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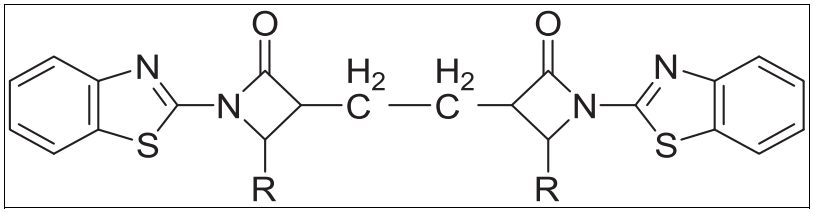

Sonochemical method is an innovative task for the sustainable chemical research industry. In this work, an attempt was made to synthesize bis-azetidin-2-ones **2**(**a–j**) by Staudinger reaction ([2 + 2] ketene-imine cycloaddition reaction) in the presence of zeolite by using both conventional and under ultrasound irradiation. The synthesized compounds have been elucidated on the basis of their elemental analysis and spectral data (IR, ^{1}H NMR, ^{13}C NMR, and mass spectra) to evaluate its performance obtained under ultrasonic waves. It was observed that complete conversion to azetidin-2-ones occurred in 1–2 h by sonochemical method and in 15–46 h by conventional method. Finally, it has been observed that 2-azetidinones synthesis using sonochemical method is an energy efficient and environmentally friendly technique over the conventional method.

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INTRODUCTION

A big challenge facing academia and industry is the relationship of modern societies to the environment that requires reinventing the manufacture and use of materials. Synthetic methodologies nowadays should be designed to use and generate substances that possess little or no toxicity to human health and the environment. Several reports have published on use of ultrasound as a process intensification tool for numerous catalytic reactions as well as in homogeneous and in heterogeneous reactions, and it has proved to be a clean tool for improving yields and decreasing reaction time [1].

As part of a program aimed at the synthesis of 2-azetidinone (β-lactam), we compare the Staudinger reaction under ultrasonic and conventional method of their construction from β-lactams. The synthesis of heterocylic compound has always drawn the attention of chemist over the years mainly because of their important biological properties. Particularly, the role of β-lactam ring is endowed with unique structure and potent antibacterial activity. The 2-azetidinone (β-lactam) ring system is the common structural feature of a number of broad spectrum β-lactam antibiotics, including penicillins, cephalosporins, carbapenems, nocardicins, monobactams, clavulanic acid, sulbactams, and tazobactams, which have been widely used as chemotherapeutic agents to treat bacterial infections and microbial diseases [2–12]. Most of the researches up to early 1990s focused on synthesis of 2-azetidinones and study of their antibacterial property. In recent years, renewed interest has been focused on the synthesis and modification of β-lactam ring to obtain compounds with diverse pharmacological activities such as cholesterol absorption inhibitory activity, human tryptase, thrombin and chymase inhibitory activity, vasopressin V1a antagonist activity, antidiabetic, anti-inflammatory, antiparkinsonian, and anti-HIV activity [13–18]. They are also found to be a potent inhibitor of serine protease, human leukocyte elastase, and human cytomegalovirus protease enzyme [19–22] and are effective on central nervous system; in recent past, these derivatives are also found to be moderately active against several types of cancer [23]. The biological activity of the β-lactam skeleton is generally believed to be associated with the chemical reactivity of their β-lactam ring; the oxo group is at 2nd position and on the substituent especially at nitrogen of the 2-azetidinone ring.

In the last two decades, many heterocyclic compounds from the benzothiazole series were synthesized and their biological and pharmacological activity investigated. The 2-aminobenzothiazole scaffold is one of the privileged structures in medicinal chemistry [24]. Indeed, various examples featuring this particular scaffold have been prepared, many exhibiting remarkable biological activities [25,26]. They were studied extensively for their antiallergic [27], anti-inflammatory [28], antitumor [29–33], and analgesic [34,35] activity. Considering the mechanism of action, it was shown that benzothiazole derivatives act as tyrosine kinase [36–39] and topoisomerase I and II inhibitors [40,41]. Therefore, various benzothiazole compounds are further of considerable interest for their diverse pharmaceutical uses.

It is surprising to note that reports do not exist in the literature for the synthesis of 2-aminobenzothiazole containing bis-azetidinones. In this paper, we wish to report herein our reports in the Staudinger reaction of 2-aminobenzothiazole containing bis-azetidinones that was synthesized using conventional and ultrasound irradiation methods. The effect of ultrasound on % yield, reaction time of synthesized bis-azetidinones has been studied to understand the role of ultrasound (ultrasonic energy) in the synthesis of azetidinone.

RESULTS AND DISCUSSION

Generally, organic reactions have been heated using conventional heat transfer equipment such as oil baths, sand baths, and heating jackets. These heating techniques are, however, rather slow and a temperature gradient can develop within the sample. In conventional method, synthesis of azetidin-2-ones, reported so far, suffer from one or more difficulties such as harsh reaction conditions, poor yields, prolonged period, use of hazardous and often expensive acid catalysts. We have employed to attain easy and eco-friendly synthetic methodology for the synthesis of substituted azetidin-2-ones using zeolite under sonochemical method.

In this paper, we synthesized azetidin-2-ones under sonochemical as well as conventional method. By conventional method, azetidin-2-ones were synthesized by stirring in the presence of TEA and acid chloride for several hours. In the present work, we report a facile ultrasound (sonochemical) synthesis of bis-azetidin-2-ones (Scheme 1). The reaction was carried out for only 60–120 min, which is far less than the conventional method (about 15–46 h) (Scheme 1). In the present research, the whole process of one-pot synthesis of bis-azetidin-2-ones took only 1–2 h, which is substantially less than the reported methods, and we achieved high yield in a much less reaction time.

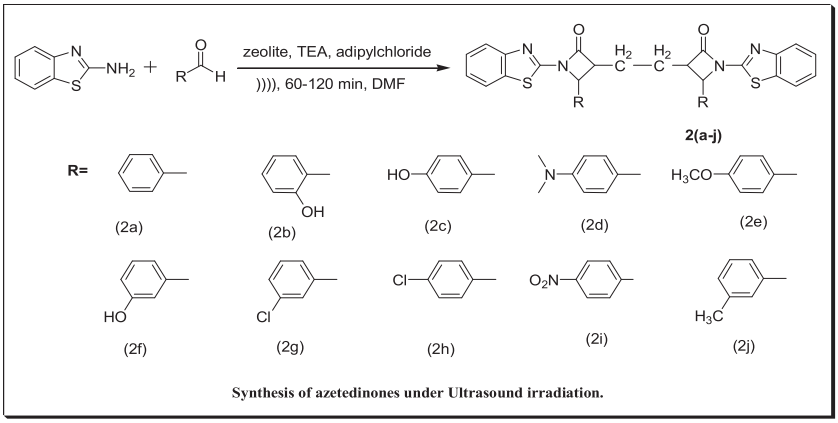
Ultrasound-assisted synthesis of azetidin-2-ones **2(a–j)** are represented in (Scheme 1). Reactions were carried out simply by mixing 2-aminobenzothiazole with different substituted aromatic aldehydes by using zeolite as acid catalyst. To this reaction mixture was added TEA and a solution of adipylchloride in DMF under ultrasound irradiation. The characteristics of ultrasound could play a role in generating cavitation in a process. Cavitation is the phenomenon of sequential formation, growth, and collapse of millions of microscopic vapor bubbles (voids) in a liquid solution [42–44]. When the bubbles collapse rapidly, it creates highly localized temperatures and pressures inside the cavities and hundreds of atmospheric pressures in several nanoseconds, which allows many chemical reactions to occur. And at the same time, fierce waves impact the surface of the zeolite catalyst (Scheme 2).

When the bubbles collapse, it accelerates chemical reactions. This support allows for easy separation of the solid catalyst and product by simple filtration, and in optimal conditions, the supported catalyst can be reused multiple times. This study describes a successful approach for the synthesis of substituted azetidin-2-ones using a laboratory ultrasonic cleaner.

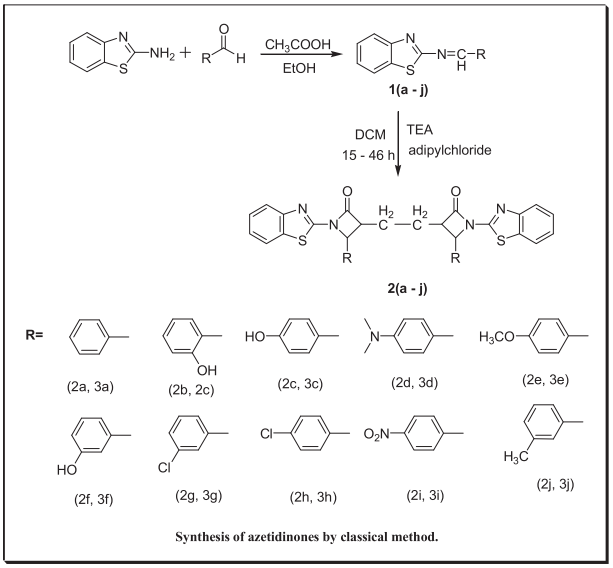
EXPERIMENTAL

Chemicals and apparatus. All the chemicals and solvents were used AR grade without further purification. Melting points were taken in an open capillary tube. IR spectra were recorded on a Shimadzu Dr-8031 instrument (Japan). ^{1}H NMR spectra of the titled compounds were recorded on a Bruker-Avance (300 MHz) spectrophotometer using DMSO solvent and TMS as the internal standard. EI-MS spectra were determined on an LCQ ion trap mass spectrometer (Thermo Fisher, San Jose, CA, USA), equipped with an EI source. The reactions were monitored, and the purity of products was checked out on precoated TLC plates (Silica gel 60 F254, Merck), visualized the spots under ultraviolet light and iodine chamber. Sonication was performed in a "Spectralab model UCB 40D Ultrasonic cleaner" with a frequency of 40 kHz and a nominal power 250 W. The reaction flask was located in the cleaner, where the surface of reactants is slightly lower than the level of the water. The reaction temperature was controlled by the addition or removal of water from ultrasonic bath.

Scheme 1. Synthesis of azetedinones under ultrasound irradiation.



Scheme 2. Synthesis of azetidinones by classical method.



Synthesis of Schiff base by ultrasound method 1(a–j). The reaction was carried out in spectra lab model UCB 40D ultrasonic cleaner. A 0.04 mol 2-aminobenzothiazole, 0.04 mol aromatic aldehyde, and ethanol were taken in a Pyrex flask (50 mL). The reaction mixture was irradiated in the water bath of an ultrasonic cleaner for the period as indicated in Table 1. The progress of the reaction was monitored by TLC. The reaction mixture was poured into crushed ice. The precipitate was separated by filtration, washed with water, and recrystallized from ethanol to obtain **1(a–j)**. The crude product obtained was purified by *n*-hexane and EtOAc.

General procedure for the synthesis of Schiff base by classical method 1(a–j). A quantity of 0.04 mol of 2-aminobenzothiazole, 0.04 mol aromatic aldehyde (**2**), and 2–3 drops of acetic acid in 20 mL of ethanol was refluxed for 120–180 min. The completion of reaction was monitored by TLC. After completion of the reaction, the residue was stirred with ice cold water; solid deposit was collected by filtration and dried. The crude product obtained was purified by *n*-hexane and EtOAc (Table 2).

Synthesis of Schiff bases 1(a–j)

N-Benzylidenebenzothiazol-2-amine (1a). IR (KBr, cm^{-1}): 1620 (-C═N-), ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 8.34 (s, 1H, CH═N), 6.6–7.7 (m, 9H, Ar-H); ^{13}C NMR: δ 121.8–148.5 for aromatic carbons, 159.07 (-HC═N-), 174.5 (-C═N-); mass spectra: *m*/*z* = 238 (100%). Elemental analysis Calcd (found) for $C_{14}H_{10}N_2S$: C, 70.50 (70.44), H, 4.23 (4.29), N, 11.76 (11.70).

2-((Benzothiazol-2-ylimino)methyl)phenol (1b). IR (KBr, cm^{-1}): 1613 (-C═N-), ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 8.41 (s, 1H, CH═N), 6.7–7.8 (m, 8H, Ar-H), 12.56 (s, 1H, OH); ^{13}C NMR: δ 111.1–156.7 for aromatic carbons, 160.5 (-HC═N-), 174.9 (-C═N-); Mass spectra: *m*/*z* = 254 (100%). Elemental analysis Calcd (found) for $C_{14}H_{10}N_2OS$: C, 66.12 (66.06), H, 3.96 (3.99), N, 11.02 (11.08).

4-((Benzothiazol-2-ylimino)methyl)phenol (1c). IR (KBr, cm^{-1}): 1608 (-CH═N-), ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 8.36 (s, 1H, CH═N), 6.5–7.8 (m, 8H, Ar-H), 11.41 (s, 1H, OH); ^{13}C NMR: δ 112.4–154.3 for aromatic carbons, 161.5 (-HC═N-), 172.4 (-C═N-); mass spectra: *m*/*z* = 254 (100%). Elemental analysis Calcd (found) for $C_{14}H_{10}N_2OS$: C, 66.12 (66.07), H, 3.96 (3.92), N, 11.02 (11.08).

N-(4-(Dimethylamino)benzylidene)benzothiazol-2-amine (1d). IR (KBr, cm^{-1}): 1615.7 (-CH═N-), ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 8.61 (s, 1H, CH═N), 3.04 (s, 6H, $N(CH_3)_2$), 6.6–7.9 (m, 8H, Ar-H); ^{13}C NMR: δ 40.54 {$N(CH_3)_2$}, 115.2–151.26 for aromatic carbons, 160.52 (-HC═N-), 171.24 (-C═N-); mass spectra: *m*/*z* = 281 (100%). Elemental analysis Calcd (found) for $C_{16}H_{15}N_3S$: C, 68.30 (68.36), H, 5.37 (5.31), N, 14.93 (14.98).

N-(4-Methoxybenzylidene)benzothiazol-2-amine (1e). IR (KBr, cm^{-1}): 1627.6 (-CH═N-), ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 8.46 (s, 1H, CH═N), 3.90 (s, 3H, OCH_3), 6.6–7.6 (m, 8H, Ar-H); ^{13}C NMR: δ 57.41 (OCH_3) 113.44–156.8 for aromatic carbons, 162.5 (-HC═N-), 173.41 (-C═N-); mass spectra *m*/*z* = 268 (100%). Elemental analysis Calcd (found) for $C_{15}H_{12}N_2OS$: C, 67.14 (67.08), H, 4.51 (4.57), N, 10.44 (10.39).

3-((Benzothiazol-2-ylimino)methyl)phenol (1f). IR (KBr, cm^{-1}): 1616 (-C═N-), ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 8.5 (s, 1H, CH═N), 6.7–7.7 (m, 8H, Ar-H), 10.92 (s, 1H, OH); ^{13}C NMR: δ 115.2–158.8 for aromatic carbons, 160.3 (-HC═N-), 176.5 (-C═N-); mass spectra: *m*/*z* = 254 (100%). Elemental analysis Calcd (found) for $C_{14}H_{10}N_2OS$: C, 66.12 (66.16), H, 3.96 (3.89), N, 11.02 (11.09).

Table 1

Time and yield comparison between classical and ultrasound irradiation **1(a–j)**.

Compound	R	Ultrasound method		Classical method		
		Reaction time (min)	Yield (%)[a]	Reaction time (min)	Yield (%)[a]	mp (°C)
1a	C_6H_5	70	91	145	65	132
1b	*o*-OHC_6H_4	45	86	125	64	139
1c	*p*-OHC_6H_4	65	93	140	62	142
1d	*p*-$N(Me)_2C_6H_4$	50	85	130	65	174
1e	*p*-$OCH_3C_6H_4$	75	94	150	59	167
1f	*m*-OHC_6H_4	45	90	125	57	140
1g	*m*-ClC_6H_4	90	95	180	61	165
1h	*p*-ClC_6H_4	85	90	165	60	169
1i	*p*-$NO_2C_6H_4$	40	88	120	63	172
1j	*m*-$CH_3C_6H_4$	60	85	135	65	134

[a]Isolated yields.

Table 2

Time and yield comparison between classical and ultrasound irradiation **2(a–j)**.

Compound	R	Ultrasound method		Classical method		
		Reaction time (min)	Yield (%)[a]	Reaction time (h)	Yield (%)[a]	mp (°C)
2a	C_6H_5	90	89	35	63	139
2b	*o*-OHC_6H_4	80	92	27	68	148
2c	*p*-OHC_6H_4	60	85	15	67	145
2d	*p*-$N(Me)_2C_6H_4$	110	90	42	71	172
2e	*p*-$OCH_3C_6H_4$	90	93	36	61	162
2f	*m*-OHC_6H_4	80	87	28	62	142
2g	*m*-ClC_6H_4	110	88	41	65	158
2h	*p*-ClC_6H_4	120	90	46	70	156
2i	*p*-$NO_2C_6H_4$	60	85	18	60	170
2j	*m*-$CH_3C_6H_4$	80	87	27	64	140

[a]Isolated yields.

N-(3-Chlorobenzylidene)benzothiazol-2-amine (1g). IR (KBr, cm^{-1}): 1619 (-C═N-), ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 8.35 (s, 1H, CH═N), 6.7–7.6 (m, 8H, Ar-H); ^{13}C NMR: δ 113.8–159.3 for aromatic carbons, 162.9 (-HC═N-), 174.8 (-C═N-); mass spectra: *m*/*z* = 272 (100%). Elemental analysis Calcd (found) for $C_{14}H_9ClN_2S$: C, 61.65 (61.60), H, 3.33 (3.29), N, 10.27 (10.31).

N-(4-Chlorobenzylidene)benzothiazol-2-amine (1h). IR (KBr, cm^{-1}): 1617.5 (-C═N-), ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 8.5 (s, 1H, CH═N), 6.5–7.7 (m, 8H, Ar-H); ^{13}C NMR: δ 116.2–158.1 for aromatic carbons, 161.4 (-HC═N-), 171.2 (-C═N-); mass spectra: *m*/*z* = 272 (100%). Elemental analysis Calcd (found) for $C_{14}H_9ClN_2S$: C, 61.65 (61.61), H, 3.33 (3.38), N, 10.27 (10.23).

N-(4-Nitrobenzylidene)benzothiazol-2-amine (1i). IR (KBr, cm^{-1}): 1614.3 (-C═N-), ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 8.42 (s, 1H, CH═N), 6.6–7.8 (m, 8H, Ar-H), ; ^{13}C NMR: δ 111.5–157.3 for aromatic carbons, 163.4 (-HC═N-), 175.1 (-C═N-); mass spectra: *m*/*z* = 283 (100%). Elemental analysis Calcd (found): for $C_{14}H_9N_3O_2S$: C, 59.35 (59.39), H, 3.20 (3.16), N, 14.83 (14.75).

N-(3-Methylbenzylidene)benzothiazol-2-amine (1j). IR (KBr, cm^{-1}): 1615.8 (-C═N-), ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 8.3 (s, 1H, CH═N), 6.6–7.6 (m, 8H, Ar-H), 3.06 (s, 3H, Ar-CH_3); ^{13}C NMR: δ 112.2–156.7 for aromatic carbons, 160.9 (-HC═N-), 172.1 (-C═N-); mass spectra: *m*/*z* = 253 (100%). Elemental analysis Calcd (found): for $C_{15}H_{12}N_2S$: C, 71.40 (71.36), H, 4.79 (4.74), N, 11.10 (11.15).

Synthesis of bis-azetidinone (2a–j)

General procedure for the synthesis of substituted bis-azetidin-2-one by classical method 2(a–j). The appropriate Schiff base (0.04 mol) and triethylamine (0.05 mol) were stirred in anhydrous dichloromethane, whereas a solution of adipylchloride (0.02 mol) in dry dichloromethane was added drop wise. The reaction mixture was stirred for 15–46 h. The completion of the reaction was monitored by TLC. The reaction mixture was washed with water and dried over sodium sulfate. The products that were obtained after removing the solvent were purified from ethyl acetate and *n*-hexane.

Synthesis of bis-azetidin-2-one base by ultrasound method 2(a–j). The reaction was carried out in spectralab model UCB 40D ultrasonic cleaner. A 0.04 mol 2-aminobenzothiazole (**1**), 0.04 mol aromatic aldehyde (**2**), and zeolite (montmorillonite K-10) (0.2 g) were stirred with glass rod in DMF (20 mL). To this solution were added triethylamine (0.05 mol) and a solution of adipylchloride (0.02 mol) in DMF (5 mL). The reaction mixture was irradiated for ~60–120 min. The completion of the reaction was monitored by TLC. After the irradiation was over, the reaction mixture was cooled and added into water. After filtering the zeolite particles, the obtained solid product was separated and purified from ethyl acetate and *n*-hexane.

3,3′-(Ethane-1,2-diyl)bis(1-(benzothiazol-2-yl)-4-phenylazetidin-2-one) (2a). IR (KBr, cm^{-1}): 1759 (C═O β-lactam), 1365 (C-N); ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 1.75 (d, 4H, -CH_2-CH_2-); 5.0 (m, 2H, >C-C═O); 4.3 (d, 2H, >C-N<); 7.2–8.2 (m, 18H, Ar-H); ^{13}C NMR: δ 29.2 ((-CH_2), 46.2 (-CH_2-C═O), 62.4 (>CH-N<), 166 (N═C<), 168 (>C═O), 120, 122.1, 126, 126.9, 127.2, 128.7, 129.1, 139.1, 151.8 for aromatic carbons; mass spectra, *m*/*z* = 586 (M^+, 100%), elemental analysis: Calcd (found): C, 69.60 (69.64); H, 4.47 (4.41); N, 9.55 (9.61).

3,3′-(Ethane-1,2-diyl)bis(1-(benzothiazol-2-yl)-4-(2-hydroxyphenyl) azetidin-2-one) (2b). IR (KBr, cm^{-1}): 1758 (C═O β-lactam), 1366 (C-N); ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 1.78 (d, 4H, -CH_2-CH_2-); 5.2 (m, 2H, O═C-CH<); 4.4 (d, 2H, >N-CH<); 7.2–8.2 (m, 16H, Ar-H); 12 (s, 2H, Ar-OH); ^{13}C NMR: δ 27.2 (-CH_2), 49 (-CH_2-C═O), 62.9 (>CH-N<), 163.4 (N═C<), 166.7 (>C═O), 116.1, 117.8, 121.9, 122.3, 126, 126.7, 129.9, 130.8, 152, 159 for aromatic carbons; mass spectra, *m*/*z* = 618 (M^+, 100%), elemental analysis: Calcd (found): C, 66 (66.2); H, 4.24 (4.20); N, 9.06 (9.02).

3,3′-(Ethane-1,2-diyl)bis(1-(benzothiazol-2-yl)-4-(4-hydroxyphenyl) azetidin-2-one) (2c). IR (KBr, cm^{-1}): 1759 (C═O β-lactam), 1366 (C-N); ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 1.8 (d, 4H, -CH_2-CH_2-); 5.2 (m, 2H, O═C-CH<); 4.2 (d, 2H, >N-CH<); 7.2–8.2 (m, 16H, Ar-H); 11.45 (s, 2H, Ar-OH); ^{13}C NMR: δ 28.1 (-CH_2), 48.2 (-CH_2-C═O), 63.5 (>CH-N<), 163.1 (N═C<), 167 (>C═O), 116.6, 118.1, 121.6, 122.8, 125.6, 126.2, 129.6, 131.4, 152.2, 158.1 for aromatic carbons; mass spectra, *m*/*z* = 618 (M^+, 100%), elemental analysis: Calcd (found): C, 66 (66.2); H, 4.24 (4.32); N, 9.06 (9.01).

3,3′-(Ethane-1,2-diyl)bis(1-(benzothiazol-2-yl)-4-(4-dimethylamino) phenyl)azetidin-2-one) (2d). IR (KBr, cm^{-1}): 1756 (C═O β-lactam), 1366 (C-N); ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 1.63 (d, 4H, -CH_2═CH_2-); 5.1 (m, 2H, O═C-CH<); 4.3 (d, 2H, >N-CH<); 7.2–8.2 (m, 16H, Ar-H); 3.06 (s, 12H, ($N(CH_3)_2$)); ^{13}C NMR: δ 41.3 (N(CH3)2), 26.9 (-CH_2), 48 (-CH_2-C-O), 62.4 (>CH-N<), 163.1 (N═C<), 166.2 (>C═O), 115.8, 117.9, 122.0, 121.9, 126,

126.2, 129.1, 130.3, 151.7, 159.2 for aromatic carbons; mass spectra, $m/z = 618$ (M^+, 100%), elemental analysis: Calcd (found): C, 66 (66.4); H, 4.24 (4.27); N, 9.06 (9.01).

3,3′-(Ethane-1,2-diyl)bis(1-(benzothiazol-2-yl)-4-(4-methoxyphenyl) azetidin-2-one) (2e). IR (KBr, cm^{-1}): 1758 (C═O β-lactam), 1366 (C-N); ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 1.54 (d, 4H, -CH_2-CH_2-); 5.2 (m, 2H, O═C-CH<); 4.68 (d, 2H, >N-CH<); 7.2–8.2 (m, 16H, Ar-H); 3.93 (s, 6H, OCH_3); ^{13}C NMR: δ 56 (-CH_3), 28.4 (-CH_2), 45.5 (-CH_2-C═O), 61 (>CH-N<), 164.5 (N═C<), 168.3 (>C═O), 117.9, 120.3, 122, 125, 126.5, 127.5, 129.9, 131.1, 153.2, 162 for aromatic carbons; mass spectra, $m/z = 646$ (M^+, 100%), elemental analysis: Calcd (found): C, 66.85 (66.75); H, 4.68 (4.7); N, 8.66 (8.59).

3,3′-(Ethane-1,2-diyl)bis(1-(benzothiazol-2-yl)-4-(3-hydroxyphenyl) azetidin-2-one) (2f). IR (KBr, cm^{-1}): 1745 (C═O β-lactam), 1353 (C-N); ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 1.72 (d, 4H, -CH_2-CH_2-); 5.2 (m, 2H, O═C-CH<); 4.31 (d, 2H, >N-CH<); 7.2–8.2 (m, 16H, Ar-H); 10.89 (s, 2H, Ar-OH); ^{13}C NMR: δ 27.4 (-CH_2), 48.4 (-CH_2-C═O), 61.7 (>CH-N<), 163 (N═C<), 165.9 (>C═O), 116.4, 117.4, 122.4, 122.1, 126.2, 126.3, 129.3, 130.5, 152.1, 159 for aromatic carbons; mass spectra, $m/z = 618$ (M^+, 100%), elemental analysis: Calcd (found): C, 66 (66.7); H, 4.24 (4.19); N, 9.06 (9.01).

3,3′-(Ethane-1,2-diyl)bis(1-(benzothiazol-2-yl)-4-(3-chlorophenyl) azetidin-2-one) (2g). IR (KBr, cm^{-1}): 1760 (C═O β-lactam), 1364 (C-N); ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 1.61 (d, 4H, -CH_2-CH_2-); 5.1 (m, 2H, O═C-CH<); 4.6 (d, 2H, >N-CH<); 7.2–8.2 (m, 16H, Ar-H); ^{13}C NMR: δ 28.1 (-CH_2), 46.9 (-CH_2-C═O), 61.1 (>CH-N<), 165.1 (N═C<), 168.4 (>C-O), 118.9, 119.8, 122.5, 124.6, 125.9, 127.5, 129.4, 131.6, 153, 161.1 for aromatic carbons; mass spectra, $m/z = 654$ (M^+, 100%), elemental analysis: Calcd (found): C, 62.29 (62.21); H, 3.69 (3.72); N, 8.55 (8.59).

3,3′-(Ethane-1,2-diyl)bis(1-(benzothiazol-2-yl)-4-(4-chlorophenyl) azetidin-2-one) (2h). IR (KBr, cm^{-1}): 1736 (C═O β-lactam), 1347 (C-N); ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 1.59 (d, 4H, -CH_2-CH_2-); 5.1 (m, 2H, O═C-CH<); 4.58 (d, 2H, >N-CH<); 7.2–8.2 (m, 16H, Ar-H); ^{13}C NMR: δ 28.6 (-CH_2), 46.5 (-CH_2-C═O), 60.8 (>CH-N<), 164.9 (N═C<), 168 (>C═O), 118.1, 120, 122.1, 124.9, 126, 127.1, 129.5, 131.2, 153.9, 162.1 for aromatic carbons; mass spectra, $m/z = 654$ (M^+, 100%), elemental analysis: Calcd (found): C, 62.29 (62.25); H, 3.69 (3.77); N, 8.55 (8.56).

3,3′-(Ethane-1,2-diyl)bis(1-(benzothiazol-2-yl)-4-(4-nitrophenyl) azetidin-2-one) (2i). IR (KBr, cm^{-1}): 1734 (C═O β-lactam), 1336 (C-N); ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 1.79 (d, 4H, -CH_2-CH_2-); 5.1 (m, 2H, O═C-CH<); 4.81 (d, 2H, >N-CH<); 7.3–8.2 (m, 16H, Ar-H); ^{13}C NMR: δ 29.1 (-CH_2), 47.2 (-CH_2-C═O), 60.9 (>CH-N<), 166 (N═C<), 167.8 (>C═O), 117.6, 119.2, 123.1, 124.9, 126.5, 128.1, 130.1, 132, 152.8, 162.2 for aromatic carbons; mass spectra, $m/z = 676$ (M^+, 100%), elemental analysis: Calcd (found): C, 60.34 (60.28); H, 3.57 (3.52); N,12.42 (12.5).

3,3′-(Ethane-1,2-diyl)bis(1-(benzothiazol-2-yl)-4-m-tolylazetidin-2-one) (2j). IR (KBr, cm^{-1}): 1746 (C═O β-lactam), 1354 (C-N); ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) = 1.59 (d, 4H, -CH_2-CH_2-); 5.0 (m, 2H, O═C-CH<); 4.61 (d, 2H, >N-CH<); 7.2–8.2 (m, 16H, Ar-H); 2.4 (s, 6H, -CH_3) ^{13}C NMR: δ 22.6 (-CH_3), 28.2 (-CH_2), 45.9 (-CH_2-C═O), 61.2 (>CH-N<), 164.7 (N═C<), 167.9 (>C═O), 117.5, 120, 121.8, 124.8, 126.8, 128, 129.4, 131.9, 153, 162.9 for aromatic carbons; mass spectra, $m/z = 614$ (M^+, 100%), elemental analysis: Calcd (found): C, 70.33 (70.39); H, 4.92 (4.87); N, 9.11 (9.07).

CONCLUSION

In summary, we report the synthesis of different substituted bis-2-azetidinones via Staudinger cycloaddition between keten and Schiff base that was performed in milder conditions under ultrasonic irradiation in the presence of zeolite that was of a high product yield and enhance product purity with a shorter reaction time, easier work-up, and environmentally friendly character compared with previous conventional synthetic methods in the literature. Hence, the present method is an ample scope for further study in developing these as good lead one-pot methodology.

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