sequences. Languages that exhibit this pattern are described as attesting trace ATR vowel harmony (Rolle et al., 2017). It may therefore be concluded that the nature of vowel harmony in Bìrọ̀m is trace ATR harmony.

The basic phonological patterning of harmony based on tongue root divides vowels generally into those produced with an advancement of the tongue root and those that are not, or those produced with a lowering of the pharyngeal cavity and those that are not. Two of the four [+ATR] vowels, [i] and [u], have no [-ATR] harmonic counterparts, and one of the three [-ATR] vowels, [a], has no [+ATR] counterpart. Returning to the data in (1), the distribution shows that in Bìrọ̀m the high and low vowels [a i u] can co-occur with all the vowels in a sequence of words, whereas the mid vowels [e ɛ o ɔ] have restricted co-occurrence based on their ATR values. The study adopts tongue root features to distinguish the co-occurrence of Bìrọ̀m vowels on the basis of the data gathered. The seven vowels of Bìrọ̀m are accordingly divided into the following harmonic classes.

Set A	Set B	Set C
[+ATR]	[-ATR]	[Neutral]
/e o/	/ɛ ɔ/	/a i u/

The first set of vowels is mutually exclusive with the second set, but not necessarily with the third, since the latter is the neutral set. The same is true of the second set, which is mutually exclusive with the first but not with the third. The Bìrọ̀m [+ATR] vowels [e o] co-occur, and the [-ATR] vowels [ɛ ɔ] co-occur, in a mutually exclusive pattern, whereas the vowels of the intersecting set [a i u] co-occur freely with either the [+ATR] or the [-ATR] vowels in words. The term neutral vowels is used here for what Morton (2012, p. 71) calls "non-participatory vowels", because they are not part of the harmonic pairs. In some languages, such as Yorùbá and dialects of Igbo (cf. Archangeli & Pulleyblank, 1989; Uguru, 2019; Akinbo et al., 2023), it is /a/ alone, but in Bìrọ̀m it is [a i u]. Examples showing why the low and high vowels in Bìrọ̀m are grouped under Set C are given in (3) to (5).

3. **[+Low] and [+Mid] vowel co-occurrence**

a…e	/wàné/ 'that'	/vàné/ 'those'
a…o	/ànó/ 'so'	/ŋámó/ 'here'
a…ɛ	/káhɛ̄/ 'each'	/káwɛ̄/ 'every'
a…ɔ	/àrɔ̀ŋ/ 'also'	/àrɔ́dà/ 'will be'

4. **[+High] and [+Mid] vowel co-occurrence: /i/**

i…e	/nìkjén/ 'life'	/jeipéŋ/ 'happy'
i…o	/símó/ 'want'	/rìhós/ 'rainy season'
i…ɛ	/nìsísɛ̀ŋ/ 'wisdom'	/rìɡjɛ̀ŋ/ 'congregation'
i…ɔ	/nìgʷɔ̀m/ 'reign'	/rìjɔ́m/ 'suffering'

5. **[+High] and [+Mid] vowel co-occurrence: /u/**

u…e	/nùjél/ 'front'	/rénújél/ 'continue to do'
u…o	/gùbǒm/ 'big lizard'	/wùmót/ 'our'
u…ɛ	/ʧúwɛ́r/ 'dive'	/wùmɛ́n/ 'their'
u…ɔ	/nùnɔ̀n/ 'beak'	/nùkɔ́n/ 'given place'

The data in (3) to (5) show that high and low vowels (Set C) can co-occur with mid vowels (Sets A and B) when the mid vowel is in V2. The reverse configuration is not attested: mid vowels cannot occur in V1 followed by high or low vowels. This suggests a positional restriction in Bìrọ̀m whereby mid vowels are excluded from the V1 slot in heterosyllabic sequences, while high and low vowels occur freely in V1. The language therefore displays a constraint under which the following do not occur.

*[+Mid]….[+High] or *[+Mid]….[+Low]
*e…i, *e…u, *ɛ…i, *ɛ…u, *o…i, *o…u, *ɔ…i, *ɔ…u, *e…a, *ɛ…a, *o…a, *ɔ…a

Put another way, low and high vowels occur in V1 while mid vowels occur in V2, and sequences such as those above are unattested. Mid vowels cannot occupy the V1 position when followed by high or low vowels, which suggests an asymmetrical co-occurrence constraint based on vowel height and position. Vowel co-occurrence in Bìrọ̀m is therefore governed not only by vowel height but also by positional restrictions, with mid vowels limited to V2 in these environments.

This section examines the mid vowels of Bìrọ̀m more closely. Bìrọ̀m has four mid vowels, which are distinguished by their tongue root features: /e/ and /o/ are [+ATR], while /ɛ/ and /ɔ/ are [-ATR]. These mid vowels exhibit contrastive distribution, as shown in the minimal and near-minimal pairs in (6).

6. **Minimal pairs and near-minimal pairs with mid vowels in words**

	[+ATR]			**[-ATR]**		
a.	*té*	/té/	'in-between'	*tẹ̀*	/tɛ̀/	'to put on'
b.	*shé*	/ʃé/	'year'	*shẹ̀*	/ʃɛ̀/	'bamboo'
c.	*yél*	/jél/	'enter'	*yẹ́r*	/jɛ́r/	'slice'
d.	*bèrè*	/bèrè/	'tendril'	*bẹ́rẹ̄*	/bɛ́rɛ̄/	'many/plenty'
e.	*véí*	/véí/	'come'	*vẹ́l*	/vɛ́l/	'heal'
f.	*dyéng*	/djéŋ/	'lie down'	*dyẹ̀ng*	/djɛ̀ŋ/	'sneeze'
g.	*télé*	/télé/	'run'	*tẹ́lẹ́*	/tɛ́lɛ́/	'flow'
h.	*mèlè*	/mèlè/	'to lick'	*mẹ́lẹl*	/mɛ́lɛ́l/	'smooth'
i.	*tò*	/tò/	'head'	*tọ̀*	/tɔ̀/	'to give birth'
j.	*sóró*	/sóró/	'marrow'	*sọ́rọ́*	/sɔ́rɔ́/	'roof'
k.	*pómó*	/pómó/	'town'	*pọlọ*	/pɔ́lɔ́/	'day'
l.	*rón*	/rón/	'hoe'	*rọ́*	/rɔ́/	'disease'
m.	*sógó*	/sógó/	'fly'	*sọ́gọ́*	/sɔ́gɔ́/	'shake'

The data in (6) show that all the mid vowels in Bìrọ̀m exhibit contrastive distribution. The vocalic segment /e/ contrasts with /ɛ/ in 6(a)–(h), while /o/ contrasts with /ɔ/ in 6(i)–(m).

The distribution of mid vowels in root words and heterosyllabic sequences shows that the [ATR] feature of mid vowels must agree, and that there are constraints on the co-occurrence of mid vowels with certain other vowels. A summary of mid-vowel co-occurrence in Bìrọ̀m is given in (7) and (8).

7.	e…e	e…o
	o…o	o…e
	ɛ…ɛ	ɛ…ɔ
	ɔ…ɔ	ɔ…ɛ

8.	*e…ɛ	*e…ɔ
	*o…ɛ	*o…ɔ
	*ɛ…e	*ɛ…o
	*ɔ…e	*ɔ…o

Example (7) gives the permissible sequences of mid-vowel co-occurrence, while (8) gives the non-permissible sequences, which are asterisked. The examples that follow provide empirical support for the distribution in (7). The non-permissible sequences in (8) justify the choice of the spelling Bìrọ̀m in this study, which reflects the usual pronunciation of native speakers, rather than Bèrọ̀m, which many non-native speakers pronounce on the basis of the orthography. This choice is not only grounded in native speakers' pronunciation but also helps to avoid the misleading assumption that there is no harmony in the language, and to clarify the pronunciation of the name of the language.

9.	e _ e		e _ o	
a.	*bérē* /bérē/	'plenty'	*rétó* /rétó/	'authority'
b.	*bézyék* /bézjék/	'sand'	*rèmó* /rèmó/	'now'
c.	*bèrè* /bèrè/	'tendril'	*séyóm* /séjóm/	'suffering'
d.	*télé* /télé/	'run'	*sénó* /sénó/	'like (that)'
e.	*yédé* /jédé/	'press'	*wèmó* /wèmó/	'this'

10.	o _ o		o _ e	
a.	*tóyó* /tójó/	'return'	*kyómé* /kjómé/	'be'
b.	*tóhó* /tóhó/	'cry'	*tósé* /tósé/	'assist (raise load)'
c.	*lòrò* /lòrò/	'pierce/stab'	*vwóspyéng* /vwóspjéŋ/	'chalk'
d.	*tónó* /tónó/	'deny'	*gòmrèí* /gòmrèí/	'python'

11.	ɛ _ ɛ		ɛ _ ɔ	
a.	*chẹ̀gẹ̀l* /ʧɛ̀gɛ̀l/	'sand'	*sẹ́ngwọm* /sɛ́ng^{w}ɔ̀m/	'kingdom'
b.	*bẹ̀rẹ̀ng* /bɛ̀rɛ̀ŋ/	'watchful'	*rẹ́mọ́* /rɛ́mɔ́/	'present'
c.	*sẹ́lẹ́* /sɛ́lɛ́/	'help'	*chẹ́tọ̀ng* /ʧɛ́tɔ̀ŋ/	'rainbow'
d.	*jẹ́rẹ́* /ʤɛ́rɛ́/	'holy'	*rẹ̀hwọ́s* /rɛ̀hwɔ́s/	'rainy season'

12.	ɔ _ ɔ		ɔ _ ɛ	
a.	*pọlọ* /pɔ́lɔ́/	'day'	*wọ́gẹ́* /wɔ́gɛ́/	'consider'
b.	*chọ̀gọ̀t* /ʧɔ̀gɔ̀t/	'tree'	*nọ́ngẹ́* /nɔ́ŋɛ́/	'blame'

c.	*họ́nọ̀s* /hɔ́nɔ̀s/	'entangle'	*rọ́họ́bẹ̀k* /rɔ́hɔ́bɛ̀k/	'eczema'
d.	*tọ̀rọ̀ng* /tɔ̀rɔ̀ŋ/	'thought'	*ǹzọ̀rẹ́* /ǹzɔ̀rɛ́/	'weaver bird'

The data in (9) to (12) show that Bìrọ̀m has harmonic root sequences among its mid vowels. The sequences of mid vowels in Bìrọ̀m agree in their value for [±ATR], and the behaviour of mid vowels in Bìrọ̀m can be gleaned from the data presented in (9) to (12). The Bìrọ̀m vowel system therefore maintains a phonological contrast between the [+ATR] and the [-ATR] mid vowels. In summary, the following generalisations hold in Bìrọ̀m.

a. If V1 is a high vowel [i u], V2 can be any vowel; and if V2 is a high vowel, V1 can be any vowel except the mid vowels [e ɛ o ɔ].
b. If V1 is a low vowel [a], V2 can be any vowel; whereas if V2 is a low vowel, any vowel can be V1 except the mid vowels [e ɛ o ɔ].
c. When V1 is a mid vowel, V2 can only be a vowel of its own set, [e o] or [ɛ ɔ]. When the mid vowel is V2, V1 can be any of the high and low vowels [i u a], as well as a vowel of its own set, [e o] or [ɛ ɔ].

This explains the permissible and restricted vowel sequences in Bìrọ̀m monomorphemic or prosodic words. Harmony therefore targets mid vowels and is triggered by mid vowels within the root of Bìrọ̀m words. Bìrọ̀m vowel harmony is thus based on tongue root position together with a specific height feature, that of the mid vowels.

Figures 2 to 5 present the spectrograms of tokens obtained from the minimal pair data, which show the [+ATR] and [-ATR] contrast of mid vowels in Bìrọ̀m words. These are sample tokens from the second female speaker. In each of Figures 2 to 5 the topmost panel is a waveform and the spectrogram is the panel immediately below it; together they show the differences in the formants of [+ATR] and [-ATR] words.

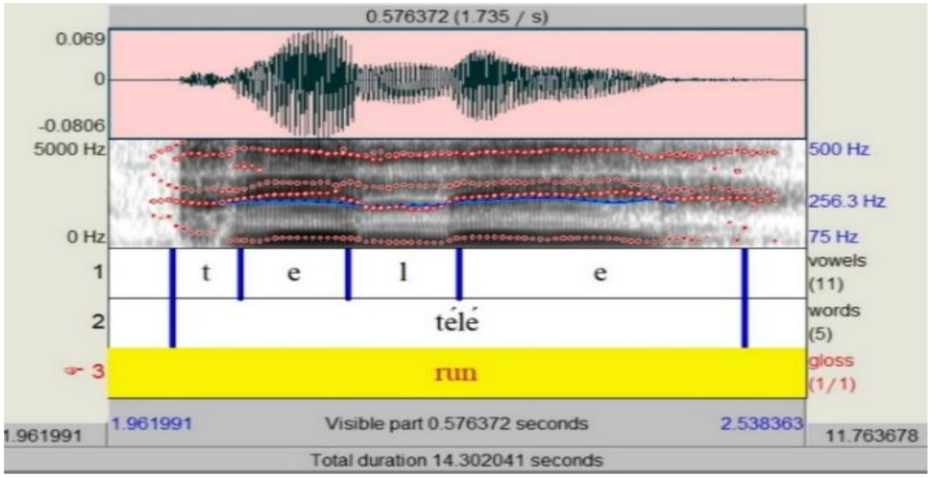

Figure 2: *Spectrogram of télé 'run'*

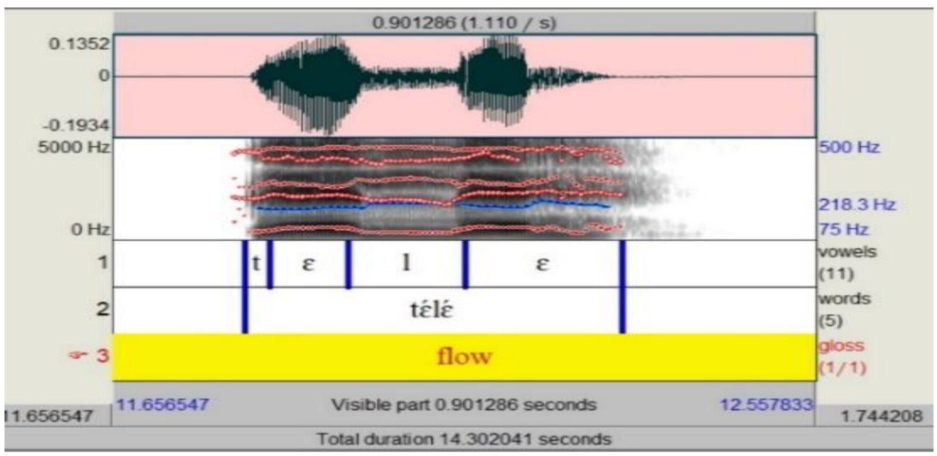

Figure 3: *Spectrogram of tɛ́lɛ́ 'flow'*

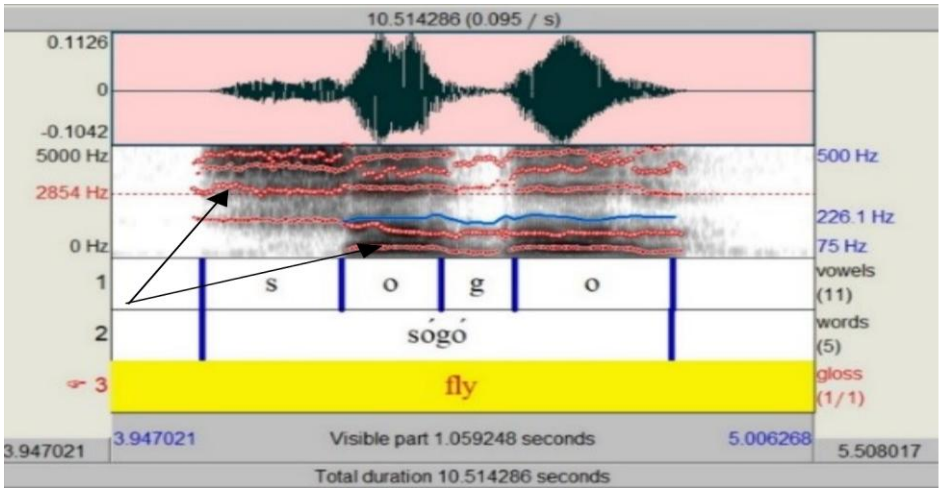

Figure 4: *Spectrogram of sógó 'fly'*

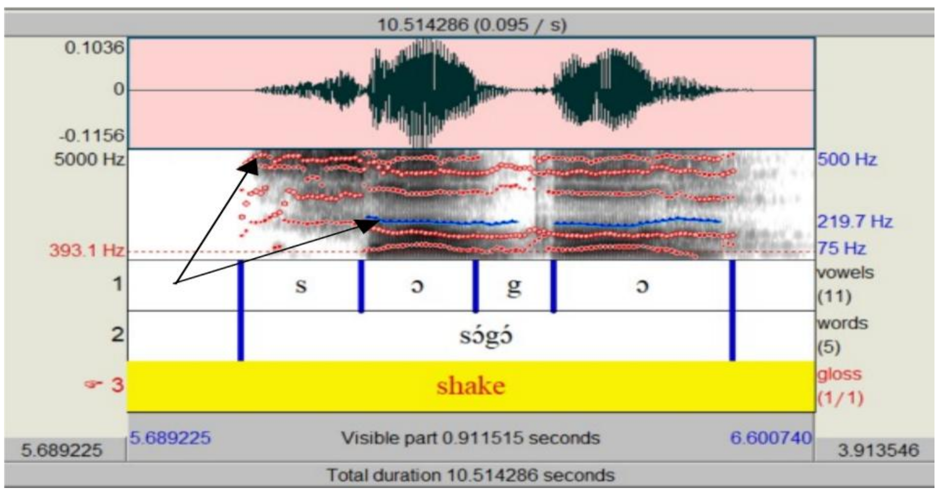

Figure 5: *Spectrogram of sɔ́gɔ́ 'shake'*

The spectrograms in Figures 2 to 5 show words in Bìrọ̀m where mid vowels co-occur with other mid vowels of the same set. These tokens were selected as near-minimal pairs of CVCV words with identical tones, in order to illustrate that even among vowels of the same height the acoustic cue F1 can be used to distinguish [+ATR] pairs from [-ATR] pairs. In these spectrograms, the formants appear as dotted lines across the dark bands of concentrated energy, where the first line represents F1, followed by F2, F3 and F4 (see the arrows pointing at them in Figures 4 and 5). To understand how ATR features affect these vowels, the close-mid front vowels in Figures 2 and 3 are compared first. In Figure 2 (*télé* 'run') and Figure 3 (*tɛ́lɛ́* 'flow'), the first line, representing F1, is visibly higher for the [-

ATR] vowel [ɛ] than for its [+ATR] counterpart [e]. The formant values confirm this visual difference. In /télé/, V1 [e] has an F1 of 369.70 Hz and V2 [e] an F1 of 492.20 Hz. By contrast, in the [-ATR] word /tɛ́lɛ́/ the F1 values for V1 [ɛ] and V2 [ɛ] are 497.25 Hz and 611.24 Hz respectively, showing a clear upward shift in frequency.

A similar pattern is observed when the back mid vowels in Figures 4 and 5 are compared. Relating Figure 4 (*sógó* 'fly') to Figure 5 (*sɔ́gɔ́* 'shake'), the energy band for F1 across the annotated vowels [o] and [ɔ] appears higher in the [-ATR] pair. Specifically, for /sógó/, V1 [o] has an F1 of 457.88 Hz and V2 [o] an F1 of 423.05 Hz, whereas for the [-ATR] /sɔ́gɔ́/, the F1 values increase to 581.86 Hz for V1 and 476.05 Hz for V2. The F1 frequencies are thus consistently higher across both pairs for the [-ATR] vowels than for their [+ATR] counterparts. This consistent distinction is presented in Table 1.

Table 1: *Mean F1 and F2 of Bìrọ̀m vowels (Hz)*

	Female speakers		Male speakers	
Vowel	**Mean F1**	**Mean F2**	**Mean F1**	**Mean F2**
i	396.40	2377.91	480.17	2205.01
u	423.83	924.48	416.24	1965.61
e	501.64	2336.16	613.79	2293.12
ɛ	639.48	1143.55	747.37	1700.97
o	524.92	1743.55	391.21	2281.98
ɔ	703.22	1115.32	507.83	883.80
a	975.95	2108.09	651.69	1615.86

Table 1 presents the mean F1 and F2 values for the ten Bìrọ̀m speakers' pronunciations of the words in the stimuli. The table shows the relative height difference between the mid vowels in relation to the high and low vowels. However similar two vowels may be in height or in ATR feature, no two vowels have identical acoustic values, although vowels of the same tongue height may fall within the same range. Acoustic analysis is used here to differentiate the [+ATR] mid vowels /e, o/ from the [-ATR] mid vowels /ɛ, ɔ/, which were justified as harmonic pairs in the phonological description earlier in this section. Table 1 shows, specifically, that the high mean F1 of /a/, 975.95 Hz, marks it as a low vowel, whereas the low means of /i/ and /u/, 396.40 Hz and 423.83 Hz, show that they are both high vowels. Turning to the mean F1 of the mid vowels, the values for the [+ATR] vowels /e/ and /o/, 501.64 Hz and 524.92 Hz, are lower than those of the [-ATR] vowels /ɛ/ and /ɔ/, which are 639.48 Hz and 703.22 Hz respectively. This explains why the [+ATR] vowels are higher than their [-ATR] counterparts, even though all four are mid vowels. The mean values of F1 and F2 in Table 1 are used to plot the vowel space in Figure 6, which shows the relationship between the vowels in terms of their height features and confirms the adaptation of Bouquiaux's (1970) vowel chart in Figure 1.

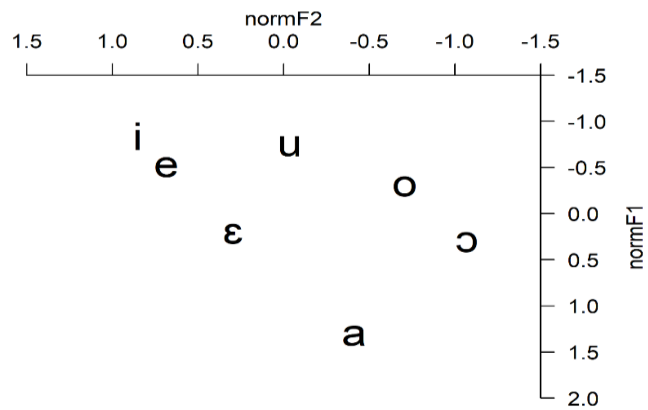

Figure 6: *Mean F1–F2 plot of Bìrọ̀m vowels*

The formant plot in Figure 6 presents the normalised measurements of Bìrọ̀m vowels across all speakers, plotted from the means of the formants in Table 1. This helps to eliminate individual speaker differences that may arise from social or physical factors; in other words, it helps to minimise inter-speaker variation, which is not the focus of this study.

The representation in Figure 6 shows the vowel space of the seven phonemic vowels of Bìrọ̀m. Lindau (1975, pp. 8–11) states that "high vowels have relatively low F1, low vowels have relatively high F1, back vowels have relatively low F2, and the front vowels have relatively high F2. Hence, mid vowels have neither high nor low F1, and central vowels also have neither high nor low F2." The F1 axis shows that, while [i] and [u] are higher than [e] and [o], between the two close-mid vowels [e] appears slightly higher than [o] and closer to the height of [i]; their F1 is low, but not as low as that of the high vowels. The vowels [ɛ] and [ɔ] are typically represented as mid vowels, and there is variation in the F1 and F2 plot of these vowels against their mid counterparts [e] and [o]. Lastly, [a] is confirmed as a low vowel, since it has the highest F1. Plotting a vowel space in this way helps to clarify the nature of the vowel system of a language and confirms the traditional vowel chart shown in Figure 1. Samples of tokens showing the contrasts between the F1 and F2 of the Bìrọ̀m mid vowels, using [+ATR] and [-ATR] minimal pairs, are presented below.

Other acoustic measurements are presented as boxplots in Figures 7 to 10. Boxplots rather than scatter plots or line graphs are used because they show the ATR contrasts clearly while taking account of all the vowel positions (V1–V2) in the tokens used for the acoustic analysis. RStudio and PhonR collect the spectral measures and generate the boxplots automatically from the sets of commands in the scripts. In each graph the y-axis carries the normalised acoustic measurements, such as F1, and the x-axis shows the vowels, presented as [+ATR] and [-ATR] pairs. The focus is primarily on the qualities of the mid vowels, showing the distribution of /e/ as against /ɛ/ and of /o/ as against /ɔ/. Figure 7 presents the boxplots of the mean first formant values of the speakers' pronunciation of the mid vowels.

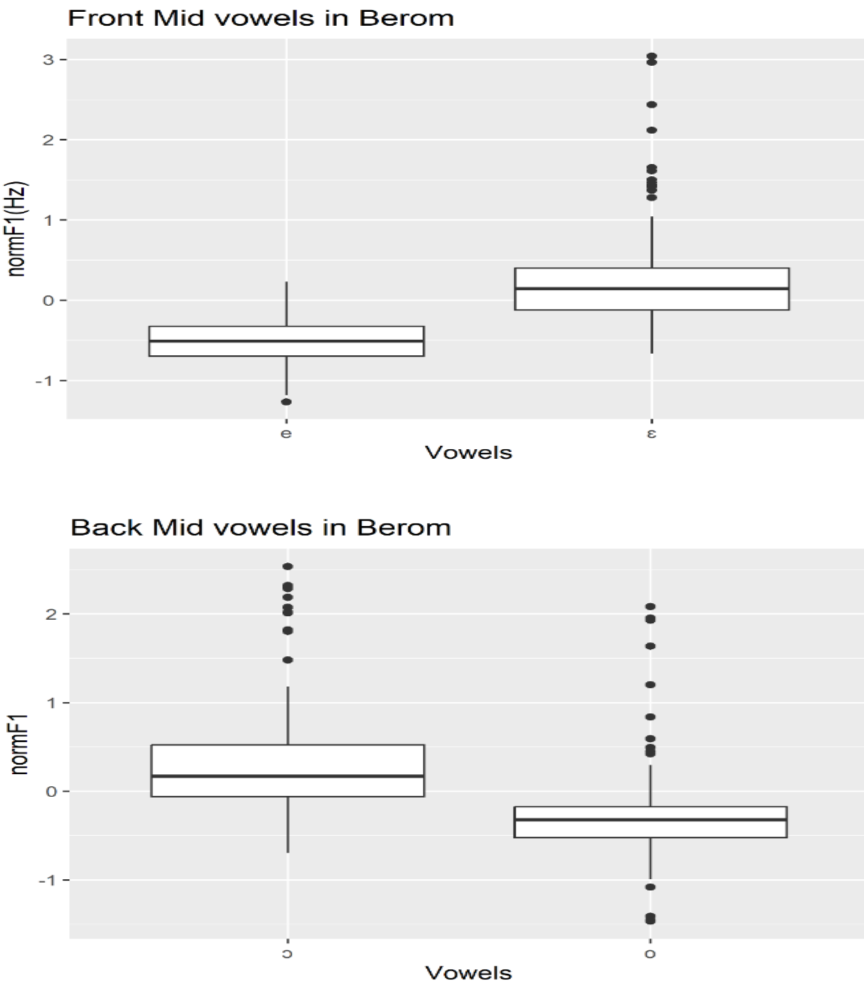

Figure 7: *Mean F1 boxplots for the [+ATR]/[-ATR] pairs [e] vs. [ɛ] and [ɔ] vs. [o]*

The mean F1 values for /e/ and /ɛ/ are 412.41 Hz and 609.08 Hz, while those for /o/ and /ɔ/ are 451.33 Hz and 607.23 Hz. These values, represented in the boxplots above, demonstrate that F1 is markedly higher in the [-ATR] pair than in the [+ATR] pair. This is well matched with the articulatory account of an upward movement of the larynx alongside tongue fronting and vocal fold closure for [+ATR] vowels, and a downward movement of the larynx accompanied by tongue retraction and vocal fold opening for [-ATR] vowels. It is also consistent with previous findings on the F1 of [-ATR] vowels.

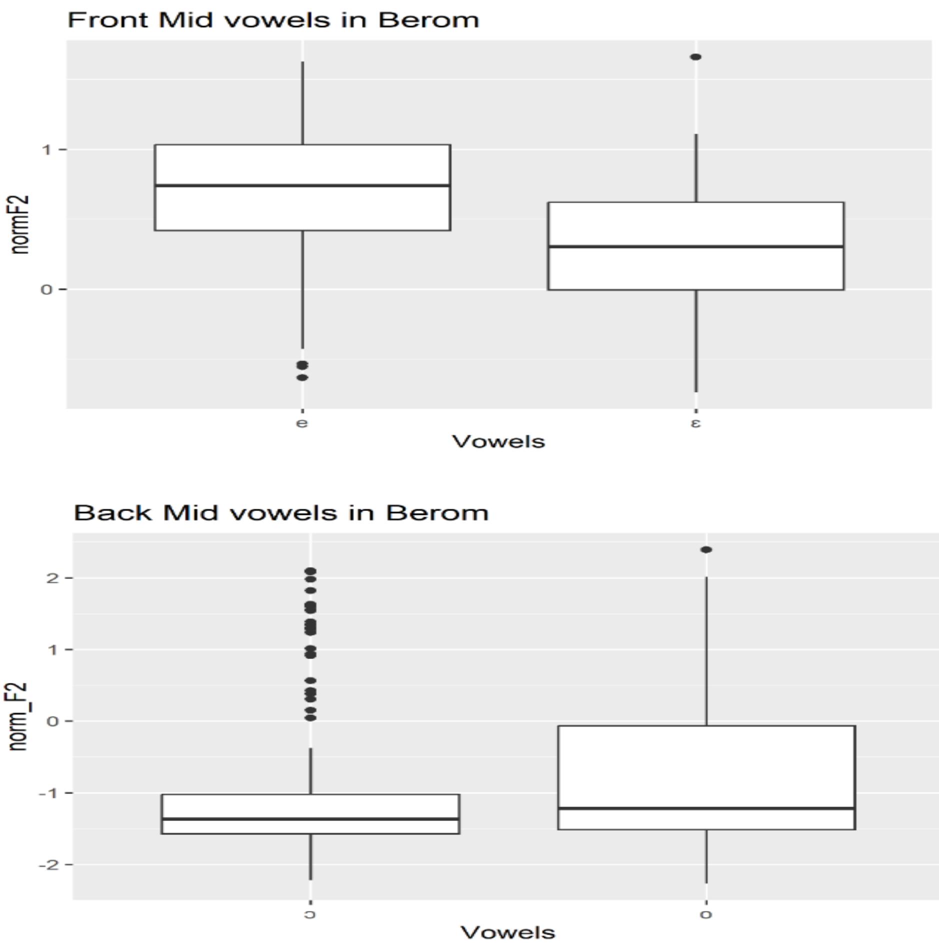

Figure 8: *Mean F2 boxplots for the [+ATR]/[-ATR] pairs [e] vs. [ɛ] and [ɔ] vs. [o]*

The results in Figure 8 reflect the mean F2 values for /e/ and /ɛ/, which are 2314.64 Hz and 1856.02 Hz, while those for /o/ and /ɔ/ are 1712.77 Hz and 999.56 Hz. These values, represented in the boxplots above, show that F2 is higher in [+ATR] vowels than in their respective [-ATR] counterparts. However, F2 differentiates the back mid vowels [o] and [ɔ] more sharply than it does the other pair, [e] and [ɛ]. This observed pattern of distinction in the F2 of ATR pairs is reflected in previous studies of F2 distinction in ATR pairs (Przezdziecki, 2005; Starwalt, 2008). This concludes the discussion of the first and second formants as acoustic cues for distinguishing [+ATR] from [-ATR] mid vowels. The next parameter presented is the speakers' formant bandwidth, specifically the F1 bandwidth, referred to in this study as B1.

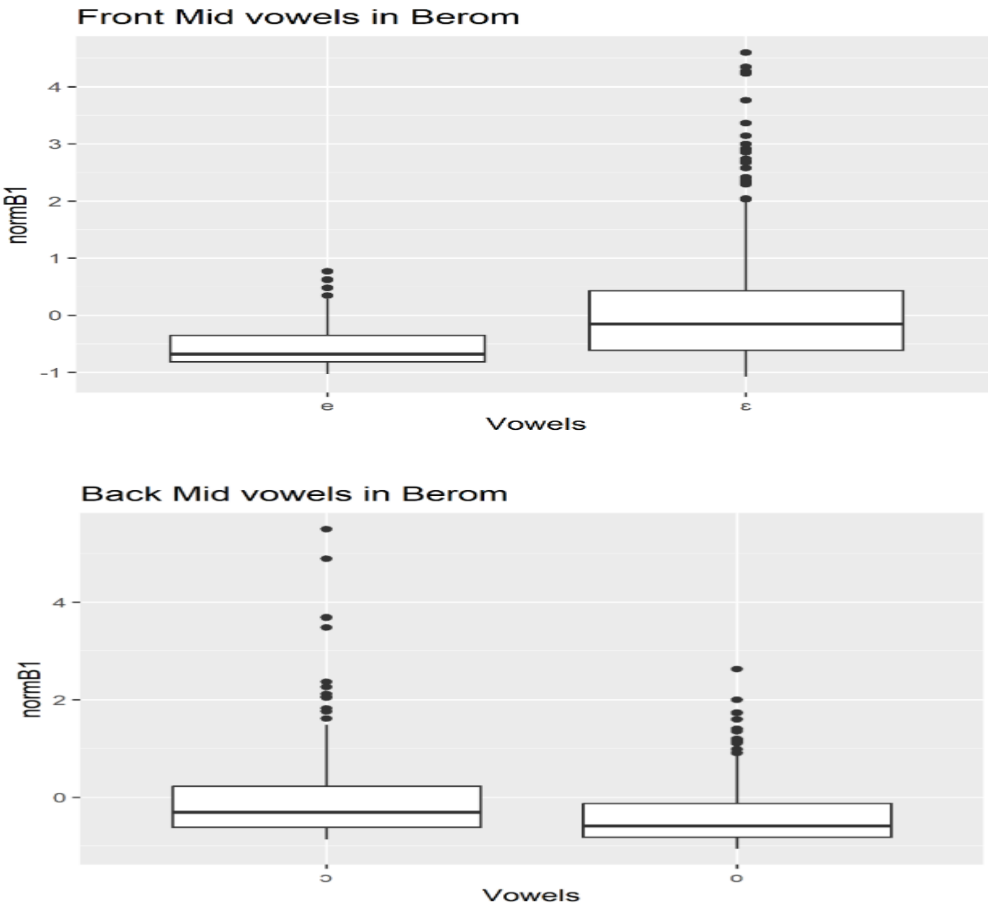

Figure 9: *Mean B1 boxplots for the [+ATR]/[-ATR] pairs [e] vs. [ɛ] and [ɔ] vs. [o]*

The mean B1 values for /e/ and /ɛ/ are 94.32 Hz and 164.43 Hz, while those for /o/ and /ɔ/ are 111.04 Hz and 298.39 Hz. This is demonstrated in the boxplots above, showing that the B1 of the [-ATR] pair [ɛ] and [ɔ] is higher than that of their [+ATR] counterparts [e] and [o]. The wider bandwidths of the [-ATR] mid vowels are consistent with the articulatory account by which the reduced vocal tract tension of retracted tongue root vowels increases damping, whereas the greater tension and pharyngeal expansion of [+ATR] vowels reduce acoustic losses and narrow the bandwidth (Stewart, 1967; Ladefoged & Maddieson, 1996; Johnson, 2012). The contrast is more marked in the back pair, where the mean B1 of [ɔ] is roughly two and a half times that of [o], than in the front pair, where the ratio is closer to 1.7. As stated earlier, voice quality has been reported to be a good parameter for ATR contrast; hence the use of CPP in the analysis to confirm whether the voicing quality of the ATR pairs shows any significant difference in Bìrọ̀m.

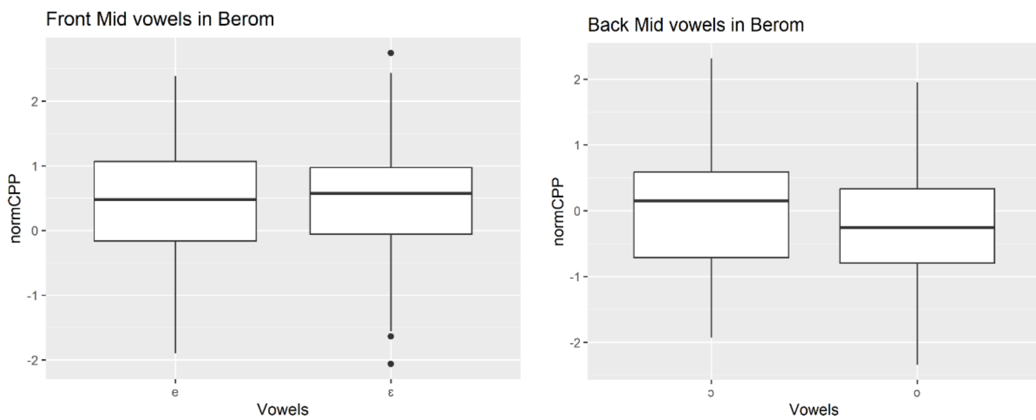

Figure 10: *Mean CPP boxplots for the [+ATR] /[-ATR] pairs [e] vs. [ɛ] and [ɔ] vs. [o]*

CPP measurements are usually lower in value for breathy voicing (Berkson, 2019; Tabain et al., 2024). In articulatory terms, CPP relates to the opening and closing of the vocal folds and the tension that occurs during this process, giving rise to different phonation types. The acoustic measurements of CPP show that /e/ and /ɛ/ have mean values of 10.08 dB and 13.15 dB, respectively, while for /o/ and /ɔ/ the mean values are 11.18 dB and 18.28 dB. As shown in Figure 10, the mean CPP measurements do not reveal much measurable phonation difference in the [+ATR]/[-ATR] pair [e] and [ɛ], although there is a slight difference between [o] and [ɔ]. This means that CPP is not consistent, and that as an acoustic cue for voice quality it does not tell us much about the difference between the [±ATR] pairs of Bìrọ̀m mid vowels. It is therefore not significant in distinguishing [+ATR] from [-ATR] Bìrọ̀m mid vowels. Despite this lack of significance, the inclusion of voice quality measures is essential to a comprehensive, multi-parameter acoustic profile that tests for the potential laryngeal correlates frequently observed in other African ATR systems. These results are important because they establish empirically that Bìrọ̀m vowel harmony is defined primarily by height-based F1 distinctions rather than by phonation contrasts. The acoustic analysis in this section has shown that three acoustic parameters, F1, F2 and B1, can be used effectively to distinguish ATR contrast between mid vowels in Bìrọ̀m. Although these cues are very reliable, their relevance may vary from language to language, as the case of CPP illustrates. It also means that even though ATR mid vowels in Bìrọ̀m show a reasonable amount of constriction in the laryngeal cavity, this has no impact on voice quality, particularly breathiness.

5 Conclusion

This study demonstrated that Bìrọ̀m operates a trace Advanced Tongue Root (ATR) harmony system. By adopting a phonetically driven approach, the investigation challenged assertions by Rolle et al. (2017) regarding the absence of ATR harmony in Platoid languages and removed Bìrọ̀m from the so-called *ATR-less zone*. The findings confirmed that [+ATR] and [-ATR] mid-height vowels do not co-occur within a root, exemplifying the structural traits of an incomplete harmony system.

Acoustically, F_1, F_2, and B_1 served as reliable correlates for distinguishing [+ATR] mid vowels (/e, o/) from their [-ATR] counterparts (/ɛ, ɔ/). Consistently higher F_1 and B_1 values in [-ATR] vowels aligned with established articulatory accounts of larynx movement, tongue positioning, and vocal fold configuration. Conversely, Cepstral Peak Prominence (CPP) showed no consistent phonation contrast between the harmonic pairs. This divergence from patterns observed in Nilo-Saharan languages highlighted how languages with similar phonetic inventories can exhibit distinct harmonic behaviors, reflecting the unique Benue-Congo heritage of Bìrọ̀m

These results carried significant implications for both language-specific description and broader typological frameworks. First, instrumental acoustic studies should be conducted across other Platoid languages before maintaining regional generalizations about ATR harmony. Second, Bìrọ̀m orthography should be revised to reflect its attested harmonic contrasts, beginning with the standardized spelling of the language’s name. Ultimately, this study underscored the necessity of acoustic documentation in understudied languages to refine global typological models of vowel harmony.

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Data availability statement
The script used for this study is available at https://data.mendeley.com/datasets/fxx2npgct9/1.

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