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Triterpenes and other minor chemical constituents of *Boophone haemanthoides* F.M. Leight (Amaryllidaceae)

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ABSTRACT

The chemical investigation of the nonpolar constituents of a methanol extract of the bulbs of *Boophone haemanthoides* yielded ten known compounds as minor constituents. The compounds were identified as stigmast-4-ene-3,6-dione (**1**); cholest-4-en-3-one (**2**); (22*E*)-stigmast-4,22-dien-3-one (**3**); stigmast-4-en-3-one (**4**); 6β-hydroxystigmast-4-en-3-one (**5**); 6β-hydroxycholest-4-en-3-one (**6**); cycloartenol (**7**); acetovanillone (**8**); tyrosol (**10**) and 3-hydroxy-1-(4-hydroxyphenyl)-1-propanone (**11**). The isolation of compound **7** with other cholestane (**2**, **6**) and stigmastane (**1**, **3**–**5**) derivatives aligned with the biosynthetic pathway of plant steroids through **7** from squalene 2,3-epoxide. This is the first report on the isolation and identification of these compounds from *B. haemanthoides* and **1**–**6** and **11** for the family Amaryllidaceae.

1. Introduction

The small African genus *Boophone* Herb. is a member of the bulbous plant family Amaryllidaceae. The family is here used in a narrow sense that is equivalent to the subfamily Amaryllidoideae within the broadly circumscribed family that includes the subfamilies Agapanthoideae and Allioideae (Chase et al., 2009). It is particularly diverse in southern Africa where 20 genera and 266 species are found (Koekemoer et al., 2014). *Boophone* commonly known as 'gifbol' comprises two species, *B. disticha* (L.f) Herb. and *B. haemanthoides* F.M. Leight (Meerow and Snijman, 1998). They occur from southern Africa to tropical East Africa with *B. disticha* more widely distributed than *B. haemanthoides*, which is limited to parts of southern Namibia and the South African winter rainfall areas of Namaqualand, Nieuwoudtville, Calvinia and West Coast to Saldanha (Wrinkle, 1984).

Plants of the genus have unique therapeutic and toxicological profiles with *B. haemanthoides* having limited traditional uses compared to the more common *B. disticha*, for example, the papery bulb scales are used to treat asthma and as a compress for aching knees (De Beer and Van Wyk, 2011).

The chemical composition of the Amaryllidaceae is very diverse. It has a rich alkaloidal content with different skeletons and some of these isolated alkaloids show promising biological activities (Nair et al., 2013a; Ding et al., 2017). Other chemical constituents such as terpenoids and flavonoids are rarely reported for the Amaryllidaceae. Previous chemical studies on *B. haemanthoides* reported eight alkaloids namely, crinine, buphanisine, buphanidrine, ambelline, undulatine, distichamine, distichaminol and lycorine. The last two compounds showed cytotoxic activity against CEM (human acute lymphoblastic), MCF-7 (breast adenocarcinoma) and HeLa (cervical adenocarcinoma) cells (Nair et al., 2013b). Our study reports the isolation and identification of the non-alkaloidal constituents from *B. haemanthoides*.

2. Material and methods

The organic solvents methanol (HPLC grade), ethanol, ethyl acetate, and hexane used for extraction and column chromatography

Abbreviations: CEM, Human acute lymphoblastic; ^{13}C NMR, Carbon-13 nuclear magnetic resonance; ^{1}H NMR, Proton nuclear magnetic resonance; C18, Reversed phase with Octadecyl silane as adsorbent layer; d, Doublet; DCM / CH2Cl2, Dichloromethane; dd, Doublet of doublet; DEPT-135, Distortionless Enhancement by Polarization Transfer-135; GC–MS, Gas Chromatography coupled with Mass spectrometer detector; HeLa, Cervical adenocarcinoma; HPLC, High performance liquid chromatography; J, Coupling constant; *m/z*, Mass/charge ratio; MCF-7, Breast adenocarcinoma; Me, Methyl; MeOH, Methanol; Prep-TLC, Preparative Thin Layer Chromatography; R_t, Retention time; *s*, Singlet; *t*, TripletTLC, Thin Layer Chromatography; TMS, Tetramethyl silane; UV, Ultraviolet

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were general purpose reagents and were obtained from Merck Chemicals (Pty) Ltd (Cape Town, South Africa). ^{1}H, ^{13}C, and DEPT-135 NMR spectra were recorded on a Bruker spectrometer operating at 400 (for ^{1}H) and 100 MHz (for ^{13}C). The chemical shift values were reported in ppm relative to TMS as the internal standard.

Final purifications were performed using Agilent Technologies 1200 series, equipped with UV detector, manual injector, quaternary pump (G1311A), vacuum degasser (G1322A), column compartment (G1316A) and reversed phase C18 column SUPELCO (25 × 1.0 cm, 5 μm). The flow rate was set at 1.5 mL/min, and detection wavelength at λ_{254} nm.

GC–MS analysis was performed utilizing an Agilent Technologies 7820A coupled with MSD5977E. Samples of ~ 1.0 mg were dissolved in CH_2Cl_2 and 1 μL was injected directly into the GC–MS operating in the electron ionization (EI) mode at 70 Ev and utilizing HP5 MS column (30 m 0.25 mm i.d., film thickness 0.25 m. The temperature gradient performed was as follows: 8 min at 40 °C, 80–220 °C at 10 °C/min and 5 min hold at 220 °C, 220–300 °C at 20 °C /min and 10 min hold at 300 °C. The injector and detector temperatures were both at 250 °C, with source and MS Quad at 230 °C and 150 °C, respectively, and the flow-rate of carrier gas (He) was 1.5 mL/min. A split ratio of 1:3 was applied and the injection volume was 1 μL.

2.1. Plant material

Bulbs of *B. haemanthoides* were collected in Nieuwoudtville in the Northern Cape Province, South Africa, in December 2016. The plants were identified by the Curator of the Hantam National Botanical Garden, Mr. Eugene Marinus and one of the co-authors (CNC). A voucher specimen (UFH 2020–3–01) was deposited in the Giffen Herbarium (UFH) at the University of Fort Hare.

2.2. Extraction and fractionation of the total extract

Fresh bulbs (~ 3.2 kg) were blended with methanol and extracted for 2 days, after filtration, the remaining plant materials were re-extracted with fresh methanol. The total extracts were combined and evaporated under reduced pressure at 40 °C to yield ~ 150 g.

The extract (~120 g) was loaded on a silica gel column (18 × 35 cm) and eluted with a gradient mixture of hexane and ethyl acetate of increasing polarity, similar fractions were pooled together according to their TLC profile to give 20 main fractions. Fraction 4 (100 mg) was purified on HPLC using MeOH:H_2O (60% MeOH to 100 MeOH in 40 min) to yield compounds **1** (**R_t** 45.91 min.), **2** (46.88), **3** (51.04), **4** (54.03) and **7** (52.82) (~ 1.0 mg/each compound), purification of fraction 7 (30.0 mg) under the same conditions gave compounds **5** (**R_t** 24.775 min.) and **6** (26.147) (1.0 mg/each). Fractions 8 (45 mg), 10 (100 mg) and 12 (96 mg) were purified on Prep-TLC using silica gel plate (F_{254}, Merck) and DCM:MeOH (97:3) as solvent system to yield compounds **8** (1.0 mg); **10** (5 mg); and **11** (7.0 mg) respectively. Purity of the isolated compounds were confirmed using ^{1}H NMR as well as GC–MS analysis.

2.3. Physical and spectroscopic data of the isolated compounds

Compound **1**. MS; 426.5 ($C_{29}H_{46}O_2$), 398.5, 285.3, 207.1, 137.1; ^{1}H NMR: 6.15 (*d*, *J* = 0.7 Hz, H-4), 2.65 (*dd*, *J* = 3.9, 15.9 Hz, H-7a), 1.15 (*s*, Me-19), 0.91 (*d*, *J* = 6.5 Hz; Me-21), 0.83 (*t*, *J* = 7.4 Hz, Me-29), 0.82 (*d*, *J* = 7.2 Hz, Me-27), 0.80 (*d*, *J* = 7.1 Hz, Me-26), and 0.70 (*s*, Me-18).

Compound **2**. MS; *m/z*: 384.5 ($C_{27}H_{44}O$), 342.5, 261.4, 229.3, 124.3; ^{1}H NMR: 5.70 (*s*, H-4), 1.16 (*s*, Me-19), 0.89 (*d*, *J* = 6.7 Hz; Me-21), 0.845 (*d*, *J* = 6.7 Hz, Me-27), 0.842 (*d*, *J* = 6.6 Hz, Me-26), and 0.67 (s, Me-18).

Compound **3**. MS; *m/z*: 410.5 ($C_{29}H_{46}O$), 341.1, 281.0, 253.2, 207.1, 147.2. ^{1}H NMR: 5.71 (*d*, 0.7 Hz, H-4), 5.13 (*dd*, *J* = 15.1; 8.5 Hz, H-22), 4.99 (*dd*, *J* = 15.1; 8.5 Hz, H-23), 1.16 (*s*, Me-19), 1.00 (*d*, *J* = 6.9 Hz; Me-21), 0.83 (*d*, *J* = 7.6 Hz, Me-26); 0.78 (*t*, *J* = 7.2 Hz, Me-29), 0.77 (*d*, *J* = 6.3 Hz, Me-27), and 0.71 (*s*, Me-18).

Compound **4**. MS: 412.5 ($C_{29}H_{46}O$), 370, 281.2, 299.3, 207.1, 124.1. ^{1}H NMR: 5.69 (*s*, H-4), 1.15 (*s*, Me-19), 0.89 (*d*, *J* = 6.5 Hz; Me-21), 0.82 (*t*, *J* = 7.4 Hz, Me-29), 0.81 (*d*, *J* = 7.2 Hz, Me-26), 0.79 (*d*, *J* = 6.7 Hz, Me-26), and 0.70 (*s*, Me-18).

Compound **5**. MS *m/z*: 428.6 ($C_{29}H_{46}O_2$), 398.5, 285.3, 207.1, 137.1, 98.2. ^{1}H NMR: 5.79 (*s*, H-4), 4.32 (*br s*, H-6a), 1.35 (*s*, Me-19), 0.90 (*d*, *J* = 6.4 Hz; Me-21), 0.82 (*t*, *J* = 7.6 Hz, Me-29), 0.81 (*d*, *J* = 7.1 Hz, Me-26), 0.79 (*d*, 6.4 Hz, Me-26), and 0.72 (*s*, Me-18).

Compound **6**. MS: *m/z*: 400.5 ($C_{27}H_{44}O_2$). 341.2, 287.3, 245.2, 207.1, 137.1. ^{1}H NMR: 5.79 (*s*, H-4), 4.32 (*br s*, H-6a), 1.35 (*s*, Me-19), 0.89 (*d*, *J* = 6.5 Hz; Me-21), 0.845 (*d*, *J* = 6.6 Hz, Me-27), 0.842 (*d*, *J* = 6.6 Hz, Me-26), and 0.71 (*s*, Me-18)

Compound **7**. ^{1}H NMR: 5.08 (*br t*, *J* = 7.4 Hz, H-24), 3.26 (*m*, H-3), 1.66 (*s*, Me-26), 1.58 (*s*, Me-27), 0.95 (6H; *s*, Me-30, –18), 0.87 (*s*, Me-32), 0.86 (*d*, *J* = 6.5 Hz, Me-21), 0.79 (*s*, Me-31), 0.53 (*d*, *J* = 4.4 Hz, H-19 *endo*), and 0.31 (*d*, *J* = 4.4 Hz, H-19 *exo*).

Compound **8**. ^{1}H NMR: 7.51 (*m*, H-2, –6), 6.92 (*d*, *J* = 8.2 Hz, H-4), 3.92 (*s*, OMe), 2.53 (*s*, Me).

Compound **10**. MS: *m/z*: 138.2, 107.1, 91.1, 77.1. ^{1}H NMR; 6.92 (2H, *d*, *J* = 8.4 Hz, H-2,–6), 6.60 (2H, *d*, *J* = 8.4 Hz, H-3, –5), 3.57 (t, *J* = 7.2 Hz, CH_2–8), 2.61 (*t*, *J* = 7.2 Hz CH_2–7). ^{13}C NMR 155.3 (C-4), 129.5 (C-1, –2, –6), 114.7 (C-3, –5), 63.2 (C-8), and 38.0 (C-8).

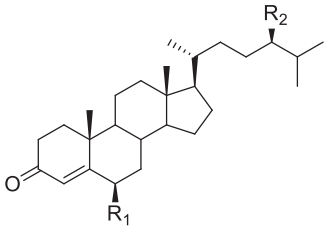
Compound **11**. MS: *m/z*: 166.1, 121.1, 93.0. ^{1}H NMR: 7.89 (2H, *d*, *J* = 8.8 Hz, H-2`,–6`), 6.84 (2H, *d*, *J* = 8.8 Hz, H-3`, –5`), 3.93 (*t*, *J* = 6.1 Hz CH_2–3), 3.16 (*t*, *J* = 6.1 Hz, CH_2–2). ^{13}C NMR 198.4 (C-1), 162.5 (C-4`), 130.5 (C-2`, –6`), 128.9 (C-1`), 114.9 (C-3`, –5`); 57.5 (C-3) and 40.3 (C-2).

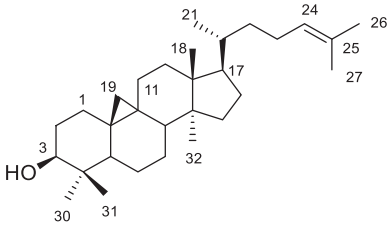
3. Results and discussion

The chromatographic purifications of the nonpolar fractions of *B. haemanthoides* total extracts using different techniques including semi-prep HPLC, resulted in the isolation and identification 10 known compounds (Fig. 1). These were identified as stigmast-4-ene-3,6-dione (**1**); cholest-4-en-3-one (**2**); (22*E*)-stigmasta-4,22-dien-3-one (**3**); stigmast-4-en-3-one (**4**); 6β-hydroxystigmast-4-en-3-one (**5**); 6β-hydroxycholest-4-en-3-one (**6**); cycloartenol (**7**); acetovanillone (**8**); tyrosol (**10**) and 3-hydroxy-1-(4-hydroxyphenyl)–1-propanone (11).

Compound **1** (stigmast-4-en-3,6-dione) was purified from the main fraction 4 using semiprep-HPLC. The GC–MS analysis showed a single peak at 43.113 min with *m/z*: 426.5 which indicated a molecular formula $C_{29}H_{46}O_2$. The ^{1}H NMR spectrum showed a typical 3,6-diketone steroid, the low field olefinic signal at 6.15 ppm indicated the presence a double bond between two carbonyl groups (Kontiza et al., 2006). Further, the aliphatic region showed signals of six methyls, two of them appeared as singlets at 1.14 and 0.70 (Me-19 and –18 respectively), and four appeared at 0.91 *d* (6.5 Hz; Me-21); 0.83 *t* (7.5 Hz; Me-29); 0.82 *d* (7.4 Hz; Me-26); 0.79 d (7.4 Hz; Me-27). Stigmast-4-en-3,6-dione (compound **1**) is widely distributed in nature and was identified in many plant extracts e.g. *Colubrina asiatica* and *Fallopia convolvulus* (Li et al., 2019; Wei et al., 2004; Cui et al., 2009; Della Greca et al., 1990).

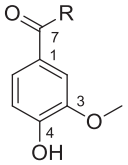
The GC-MS analysis of compound **4** (stigmast-4-en-3-one), showed a single peak with *m/z*: 412 ($C_{29}H_{46}O$) with 14 amu less than that of compound **1**. On the other hand the, ^{1}H NMR spectrum of compound **4** showed similar signals with that of compound **1,** except the for high chemical shift of H-4 to δ_H 5.69 ppm which indicated the absence of a C-6 carbonyl group. (Kontiza et al., 2006; Prachayasittikul et al., 2009; Georges et al., 2006). The presence of compound **4**

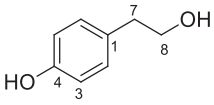


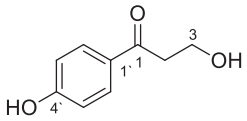


Stigmast-4-ene-3, 6-dione (**1**): R_1 = =O; R_2 = Et
Cholest-4-en-3-one (**2**): R_1 = H; R_2 = H
(22*E*)-Stigmasta-4,22-dien-3-one (**3**): R_1 = H; R_2 = Et; Δ^{22}
Stigmast-4-en-3-one (**4**): R_1 = H; R_2 = Et
6β-Hydroxystigmast-4-en-3-one (**5**): R_1 = OH; R_2 = Et
6β-Hydroxycholest-4-en-3-one (**6**): R_1 = OH; R_2 = H

Cycloartenol (**7**)







Acetovanillone (R = Me; **8**)
Vanillin (R = H; **9**)

Tyrosol (**10**)

3-Hydroxy-1-(4`-hydroxyphenyl)-1-propanone (**11**)

Fig. 1. Chemical structure of compounds **1**–**11**.

(also known as *β*-sitostenone) was previously reported for *Spilanthes acmella*, *Anacardium occidentale*, and *Morinda citrifolia* (Prachayasittikul et al., 2009; Alexander-Lindo et al., 2007; Saludes et al., 2002).

The GC–MS analysis of compound **5** (6*β*-hydroxystigmast-4-en-3-one) showed a single peak at R_t 43.165 min with *m/z*: 428.6 ($C_{29}H_{46}O_2$). The ^{1}H NMR spectrum of this compound showed similarity with compound **4**, except for the appearance of a signal at 4.32 belonging to H-6, which indicates the presence of a hydroxy group at C6. The chemical shift of H-4 (δ_H 5.79) slightly differs from compounds **1** and **4**. (Kontiza et al., 2006; Georges et al., 2006). Compound **5** was previously isolated from *Microcos tomentosa* (Kaennakam et al., 2013) and the red alga *Jania adhaerens* (Alarif et al., 2012).

The GC–MS analysis of compound **3** (22*E*)-stigmast-4,22-dien-3-one) showed a single peak at R_t 39.807 min with *m/z*: 410 ($C_{29}H_{46}O$). It showed ^{1}H NMR signals closely related to compound **4**, except for the presence of a double bond between C22-C23 which was confirmed by the appearance of signals at 5.13 and 4.99 (*dd*, *J* = 15.1; 8.5 Hz/H-22, H-23) (Kontiza et al., 2006; Georges et al., 2006). Similar to Compound 1, this compound is also widely distributed in nature and was identified in many plant extracts e.g. *Croton palanostigma* and *Vigna luteola* (Mochiutti et al., 2019; Lam et al., 2019).

The GC–MS analysis of compound **2** (cholest-4-en-3-one) showed a single peak at R_t 38.319 min with *m/z*: 384 ($C_{27}H_{44}O$). The ^{1}H NMR profile showed signals that are closely related to that of compound **4**, except for the presence of a side aliphatic chain. In compound **2** the C-24 ethyl group is absence and the MS spectra showed a difference of 29 amu, which supports this absence. The methyl pattern demonstrated by compound **2** is a typical C27-cholestane skeleton (Kontiza et al., 2006; Rebelo et al., 2004; Mushfiq and Rehman, 2010; Georges et al., 2006). As in the case of compound **5,** this compound was also recently isolated from *Microcos tomentosa* (Kaennakam et al., 2013).

The GC–MS analysis of compound **6** (6*β*-hydroxycholest-4-en-3-one) showed a single peak in GC–MS analysis at 40.021 min with *m/z*: 400.5 ($C_{27}H_{44}O_2$). The ^{1}H NMR spectrum is closely related to compound **5** except for the absence of the ethyl group signals at C-24, this was supported by the MS spectra as mentioned earlier. The methyl ^{1}H NMR pattern showed a typical 27-cholestane skeleton that is similar to compounds **2.** However, the presence of the 6*β*-OH causes the Me-19 to shift to δ_H 1.36 (from 1.16 of compound **4**) (Kontiza et al., 2006; Georges et al., 2006). This compound is common in nature and was previously identified from *Bombax ceiba*, *Microcos tomentosa*, and *Tinospora sinensis* (Wang et al., 2017; Kaennakam et al., 2013; Lam et al., 2018).

The stereochemistry at C-24 (compounds 1, 3–5) could not be ascertained from the given data, however, it is expected that they have 24*α*-configuration (24*R*) based on biosynthetic ground since higher plants predominantly produce this configuration (Sica et al., 1984; Adewusi et al., 2013).

Compound **7** was identified as cycloartenol based on ^{1}H NMR spectra which showed a signal at 5.08 ppm (*br t*, *J* = 7.1 Hz, H-24); a signal a proton adjacent to hydroxyl group at 3.26 (*m*, H-3); two high field shifted two protons at 0.53, and 0.31 both are *d* (*J* = 4.1 Hz; 19-*endo* and –*exo* respectively) in addition to signals of seven methyl's six of them are singlet at 1.66 and 1.58 (Me-25 and 26), 0.94 *s* (6H, Me-18, 30); 0.87, 78 (Me-32, 31), and a doublet 0.86 (6.3 Hz; Me-21). This compound is widely distributed in nature and was identified from *Crinum asiaticum* (Takagi and Yamaki, 1977).

Acetovanillone (**8**) was isolated as white aromatic crystals and has similar structure of vanillin (**9**) (Lee et al., 2015). The GC–MS analysis showed a single peak at R_t 20.861 min with *m/z* 166.2 ($C_9H_{10}O_3$). The ^{1}H NMR is matching with the data reported for the same compound in literature (Ha et al., 2009), and it was isolated from *B. disticha* (Tagwireyi and Majinda, 2017), *Crinum buphanoides* and *C. graminicola* (Masi et al., 2018).

Tyrosol (**10**) was isolated as amorphous white powder. The GC–MS analysis showed a single peak at Rt 20.104 min with *m/z* 138.2 (M^+) corresponding to $C_8H_{10}O_2$, which showed fragment at *m/z* 107.1 (base peak) and *m/z* 91.1.

The ^{1}H NMR spectra showed 1,4-disubstituted benzene as indicated by the signals at δ_H 6.92 (2H, *d*, *J* = 8.4 Hz, H-2,–6) and 6.60 (2H, *d*, *J* = 8.4 Hz, H-3, –5); two isolated methylene groups at 3.57 (CH_2–8) and 2.61 (CH_2–7) (*t*/each; *J* = 7.2 Hz). The ^{13}C NMR (with DEPT-135) showed signals of 8 carbons that could be classified as 6 aromatic carbons at 155.3 (C-4), 129.5 (3C; C-1, –2, –6), 114.7 (2C; C-3, –5), and two methylene at 63.2 (C-8) and 38.0 (C-8), with one of them (δ_H 3.57/δ_C 63.2) being attached to a hydroxyl group. The above profile is identical with that of tyrosol, a common phenolic alcohol. Tyrosol was previously isolated from olives and *Vitis vinifera* (Covas et al., 2003). Tyrosol demonstrated antioxidant (Puerta et al., 2001; Bertelli et al., 2002), anti-inflammatory (Giovannini et al., 2002), antidiabetic (Dej-adisai et al., 2017), and neuroprotective (Bu et al., 2007) activities.

3-Hydroxy-1-(4`-hydroxyphenyl)–1-propanone (**11**) was isolated as amorphous white powder. The GC–MS showed a single peak at Rt 23.875 min with *m/z* 166.1 (M^+) corresponding to $C_9H_{10}O_3$, it and fragments at *m/z* 121 (base peak) and *m/z* 93.

The ^{1}H NMR spectra deduced 1,4-disubstituted benzene as indicated from the signals at δ_H 7.89 and 6.84 (2H/each; *d*/each; *J* = 8.8 Hz); two isolated methylene groups at 3.93 (CH_2–3) and 3.16 (CH_2–2) (*t*/each; *J* = 6.1 Hz). The ^{13}C NMR (with DEPT-135) showed signals of 9 carbons that could be classified as 6 aromatic carbons at 162.5 (C-4`), 130.5 (2C; C-2`, –6`), 128.9 (C-1`), 114.9 (2C; C-3`, –5`); a carbonyl group at 198.4 (C-1) and two methylene at 57.5 (C-3) and 40.3 (C-2), one of the methylene group is hydroxylated while the other is next to the carbonyl group. The above data indicate that compound **11** has a chemical structure of 3-hydroxy-1-(4`-hydroxyphenyl)–1-propanone (Fig. 1), which is supported by recently published data for *Ailanthis altissima* (Ni et al., 2019).

Except for Compounds **7** and **8**, all other isolated compounds are here reported for the first time for the Amaryllidaceae. The phytosterols (C-24 alkyl-substituted sterols) e.g. ergostane, and stigmastane are the most abundant sterols in the plant kingdom, while the cholestane is commonly accumulating in animals. However, some compounds related to cholestane have been reported for certain species of higher plants. Sterols play important roles in the physiology and biochemistry of most living organisms.

The presence of acylated cholestanes (mainly glycosides) from the genus *Allium*, which is a member of the Alliaceae, a family that is closely related to the Amaryllidaceae, are well-documented (Sobolewska et al., 2016). On the other hand, the isolation of cholestane related structures (compounds **2** and **6**) for the South African Amaryllidaceae is reported for the first time in this study.

4. Conclusion

This study provides an overview of the chemistry of *B. haemanthoides* and a newly isolated class of compounds not previously described for the Amaryllidaceae. However, the triterpenoids are poorly described for this family, it is considered as an important class of secondary metabolites and is contributing to the chemical profile of the species. New phytochemical studies for other Amaryllidaceae members will be important to discover other metabolites in addition to the alkaloids.

Declaration of Competing Interest

The authors declare no conflict of interest in this work.

Author Contributions

AH conceived the research idea. AI carried out the isolation of the compounds, AH and AI elucidated the structures. TL ran all the GC–MS analysis, CNC identified the plant material. All authors read, edited and contributed to the manuscript. JSB, CNC, and AH are AI supervisors.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.sajb.2020.06.025.

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