3-[2-OXO-2H-CHROMEN-3(6)(8)-YL]-1-ARYL/HETEROARYL-1H-PYRAZOLE-4-CARBALDEHYDES: SYNTHESIS, REACTIONS AND APPLICATIONS

Ayat K. Alsolimani,1 Mohammed A. Assiri,1 and Tarik E. Ali1,2*

1Department of Chemistry, Faculty of Science, King Khalid University, Abha, Saudi Arabia. *E-mail: tarik_elsayed1975@yahoo.com and tismail@kku.edu.sa
2Department of Chemistry, Faculty of Education, Ain Shams University, Roxy, Cairo, Egypt. *E-mail: tarik_elsayed@edu.asu.edu.eg

Abstract – The chemistry of 3-(2-oxo-2H-chromen-3(6)(8)-yl)-1-aryl/heteroaryl-1H-pyrazole-4-carbaldehydes has gained increased interest in both synthetic organic and biological fields, since a large number of developments in the use of such compounds seem to be of considerable value. This review describes all the available synthetic methods for diverse 3-(2-oxo-2H-chromen-3(6)(8)-yl)-1-aryl/heteroaryl-1H-pyrazole-4-carbaldehydes in the literature survey. It also summarizes their chemical behaviors as building blocks towards a variety of chemical reagents to construct related compounds as well as their biological applications.

1. INTRODUCTION

Heterocycles are the principal structural motif of life because of their widespread distribution in nature and essential roles in numerous chemical processes. All living creatures are provided by heterocycles, which serve as the primary building blocks of their DNA and RNA. In addition, heterocyclic compounds demonstrated great physiological and pharmacological activities.1 Nitrogen and oxygen heterocycles are fundamental building blocks of many physiologically active molecules, which have various uses in chemistry and biology.2 Particularly, coumarin derivatives are essential components of fruits and crops and have antifungal and phytotoxic properties. In addition, coumarin compounds exhibited prominent biological properties such as antidepressant,3 antioxidant,4,5 antiviral,6 antimicrobial,7 antibiotic,8 muscle relaxant,9 anti-inflammatory,10 antinociceptive,11 antitumor12 and anti-HIV.13 On the other hand, pyrazoles are aromatic heterocycles with two nitrogen atoms in their five-membered rings.14 They form a significant
heterocyclic family that contains a variety of synthetic and natural compounds with a wide pharmacological and agrochemical effects. Further, they have an importance in medicinal chemistry due to their wide range of pharmacological activities such as anticonvulsant, antifungal, antitubercular (anti-TB), antimicrobial, anti-inflammatory, antiproliferative, anticancer and anti-HIV. When pyrazole ring was incorporated with coumarin moiety, the merged structure showed a significant change in pharmacological properties. Moreover, different biochemical and synthetic studies confirmed the hypothesis that the coumarinyl-pyrazole moiety is a basic structural motif for producing bioactive components in drug discovery. Coumarinyl-pyrazole compounds exhibited biologically properties such as anti-TB, antioxidant, anticancer, antihyperglycemic agents, antimicrobial, antibacterial, antiproliferative, and PDE inhibitor. With a part of our ongoing studies on biologically active relevant heterocycles, we make a serious effort to present concise review focusing on the synthesis, reactions and applications of diverse 3-(2-oxo-2H-chromen-3(6)(8)-yl)-1-aryl/heteroaryl-1H-pyrazole-4-carbaldehydes and related compounds.

2. THE SYNTHETIC METHODS
The synthetic methods of 3-(2-oxo-2H-chromen-3-yl)-4-formylpyrazoles (3) were described. 3-Acetyl-coumarins (1) were reacted with arylhydrazines using different reaction conditions to afford the corresponding arylhydrazones 2a-x. Upon subjection of these hydrazones 2a-x to Vilsmeier-Haack reaction afforded a series of 1-aryl-4-formyl-3-(2-oxo-2H-chromen-3-yl)-1H-pyrazoles (3a-x) (Scheme 1 and Table 1).

![Scheme 1](image-url)
Table 1. The specific reaction conditions for the formation of products 3a-x

<table>
<thead>
<tr>
<th>Product</th>
<th>R</th>
<th>R¹</th>
<th>R²</th>
<th>R³</th>
<th>R⁴</th>
<th>X</th>
<th>Reaction conditions I</th>
<th>Reaction conditions II</th>
</tr>
</thead>
<tbody>
<tr>
<td>3a</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>1. AcOH, rt, 30 min</td>
<td>1. 0 °C, rt, 24 h</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2. EtOH-AcOH, reflux</td>
<td>2. US, 80 °C, 30 min</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3. MW, 100 W, 80 °C, 5 min</td>
<td>3. 0 °C, 60 °C, 5 h</td>
</tr>
<tr>
<td>3b</td>
<td>H</td>
<td>H</td>
<td>Cl</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>EtOH-AcOH, reflux</td>
<td>0-80 °C, 8 h</td>
</tr>
<tr>
<td>3c</td>
<td>H</td>
<td>H</td>
<td>Br</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>EtOH, 90 °C, 8 h</td>
<td>0-80 °C, 8 h</td>
</tr>
<tr>
<td>3d</td>
<td>H</td>
<td>H</td>
<td>F</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>EtOH, 90 °C, 8 h</td>
<td>0-80 °C, 8 h</td>
</tr>
<tr>
<td>3e</td>
<td>H</td>
<td>H</td>
<td>NO₂</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>EtOH, NaOAc, reflux</td>
<td>0 °C, 60 °C, 5 h</td>
</tr>
<tr>
<td>3f</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>OH</td>
<td>H</td>
<td>H</td>
<td>AcOH, rt, 30 min</td>
<td>0 °C, 90 °C, 8 h</td>
</tr>
<tr>
<td>3g</td>
<td>MeO</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>AcOH, rt, 30 min</td>
<td>0 °C, 90 °C, 8 h</td>
</tr>
<tr>
<td>3h</td>
<td>Cl</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>AcOH, rt, 30 min</td>
<td>0 °C, 90 °C, 8 h</td>
</tr>
<tr>
<td>3i</td>
<td>Br</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>AcOH, rt, 30 min</td>
<td>0 °C, 90 °C, 8 h</td>
</tr>
<tr>
<td>3j</td>
<td>Br</td>
<td>H</td>
<td>Br</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>AcOH, rt, 30 min</td>
<td>0 °C, 90 °C, 8 h</td>
</tr>
<tr>
<td>3k</td>
<td>H</td>
<td>H</td>
<td>Br</td>
<td>H</td>
<td>H</td>
<td>Br</td>
<td>EtOH-AcOH, reflux</td>
<td>rt, 2-3 h</td>
</tr>
<tr>
<td>3l</td>
<td>H</td>
<td>NEt₂</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>AcOH, rt, 30 min</td>
<td>0 °C, 60 °C, 5 h</td>
</tr>
<tr>
<td>3m</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>NO₂</td>
<td>AcOH, 80 °C, 10-15 min</td>
<td>rt, 2-3 h</td>
</tr>
<tr>
<td>3n</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>Cl</td>
<td>AcOH, 80 °C, 10-15 min</td>
<td>rt, 2-3 h</td>
</tr>
<tr>
<td>3o</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>F</td>
<td>AcOH, 80 °C, 10-15 min</td>
<td>rt, 2-3 h</td>
</tr>
<tr>
<td>3p</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>Cl</td>
<td>AcOH, 80 °C, 10-15 min</td>
<td>rt, 2-3 h</td>
</tr>
<tr>
<td>3q</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>Me</td>
<td>AcOH, 80 °C, 10-15 min</td>
<td>rt, 2-3 h</td>
</tr>
<tr>
<td>3r</td>
<td>H</td>
<td>H</td>
<td>Br</td>
<td>H</td>
<td>H</td>
<td>MeO</td>
<td>AcOH, 80 °C, 10-15 min</td>
<td>rt, 2-3 h</td>
</tr>
<tr>
<td>3s</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>Br</td>
<td>H</td>
<td>CO₂H</td>
<td>EtOH, 90 °C, 8 h</td>
<td>0-80 °C, 8 h</td>
</tr>
<tr>
<td>3t</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>Cl</td>
<td>H</td>
<td>CO₂H</td>
<td>EtOH, 90 °C, 8 h</td>
<td>0-80 °C, 8 h</td>
</tr>
<tr>
<td>3u</td>
<td>H</td>
<td>OH</td>
<td>H</td>
<td>H</td>
<td>CO₂H</td>
<td>EtOH, 90 °C, 8 h</td>
<td>0-80 °C, 8 h</td>
<td></td>
</tr>
<tr>
<td>3v</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>CO₂H</td>
<td>EtOH, 90 °C, 8 h</td>
<td>0-80 °C, 8 h</td>
<td></td>
</tr>
<tr>
<td>3w</td>
<td>H</td>
<td>Benzo</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>EtOH-AcOH, reflux</td>
<td>rt, 6 h</td>
<td></td>
</tr>
<tr>
<td>3x</td>
<td>H</td>
<td>H</td>
<td>Benzo</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>EtOH-AcOH, reflux</td>
<td>rt, 6 h</td>
</tr>
</tbody>
</table>

Also, 3-(2-oxo-2H-chromen-3-yl)-1-(4-arylthiazol-2-yl)-1H-pyrazole-4-carbaldehydes (5a-n)⁴¹ and 3-(2-oxo-2H-chromen-3-yl)-1-(benzothiazol-2-yl)-1H-pyrazole-4-carbaldehydes (8)⁶⁷ were synthesized by a sequential Hantzsch thiazole synthesis and Vilsmeier–Haack reaction. An equimolar mixture of α-haloketone and thiosemicarbazide in ethanol, was added to the substituted 3-acetylcoumarins (1) under refluxing to give the non-isolated hydrazones 4 (Scheme 2). Similarly, the acetyl derivatives 1 condensed with 2-hydrazinobenzothiazole (6) in ethanol to afford the hydrazones 7 (Scheme 3). Applying of Vilsmeier-Haack formylation of the latter hydrazones 4 and 7 gave the target compounds 5 (Table 2) and 8, respectively (Scheme 2 and 3).

![Scheme 2](image-url)
Table 2. The derivatives of 3-(2-oxo-2H-chromen-3-yl)-1-(4-arylthiazol-2-yl)-1H-pyrazole-4-carbaldehydes (5a-n)

<table>
<thead>
<tr>
<th>Product</th>
<th>R</th>
<th>R¹</th>
<th>Ar</th>
<th>Product</th>
<th>R</th>
<th>R¹</th>
<th>Ar</th>
</tr>
</thead>
<tbody>
<tr>
<td>5a</td>
<td>H</td>
<td>H</td>
<td>Ph</td>
<td>5h</td>
<td>H</td>
<td>H</td>
<td>4-MeOC₆H₄</td>
</tr>
<tr>
<td>5b</td>
<td>H</td>
<td>Cl</td>
<td>Ph</td>
<td>5i</td>
<td>H</td>
<td>Cl</td>
<td>4-MeOC₆H₄</td>
</tr>
<tr>
<td>5c</td>
<td>Cl</td>
<td>Cl</td>
<td>Ph</td>
<td>5j</td>
<td>Cl</td>
<td>Cl</td>
<td>4-MeOC₆H₄</td>
</tr>
<tr>
<td>5d</td>
<td>H</td>
<td>Br</td>
<td>Ph</td>
<td>5k</td>
<td>H</td>
<td>Br</td>
<td>4-MeOC₆H₄</td>
</tr>
<tr>
<td>5e</td>
<td>Br</td>
<td>Br</td>
<td>Ph</td>
<td>5l</td>
<td>Br</td>
<td>Br</td>
<td>4-MeOC₆H₄</td>
</tr>
<tr>
<td>5f</td>
<td>OMe</td>
<td>H</td>
<td>Ph</td>
<td>5m</td>
<td>OMe</td>
<td>H</td>
<td>4-MeOC₆H₄</td>
</tr>
<tr>
<td>5g</td>
<td>OMe</td>
<td>Br</td>
<td>Ph</td>
<td>5n</td>
<td>OMe</td>
<td>Br</td>
<td>4-MeOC₆H₄</td>
</tr>
</tbody>
</table>

In 2013, Nagamallu et al. applied the similar strategy to synthesize new coumarinyl-pyrazole derivatives. The starting material, 8-acetyl-7-hydroxy-4-methyl-2H-chromen-2-one (9), was heated with different aryl-hydrazines under reflux in ethanol and a catalytic acetic acid to yield the corresponding hydrazones 10a-e. The aimed 1-aryl-3-(7-hydroxy-4-methyl-2-oxo-2H-chromen-8-yl)-1H-pyrazole-4-carbaldehydes (11a-e) were obtained in 62-78% yields by Vilsmeier-Haack formylation of the hydrazones 10a-e (Scheme 4).

Scheme 3

Scheme 4
In continuation, Nagamallu et al.\textsuperscript{59} used a similar route for the synthesis of 3,3’-(7-hydroxy-4-methyl-2-oxo-2\textsubscript{H}-chromene-5,8-diyl)-bis-(1-aryl/alkyl-1\textsubscript{H}-pyrazole-4-carbaldehydes) (14a-g). Initially, treatment of different alkyl/aryl-hydrazines with 6,8-diacetyl-7-hydroxy-4-methylcoumarin (12) at refluxing conditions produced the respective hydrazone derivatives 13a-g. Subsequently, Vilsmeier-Haack formylation on hydrazone intermediates 13a-g led to the formation of desired coumarin bis-(4-formylpyrazoles) 14a-g as shown in Scheme 5.

\begin{align*}
14a, R=C\textsubscript{6}H\textsubscript{5}, & \quad 14b, R=4-MeC\textsubscript{6}H\textsubscript{4}, \quad 14c, R=3-MeC\textsubscript{6}H\textsubscript{4}, \quad 14d, R=4-MeOC\textsubscript{6}H\textsubscript{4}, \\
14e, R=4-ClC\textsubscript{6}H\textsubscript{4}, & \quad 14f, R=CON\textsubscript{2}, \quad 14g, R=CSNH\textsubscript{2}
\end{align*}

### Scheme 5

Similarly, condensation of 1-(3-aryl-1,8-naphthyridin-2-yl)hydrazines (15) with different 3-acetyl-coumarins (1) in the presence of a catalytic amount of DMF under MW irradiation afforded the corresponding 3-\{1-[2-(3-aryl-1,8-naphthyridin-2-yl)hydrazinylidene]ethyl\}-2\textsubscript{H}-chromen-2-ones (16) in excellent yields. When the hydrazones 16 were subjected to the Vilsmeier-Haack reaction with POCl\textsubscript{3}-DMF/SiO\textsubscript{2} under MW irradiation, the respective 1-[3-(3-aryl-1,8-naphthyridin-2-yl)]-3-(2-oxo-2\textsubscript{H}-chromen-3-yl)-1\textsubscript{H}-pyrazole-4-carbaldehydes (17a-x) were isolated (Scheme 6 and Table 3).\textsuperscript{60-68}

\begin{align*}
R^1, R^2, R^3, & \quad Ar \\
Me, & \quad DMF
\end{align*}

### Scheme 6
Table 3. The derivatives of 1-[3-(3-aryl-1,8-naphthyridin-2-yl)]-3-(2-oxo-2H-chromen-3-yl)-1H-pyrazole-4-carbaldehydes (17a-x)

<table>
<thead>
<tr>
<th>Product</th>
<th>R</th>
<th>R¹</th>
<th>R²</th>
<th>R³</th>
<th>Ar</th>
<th>Product</th>
<th>R</th>
<th>R¹</th>
<th>R²</th>
<th>R³</th>
<th>Ar</th>
</tr>
</thead>
<tbody>
<tr>
<td>17a</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>1-naphthyl</td>
<td>17m</td>
<td>Br</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>3-MeOC₆H₄</td>
</tr>
<tr>
<td>17b</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>3-MeOC₆H₄</td>
<td>17n</td>
<td>Br</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>4-FC₆H₄</td>
</tr>
<tr>
<td>17c</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>4-FC₆H₄</td>
<td>17o</td>
<td>Br</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>3-FC₆H₄</td>
</tr>
<tr>
<td>17d</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>3-FC₆H₄</td>
<td>17p</td>
<td>Br</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>4-MeOC₆H₄</td>
</tr>
<tr>
<td>17e</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>4-MeOC₆H₄</td>
<td>17q</td>
<td>Br</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>2-ClC₆H₄</td>
</tr>
<tr>
<td>17f</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>2-ClC₆H₄</td>
<td>17r</td>
<td>NO₂</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>3-MeOC₆H₄</td>
</tr>
<tr>
<td>17g</td>
<td>OMe</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>1-naphthyl</td>
<td>17s</td>
<td>Cl</td>
<td>H</td>
<td>Cl</td>
<td>H</td>
<td>1-naphthyl</td>
</tr>
<tr>
<td>17h</td>
<td>OMe</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>3-MeOC₆H₄</td>
<td>17t</td>
<td>Cl</td>
<td>H</td>
<td>Cl</td>
<td>H</td>
<td>3-MeOC₆H₄</td>
</tr>
<tr>
<td>17i</td>
<td>OMe</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>4-FC₆H₄</td>
<td>17u</td>
<td>Br</td>
<td>H</td>
<td>Br</td>
<td>H</td>
<td>4-MeOC₆H₄</td>
</tr>
<tr>
<td>17j</td>
<td>OMe</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>3-FC₆H₄</td>
<td>17v</td>
<td>NO₂</td>
<td>H</td>
<td>NO₂</td>
<td>H</td>
<td>1-naphthyl</td>
</tr>
<tr>
<td>17k</td>
<td>OMe</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>4-MeOC₆H₄</td>
<td>17w</td>
<td>H</td>
<td>H</td>
<td>4-FC₆H₄</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17l</td>
<td>OMe</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>4-FC₆H₄</td>
<td>17x</td>
<td>H</td>
<td>H</td>
<td>4-FC₆H₄</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. CHEMICAL REACTIONS

3.1. Reaction with sodium borohydride

Srikrishna and Dubey²⁸ studied the reduction of 3-(2-oxo-2H-chromen-3-yl)-1-phenyl-1H-pyrazole-4-carbaldehyde (3a) with sodium borohydride in tetrahydrofuran to result in the formation of 3-(4-(hydroxy-methyl)-1-phenyl-1H-pyrazol-3-yl)-2H-chromen-2-one (18) (Scheme 7).

![Scheme 7](image)

3.2. Reaction with amines

In 1999, Bratenko and others synthesized a series of 3-aryl-(heteroaryl)pyrazoles containing azomethine fragments in position 4, bearing carboxyl, hydroxyl and ethoxycarbonyl groups in N-aryl substituents. Thus, 1-phenyl-3-(2-oxo-2H-chromen-3-yl)pyrazol-4-ylideneaminobenzoic acids and their esters (19a-f) were formed by condensation of aniline derivatives with aldehyde 3a in toluene (Scheme 8).⁶⁹
Preparation of the pyrazolyl-coumarinyl-methylphosphonic acid 22 was achieved by Bratenko in 1990. The synthesis of aldimine 20 was performed by heating aldehyde 3a with benzylamine in boiling benzene in the presence of acetic acid. Addition of diethyl phosphite to azomethine 20, was carried out in toluene to form diethyl [(benzylamino)(3-(2-oxo-2H-chromen-3-yl)-1-phenyl-1H-pyrazol-4-yl)methyl]-phosphonate (21) in high yield. The acid hydrolysis of the latter ester with hydrochloric acid afforded the corresponding α-amino phosphonic acid 22 (Scheme 9).70

Treatment of the aldehydes 3a,c,k with hydroxylamine hydrochloride in the presence of anhydrous sodium
acetate under reflux for one hour gave the corresponding oximes 23. The dehydration of the latter oximes gave the corresponding nitrile products 24a-c (Scheme 10).  

![Scheme 10](image)

**Scheme 10**

### 3.3. Reaction with hydrazines

The target products 3-{-4-[(2-arylhydrazinylidene)methyl]-1-phenyl-1H-pyrazol-3-yl]-2H-chromen-2-ones (25a-e) were obtained in 82-87% yields under effect of microwave at 80 °C by treatment of the aldehyde 3a with substituted phenylhydrazine (Scheme 11).

![Scheme 11](image)

**Scheme 11**

Whitt *et al.* designed 4-[3-(2-oxo-2H-chromen-3-yl)-4-((2-arylhydrazono)methyl)-1H-pyrazol-1-yl]-
benzoic acids (26). In this, different hydrazines underwent reaction with aldehydes 3o,v by conventional method in ethanol using a catalytic acetic acid to afford the corresponding hydrazones 26 in 68-88% yields (Scheme 12).

Several synthetic protocols were reported to construct the hydrazone functionalization of coumarinyl-pyrazole scaffold. Condensation of a variety of acyl hydrazines with 3-(2-oxo-2H-chromen-3-yl)-1-phenyl-1H-pyrazole-4-carbaldehyde (3a) in the presence of amount of glacial acetic acid under reflux furnished the corresponding hydrazones 27a-j in good to excellent yields (Scheme 13).

In 2012, Zaki et al. reported that the aldehyde 3x condensed with thiosemicarbazide in acetic acid affording the corresponding thiosemicarbazone (28) (Scheme 14).
3.4. Reaction with active methyl and methylene compounds

4-Formyl-3-(2-oxo-2H-chromen-3-yl)-1-phenyl-1H-pyrazole (3a) condensed with malonic acid in pyridine under conventional heating or microwave irradiation to afford 3-[3-(2-oxo-2H-chromen-3-yl)-1-phenylpyrazol-4-yl]propenoic acid (29). In the presence of raney nickel, the latter acid 29 was reduced with hydrazine hydrate to furnish 3-[3-(2-oxo-2H-chromen-3-yl)-1-phenylpyrazol-4-yl]propanoic acid (30) in high yield (Scheme 15).

![Scheme 15](image)

An efficient, eco-friendly glycine catalyzed Knoevenagel condensation route for the synthesis of coumarinyl arylidenes was demonstrated by Chaudhry et al. Malonic acid and cyanoacetic acid were used as acyclic active methylene compounds to react with the aldehyde 3a to yield the corresponding arylidene derivatives 31a,b. These valuable green reactions resulted in excellent yields of the target compounds in DMSO solvent at room temperature by using glycine as a catalyst (Scheme 16).

![Scheme 16](image)

In addition, the aldehyde 3f underwent reaction with other active methylene compounds. Thus, the aldehyde
3f was treated with malononitrile, 2-(1-phenylethylidene)malononitrile and 2-(3,5,5-trimethylcyclohex-2-en-1-ylidene)malononitrile in ethanol and piperidine to give the corresponding arylidenes 32a-c (Scheme 17).\textsuperscript{54}

![Scheme 17](attachment:image1.png)

Claisen-Schmidt condensation reaction of 3-(6-substituted-2-oxo-2H-chromen-3-yl)-1-(4-substituted phenyl)-1H-pyrazole-4-carbaldehydes (3a,c,m,n,o,p,q,r) with 5,6-dimethoxy-2,3-dihydro-1H-inden-1-one in methanolic sodium methoxide led to the formation of corresponding 6-substituted-3-{1-(4-substituted phenyl)-4-[(5,6-dimethoxy-1-oxo-1H-inden-2(3H)-ylidene)methyl]-1H-pyrazol-3-yl}-2H-chromen-2-ones (33a-l) (Scheme 18).\textsuperscript{26}

![Scheme 18](attachment:image2.png)
3.5. Construction of heterocycles containing coumarin-pyrazole moiety

3.5.1. Five-membered heterocycles containing coumarin-pyrazole moiety

3.5.1.1. Formation of oxazoles

The 2-alkyl(aryl)oxazolone heterocycles affixed coumarin-pyrazole moiety \(34a-f\) were reported by Patel et al.\(^{30}\) The reaction of aldehydes \(3a,c,j\) with \(N\)-acetyl or \(N\)-benzoylglycine in acetic anhydride and sodium acetate afforded the desired azalactone products, namely 2-alkyl/aryl-4-[(3-(2-oxo-2H-chromen-3-yl)-1-phenyl-1H-pyrazol-4-yl)methylene]oxazol-5(4H)-ones \((34a-f)\) in 55-62% yields (Scheme 19).

\[
\begin{align*}
\text{R}^1 & \text{N}-\text{Ph} & \text{CHO} & \text{O} & \text{N} & \text{R}^2 \\
3a,c,j & & & & & \\
\text{Ac}_2\text{O} & \text{NaOAc} & & & & \\
34a-f (55-62\%) & & & & & \\
34a, R=H, R^1=H, R^2=Me & 34d, R=H, R^1=Br, R^2=Ph \\
34b, R=H, R^1=H, R^2=Ph & 34e, R=Br, R^1=Br, R^2=Me \\
34c, R=H, R^1=Br, R^2=Me & 34f, R=Br, R^1=Br, R^2=Ph \\
\end{align*}
\]

Scheme 19

3.5.1.2. Formation of thiazoles

Thacker and co-workers reported a series of coumarin-linked to thiazolidinone \(35a-n\) through pyrazole linker.\(^{42}\) The aldehyde \(3a\) reacted with various anilines and thioglycollic acid in the presence of silica gel (100–200 mesh) and dichloromethane as a solvent to afford the 1-phenyl-3-(2-oxo-2H-chromen-3-yl)-4-thiazolidinonylpyrazoles \((35a-n)\) (Scheme 20).

\[
\begin{align*}
\text{OHC} & \text{N}-\text{Ph} & \text{R} & \text{H}_2\text{N} & \text{H}_2\text{C} & \text{S} & \text{O} & \text{acid} \\
3a & & & & & & & \\
\text{silica gel (100–200 mesh)} & \text{DCM, rt 3–12 h} & & & & & & \\
& & & & & & & \\
35a-n (42-64\%) & & & & & & & \\
35a, R=H & 35h, R=4-HO \\
35b, R=4-Me & 35i, R=3-Me \\
35c, R=4-Br & 35j, R=4-Cl \\
35d, R=3-Br & 35k, R=4-\text{Pr} \\
35e, R=4-\text{Cl} & 35l, R=3-\text{CF}_3 \\
35f, R=3-\text{Cl} & 35m R=3,4-(\text{MeO})_2 \\
35g, R=4-\text{MeO} & 35n, R=3,4,5-(\text{MeO})_3 \\
\end{align*}
\]

Scheme 20
One-pot three-component synthesis of new coumarin-pyrazole affixed substituted thiazole, namely \( 3-\{1-\text{phenyl}-4-[(2-(4-\text{arylthiazol-2-yl})hydrazono)ethyl]-1H-pyrazol-3-yl\}-2H-chromen-2-ones \) (36a-l) was done by Gondru et al.\textsuperscript{77} Three-component reactions of the aldehyde 3a, thiosemicarbazide and 1-aryl-2-bromoethan-1-ones under reflux in ethanol using a catalytic acetic acid furnished the final products 36 in good to excellent yields (Scheme 21).

![Scheme 21](image)

One-pot multicomponent reaction of the substituted aldehydes 3a,b,c,g, thiosemicarbazide and dialkyl acetylenedicarboxylates in ethanol under reflux for 2-3 h gave the corresponding coumarinyl-pyrazolyl-thiazolidinones 37a-h with good to excellent yields (Scheme 22).\textsuperscript{43}

![Scheme 22](image)
Zaki et al.\textsuperscript{26} have reported synthesis of the thiazolyl-pyrazoles 38 and 39\textsubscript{a,b} derivatives containing a coumarin ring as shown in Scheme 23. Refluxing of the thiosemicarbazone 28 with ethyl chloroacetate or different α-bromoketones in the presence of ethanolic sodium acetate, led to the desired thiazoles 38 and 39\textsubscript{a,b}, respectively, with 56-68\% yields.

![Scheme 23]

In the same way, reaction of 1-(benzothiazol-2-yl)-3-(2-oxo-2\textsubscript{H}-chromen-3-yl)-1\textsubscript{H}-pyrazole-4-carbaldehyde (8\textsubscript{a}) with thiosemicarbazide and various α-bromoketones by refluxing in ethanol in the presence of a catalytic amount of glacial acetic acid led to formation of 3-\{1-(benzothiazol-2-yl)-4-[(2-arylthiazol-2-yl)hydrazono]methyl]-1\textsubscript{H}-pyrazol-3-yl\}-2\textsubscript{H}-chromen-2-ones (40\textsubscript{a}-l) (Scheme 24).\textsuperscript{57}

One-pot three-components reaction of 3,4-dihydropyrimidine-2(1\textsubscript{H})-thiones (41), chloroacetic acid and 3-(2-oxo-2\textsubscript{H}-chromen-3-yl)-1-aryl-1\textsubscript{H}-pyrazole-4-carbaldehydes (3\textsubscript{a,m}) in acetic acid and in the presence of acetic anhydride and anhydrous sodium acetate afforded 10-\{3-(2-oxo-2\textsubscript{H}-chromen-3-yl)-1-aryl-1\textsubscript{H}-pyrazol-4-yl)methylene\}-7-aryl-5,7-dihydro-6\textsubscript{H}-benzo[h]thiazolo[2,3-b]quinazolin-9(10\textsubscript{H})-one derivatives 42 (Scheme 25).\textsuperscript{78}
Scheme 24

8a

EtOH, AcOH

\[ \text{Scheme 24 (75-91\%)} \]

40a-l

\[ 40a, R=\text{Ph}, \quad 40b, R=\text{4-MeC}_6H_4, \quad 40c, R=\text{4-MeOC}_6H_4, \quad 40d, R=\text{4-PhC}_6H_4, \]

\[ 40e, R=\text{4-FC}_6H_4, \quad 40f, R=\text{4-ClC}_6H_4, \quad 40g, R=\text{4-BrC}_6H_4, \quad 40h, R=\text{4-NO}_2C_6H_4, \]

\[ 40i, \text{R=coumarin-3-yl}, \quad 40j, R=\text{5,6-C}_6H_4-coumarin-3-yl, \]

\[ 40k, R=\text{8-Br-coumarin-3-yl}, \quad 40l, R=\text{6,8-Br-coumarin-3-yl} \]

Scheme 25

AcOH

NaOAc, Ac_2O

\[ \text{Scheme 25 (79-92\%)} \]

R=H, NO_2, \quad R'=H, \text{MeO} \]

Ar=Ph, 1-naphthyl, 4-ClC_6H_4, 4-MeOC_6H_4, 3,4-(MeO)_2C_6H_4, 2,3,4-(MeO)_3C_6H_2, 3-HO-4-MeOC_6H_4, 4-FC_6H_4, 4-BrC_6H_4, 4-HOC_6H_4, 3-MeO-4-HOC_6H_3, 3-EtO-4-HOC_6H_3, 2-ClC_6H_4
3.5.1.3. Formation of pyrazoles

Chaudhry et al.\textsuperscript{79} suggested potassium carbonate as green catalyst for the synthesis of 5-alkyl/aryl-4-\{[3-(2-oxo-2H-chromen-3-yl)-1-phenyl-1H-pyrazol-4-yl]methylene\}-2-aryl-2,4-dihydro-3H-pyrazol-3-one (44) by reaction of the aldehydes 3a,b with 2-aryl-5-substituted-2,4-dihydro-3H-pyrazol-3-one (43) in ethanol as shown in Scheme 26.

\begin{scheme}
\centering
\includegraphics[width=\textwidth]{scheme26}
\caption{Scheme 26}
\end{scheme}

The aldehyde 3a was treated with different acetophenone derivatives in ethanol and in the presence of piperidine to afford the corresponding chalcones 45. These chalcones were ready cyclized by reaction with 4-substituted phenylhydrazines in the presence of ethanol and glacial acetic acid affording the coumarinyl-bis-pyrazole derivatives 46 (Scheme 27).\textsuperscript{80}

\begin{scheme}
\centering
\includegraphics[width=\textwidth]{scheme27}
\caption{Scheme 27}
\end{scheme}
3.5.1.4. Formation of imidazoles

Treatment of the aldehydes 3a,c with a mixture of benzil, ammonium acetate and different amines led to construct structurally diversified 3-(2-oxo-2H-chromen-3-yl)-4-imidazolopyrazoles 47. This cyclization reaction was successfully carried out with catalytic amount of p-toluenesulfonic acid (PTSA) by refluxing in ethanol for 2 h (Scheme 28).81,82

One-pot synthetic methodology was performed by Kumbar and co-workers83 to synthesize 3-(4-(1H-benzo[d]imidazol-2-yl)-1-phenyl-1H-pyrazol-3-yl)-2H-chromen-2-one and 3-[4-(3H-imidazo[4,5-b]pyridin-2-yl)-1-phenyl-1H-pyrazol-3-yl]-2H-chromen-2-one derivatives 49. In this protocol, the conventional heating and microwave irradiation assisted reaction of the aldehydes 3a,b with substituted aryl-1,2-diamine compounds 48 to afford the desired products 49 in excellent yields 80-94% (Scheme 29).

Srikrishna et al.84 disclosed the different strategies to synthesize biologically active coumarin-pyrazole affixed benzimidazole scaffold. In this protocol, the aldehyde 3a was reduced by sodium borohydride,
followed by refluxing with thionyl chloride in benzene to afford 3-[4-(chloromethyl)-1-phenyl-1H-pyrazol-3-yl]-2H-chromen-2-one (50). Then, on the reaction of compound 50 with O-ethyl carbonodithioate (51) provided the intermediate 52, which on refluxing with the substituted 1,2-phenylenediamine furnished the desired 3-[4-[(1H-benzo[d]imidazol-2-ylthio)methyl]-1-phenyl-1H-pyrazol-3-yl]-2H-chromen-2-ones (53) (Scheme 30).

**Scheme 30**

### 3.5.1.5. Formation of oxadiazoles

3-{4-[3-Acetyl-5-(pyridin-4-yl)-2,3-dihydro-1,3,4-oxadiazol-2-yl]-1-phenyl-1H-pyrazol-3-yl]-2-oxo-2H-chromene (54) was synthesized in good yield by an intramolecular oxidative cyclization of the hydrazone 27c in acetic anhydride (Scheme 31).}

**Scheme 31**
3.5.1.6. Formation of tetrazoles

1,3-Dipolar cyclization of 3-(6-substituted-2-oxo-2H-chromen-3-yl)-1-aryl-1H-pyrazole-4-carbonitriles (24a-c) with sodium azide in the presence of triethylamine in toluene gave 3-[1-aryl-4-(1H-tetrazol-5-yl)-1H-pyrazol-3-yl]-2H-chromen-2-ones (55a-c) in 70-85% yields (Scheme 32).\(^{21}\)

![Scheme 32](image)

3.5.2. Six-membered heterocycles containing coumarin-pyrazole moiety

3.5.2.1. Formation of pyridines

Zaki et al.\(^{26}\) developed a route for synthesis of 2-amino-6-mercaptop-4-[3-(2-oxo-2H-aryl[h]chromen-3-yl)-1-phenyl-1H-pyrazol-4-yl]pyridine-3,5-dicarbonitrile (56) in good yield by reaction of 3-(3-oxo-3H-benzo[f]chromen-2-yl)-1-phenyl-1H-pyrazole-4-carbaldehyde (3x) with cyanothioacetamide in ethanol containing a catalytic amount of piperidine under reflux (Scheme 33).

![Scheme 33](image)

Patel et al. in 2008, reported Hantzsch reaction for the synthesis of 3-[1-phenyl-4-(2,6-dimethyl-3,5-disubstituted-1,4-dihydropyridin-4-yl)-pyrazol-3-yl]coumarins (57). When a mixture of the aldehydes 3a,c,g,j, 1,3-dicarbonyl compound and ammonium acetate, was heated under reflux in acetic acid, the target products 57 were obtained in 53-62% yields (Scheme 34).\(^{30}\)
It was also found that condensation of the aldehyde 3a with 3-acetyl-4-hydroxyquinolin-2-(1H)-one (58) in ethanol and piperidine gave the corresponding chalcone system 4-hydroxy-1-methyl-3-[4-(2-oxo-2H-chromen-3-yl)prop-2-enoyl]-1-phenyl-1H-pyrazol-4-yl)quinolin-2(1H)-one (59) (Scheme 35).

### Scheme 34

### Scheme 35

#### 3.5.2.2. Formation of pyrimidines

One-pot, three-components reaction of the aldehydes 3a,c, 1,3-dicarbonyl compound and urea in methanol under reflux according to Biginelli reaction conditions furnished 3-[1-phenyl-4-(6-methyl-5-substituted-2-oxo-1,2,3,4-tetrahydropyrimidin-4-yl)pyrazol-3-yl]-2-oxo-2H-chromenes (60) (Scheme 36).
Microwave-assisted condensation route for the preparation of 5-[[3-(2-oxo-2H-chromen-3-y1)-1-phenyl-1H-pyrazol-4-y1]methylene]pyrimidine-2,4,6(1H,3H,5H)-triones (61) and 5-[[3-(2-oxo-2H-chromen-3-y1)-1-phenyl-1H-pyrazol-4-y1]methylene]-2-thioxodihydropyrimidine-4,6-(1H,5H)-diones (62), was achieved by Vijaya Laxmi and co-workers. Thus, reaction of the aldehydes 3a,b,c,w with barbituric acid and thiobarbituric acid in acetic acid under microwave irradiation produced the corresponding products 61 and 62, respectively, in good to excellent yields (Scheme 37).

![Scheme 37](image)

4. THE APPLICATIONS

The laser efficiency and spectra related to the aldehyde 3l was studied, and compared with a common coumarin laser dye, C₅₁₅, in several solvents. The aldehyde 3l decomposed fast in chloroform. Further, the integrated intensity was very low in dichloromethane and DMF as compared to standard. The range covered was also to shorter wavelength side where many other standard dyes are available.
3-(2-Oxo-2H-benzo[g]chromen-3-yl)-1-phenyl-1H-pyrazole-4-carbaldehyde (3w) has little absorption-emission characteristics and whitening/dyeing properties on polyester.\(^{51}\)

![3w](image)

3-(8-Methoxy-2-oxo-2H-chromen-3-yl)-1-[4-(4-methoxyphenyl)thiazol-2-yl]-1H-pyrazole-4-carbaldehyde (5m) has shown significant antiproliferative activity against different human cancer cell lines such as cervical cancer (HeLa), breast cancer (MCF7), and adenocarcinoma (A549) cell lines by using Nocodazole as a positive control.\(^{41}\)

![5m](image)

The 1-(1,8-naphthyridin-2-yl)-3-(2-oxo-2H-chromen-3-yl)-1H-pyrazole-4-carbaldehydes (17a-x) showed acceptable antibacterial activities against *Bacillus subtilis* and *Escherichia coli*. However, the derivatives 17k and 17w displayed the high effects.\(^{60-63,66}\)

![17a-x](image)

1-Phenyl-3-(2-oxo-2H-chromen-3-yl)-pyrazol-4-ylideneaminobenzoic acids and their esters 19c,d have moderate bactericidal properties.\(^{60}\)
Jain et al.\textsuperscript{37} described an unprecedented 3-\{4-[(2,4-dinitrophenyl)hydrazonomethyl]-1-phenyl-1H-pyrazol-3-yl\}-chromen-2-one (25e) as colorimetric receptor R1 which can help with the semi-quantitative detection of inorganic fluoride in actual samples without being interfered with by other anions.

Some of the coumarinyl-pyrazole-hydrazones 26 were tested against several bacterial strains. Several molecules showed promising results with MIC values as low as 1.56 $\mu$g/mL. It was found that fluoro-substituted compounds are most potent than the hydroxy-substituted compounds.\textsuperscript{45}

The coumarinyl-pyrazole-hydrazone 27a-j exhibited weak bacteriostatic effects. The maximum activity among these compounds, was observed for $N$-acylhydrazone containing the isonicotinoyl fragment 27c.\textsuperscript{31}
Also, 2-chlorobenzyl \(2-[(3-(2-oxo-2H-chromen-3-yl)-1-phenyl-1H-pyrazol-4-yl)methylene]hydrazine-1-carboxylate\) (27b) showed a high docking score \textit{in silico} studies exhibiting good antibacterial properties against \textit{S. aureus}.\textsuperscript{73}

6-Substituted-3-{1-(4-substituted)-4-[(5,6-dimethoxy-1-oxo-1H-inden-2(3H)-ylidene)methyl]-1H-pyrazol-3-yl]-2H-chromen-2-ones (33a-l) were screened for their antioxidant activity. It was discovered that the presence of compounds with halogen substituents and electron-withdrawing groups as 33b,e,f,k,l demonstrated strong antioxidant properties. Compounds 33c,d (\(R^1=\text{Me}\) and 4-MeO) had strong antidiabetic action when was screened to antihyperglycemic activity.\textsuperscript{76}
The products 35a-n were subjected for evaluation against the four physiologically and pharmacologically relevant human carbonic anhydrases (hCA) isoforms. All the compounds showed selective inhibition for hCA. 2-[3-(2-Oxo-2H-chromen-3-yl)-1-phenyl-1H-pyrazol-4-yl)-3-(m-tolyl)thiazolidin-4-one (35i) recorded the best inhibition of hCA.²²

Gondru et al.²² synthesized a series of coumarin compounds linked to pyrazole and thiazole 36a-l which were evaluated for their in vitro antimicrobial and antioxidant activities. The derivatives which have phenyl (36a), benzo[f]coumarin-3-yl (36h) or 7-Br-coumarin-3-yl (36k) demonstrated a broad range of antibacterial properties. The derivatives attached to 4-MeC₆H₄ (36b) and 4-NO₂C₆H₄ (36g) were found to be effective antifungal compounds.

Zaki et al.²⁶ reported that the thiazolyl-pyrazole 39a showed good activity against some strains of bacteria and fungi while the thiazolinone compound 38 exhibited a remarkable activity especially against Pseudomonas aeruginosa.
A series of coumarin-pyrazolyl-thiazole frameworks 40a-l were evaluated for their antibacterial activities. Compounds 40b,g,k,l exhibited promising inhibitory activities against the tested bacterial strains with minimum inhibitory concentration (MIC)/minimum bactericidal concentration (MBC) spectrum of 1.9/7.8 μg/mL to 3.9/7.8 μg/mL. The derivatives of 7-aryl-10-((3-(2-oxo-2H-chromen-3-yl)-1-phenyl-1H-pyrazol-4-yl)methylene)-7,10-dihydro-5H-benzo[h]thiazolo[2,3-b]quinazolin-9(6H)-one derivatives 42 were investigated for their in vitro antiproliferative and antibacterial activities. The derivatives which have Ar=4-ClC₆H₄, and Ar=3-MeO-4-HOC₆H₃, displayed better antiproliferative activity against HepG2 (hepatocellular carcinoma) cell line. Also, some of these compounds showed broad and excellent antibacterial efficacy comparable to that of the standards.

The derivatives of 5-alkyl/aryl-4-[(3-(2-oxo-2H-chromen-3-yl)-1-phenyl-1H-pyrazol-4-yl)methylene]-2-aryl-2,4-dihydro-3H-pyrazol-3-one (44) were evaluated against the α-glucosidase enzyme. The derivative
R^1=Br, R^2=NO_2, R^3=Me showed excellent results of IC_{50} in comparison to clinical drug acarbose.\textsuperscript{79}

The coumarinyl-bis-pyrazole derivatives 46 were evaluated for their \textit{in vitro} antibacterial, antitubercular and antimalarial activities. The biological screens of 46 provided real insight into how to modify the basic nucleus and substitution patterns to increase effectiveness. The fluorine and chlorine derivatives played very important role to achieve significant change in antimicrobial and antitubercular activities while the nitro and bromo derivatives showed better antimalarial activity.\textsuperscript{80}

The coumarin-pyrazolyl-imidazoles 47 were evaluated for their \alpha-glucosidase inhibition potentials. All of the derivatives showed effects that ranged from good to exceptional and were on par with or even superior to those of the medication acarbose. The most effective one was the derivative R^1=Br, R^2=4-ClC_6H_4.\textsuperscript{81,82}
Hassan et al.\textsuperscript{44} studied the effects of some chalcones of coumarinyl-pyrazoles on the growth of a few types of plants such as hibiscus, mint, and basil. The results indicated that 4-hydroxy-1-methyl-3-\{3-[3-(2-oxo-2H-chromen-3-yl)-1-phenyl-1H-pyrazol-4-yl]acryloyl\}quinolin-2(1H)-one (59) has the ability to promote the growth of particular agricultural crop plants.

Compounds 61 (R=H, R\textsuperscript{1}=H, R\textsuperscript{2}=Br) and (R=Br, R\textsuperscript{1}=H, R\textsuperscript{2}=Br) exhibited high effects against \textit{Aspergillus niger}. Structure–activity relationship studies revealed that the presence of bromo at position 6 on the coumarin ring enhanced the activity.\textsuperscript{33}

CONCLUSION

The constantly increasing number of papers describing synthesis of heterocyclic compounds based on 3-(2-oxo-2H-chromen-3(6)(8)-yl)-1-aryl/heteroaryl-1H-pyrazole-4-carbaldehydes indicates their growing
importance as building blocks with high synthetic potential. The aim of this review is to demonstrate the widespread applications of 3-(2-oxo-2H-chromen-3(6)(8)-yl)-1-aryl/heteroaryl-1H-pyrazole-4-carbaldehydes in organic synthesis and the outlook for potential future developments. Due to their chemical reactivity and versatility, these aldehyde derivatives constitute valuable synthetic units giving rise to a number of useful classes of organic compounds.

ACKNOWLEDGMENT
The authors extend their appreciation to the Deanship of Scientific Research at King Khalid University for funding this work through large research groups program under grant number RGP.2/8/43.

REFERENCES
Ayat K. Alsolimani was born in 1990 in Makkah, Saudi Arabia. In 2013, she graduated BSc in Chemistry from Umm Al-Qura University in Mecca, Saudi Arabia. In 2018, she received her MSc degree in Chemistry from Howard University in Washington, D.C. USA. She is still working on her PhD thesis which includes the design and synthesis of some heterocyclic systems linked to coumarin ring as potent anticancer agents. Her research interests are design, characterization, and biological evaluations of novel bioactive heterocyclic systems.

Mohammed A. Assiri is presently associate professor at Department of Chemistry, Faculty of Science, King Khalid University, Abha, Saudi Arabia. He graduated with BSc (Chemistry) from Department of Chemistry, Faculty of Science, King Khalid University, Abha, Saudi Arabia in 2004. Also, he received his MSc and PhD degrees in 2014 and 2016, respectively, in organic and green Chemistry from University of Wyoming, Laramie, WY, USA. His research interests are in activities related to organic chemistry, green chemistry, and chemical engineering.

Tarik E. Ali was born in Cairo, Egypt, in 1975. He is presently full professor of Organic Chemistry, Department of Chemistry, Faculty of Education, Ain Shams University, Cairo, Egypt. Currently, he works at Department of Chemistry, Faculty of Science, King Khalid University, Abha, Saudi Arabia. He graduated with BSc (Physics and Chemistry) from Ain Shams University in 1997. He received his MSc and PhD degrees in 2001 and 2005, respectively, in Heterocyclic Chemistry from Ain Shams University. Awarded a post-doctoral scientific grant for supporting young researchers (2007) from the Ministry of Higher Education and Scientific Research (Egypt) in organophosphorus laboratory, Institute of Polymers, Bulgarian Academy of Science, Sofia, Bulgaria. His CV was mentioned in Who’s Who in the World in 2011, 2012, 2013, 2015, 2016, 2018 and 2020. He has published more than 110 scientific papers including 15 review articles, all in international journals. His research interests are in synthetic organic chemistry and phosphorus compounds containing bioactive heterocyclic systems.