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Cascade Reactions of Nitrones and Allenes for the Synthesis of Indole Derivatives

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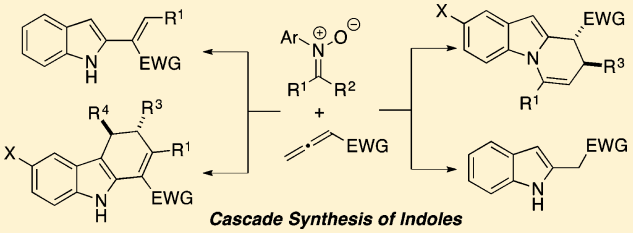
ABSTRACT: Cascade reactions involving nitrones and allenes are known to facilitate the rapid synthesis of several indole derivatives. The chemoselectivity of these complicated transformations can be influenced by substrate functionalization, reaction conditions, and catalyst control. While seminal studies established primary reactivity patterns, recent work has illustrated the impact of these cascade reactions for creating diverse libraries, increased the breadth of these methods with facilitated access to challenging nitrones, and shown that these transformations can be controlled by asymmetric catalysis.



Substituted indoles are important structural motifs in biologically active compounds and organic materials.[1−6] While many synthetic methods exist for the preparation of indoles (Scheme 1A), nitrones are unusual starting materials for these privileged heterocycles.[7−14] In contrast, nitrones are common reagents for dipolar cycloadditions used in the preparation of several other types of heterocyclic structures such as isoxazolines, isoxazolidines,[15−24] 1,2-oxazines,[25−28] β-lactams,[29−32] and pyrrolizidines (Scheme 1B).[33−35] The wide applicability of nitrones as 1,3-dipoles for heterocycle synthesis prompted testing their reactivity with electron-deficient allenes to form exomethylene isoxazolines such as **4** and **5** (Scheme 1C). Surprisingly, the products of these dipolar cycloadditions were shown to undergo a variety of rearrangement processes.[36−40] When *N*-alkylnitrones **1** were paired with allenes **3**, rearrangement occurred to the corresponding isoxazoline isomer **6**. When *N*-arylnitrones **2** were paired with allenes **3**, the initial dipolar cycloaddition product prompted a spontaneous rearrangement to provide access to indoles **7** and **8**. While these cascade processes for the synthesis of indoles **7** and **8** were discovered almost 40 years ago, they have remained underutilized and underexplored routes to these types of heterocyclic compounds. Recent advances have expanded the diversity and flexibility of these transformations for selectively accessing a variety of indole-based structures. Herein, we describe these recent advances and their potential impact on expanding synthetic access and providing new examples of these privileged heterocycles.

SYNTHESIS OF INDOLES FROM NITRONES AND ALLENES: SEMINAL STUDIES

Tufariello and co-workers first reported that when a mixture of nitrone **2** and allene **9** was heated, three different heterocyclic products could be isolated (Scheme 2).[36] While previous reports had shown that [3 + 2]-cycloadditions of **2** and **9** could provide exomethylene isoxazolines **10** or the corresponding 1,3-rearrangement products **11**, this was the first report of the formation of benzazepinone **12** through the dipolar cycloaddition of an *N*-arylnitrone and an allene.[41,42] The observation that isoxazolines **10** can rearrange to benzazepinones **12** provided the opportunity for the development of cascade reactions based on ring-opening strategies for **12**.

Blechert and co-workers pursued the novel rearrangement reactivity initially identified by Tufariello and reported that 2-vinylindole **16** could be prepared by mixing nitrone **13** and cyano allene **14** in EtOH and heating to 80 °C (Scheme 3A).[37] This transformation was proposed to occur via an initial dipolar cycloaddition to form isoxazoline **19**, followed by a formal [3,3]-rearrangement to form benzazepinone **21**, which could undergo a retro-Michael reaction to form aniline **22** and condense with the tethered ketone to form 2-vinylindole **16** (Scheme 3B). In their initial publication, Blechert and co-workers also observed that mixing nitrone **13** with allene **15** did not lead to the corresponding 2-vinylindole but gave benzazepinone **17** and indole **18** depending on the reaction conditions (Scheme 3A). The authors proposed that **17** and **18** are formed along a similar pathway to **16** but that steric interactions prevent the retro-Michael opening of **17**. In the presence of water, an alternative retro-Mannich opening of benzazepinone **17** can give enamino ketone **23**, which can undergo hydrolysis and condensation with the tethered ketone to form 2-substituted indole **18** (Scheme 3B). These initial studies established the viability of using nitrones as precursors to 2-vinylindoles such as **16** and 2-substituted indoles such as **18** through a common benzazepinone intermediate generated through the addition and rearrangement of a nitrone and an allene. In addition, the sensitivity of these reactions to the identity of the allene substituent was observed and the use of this substituent to control the chemoselectivity of the cascade reaction was established.

Further studies by Blechert and co-workers showed that the scope of the 2-vinylindole synthesis could be extended significantly by generating the nitrone in situ from the

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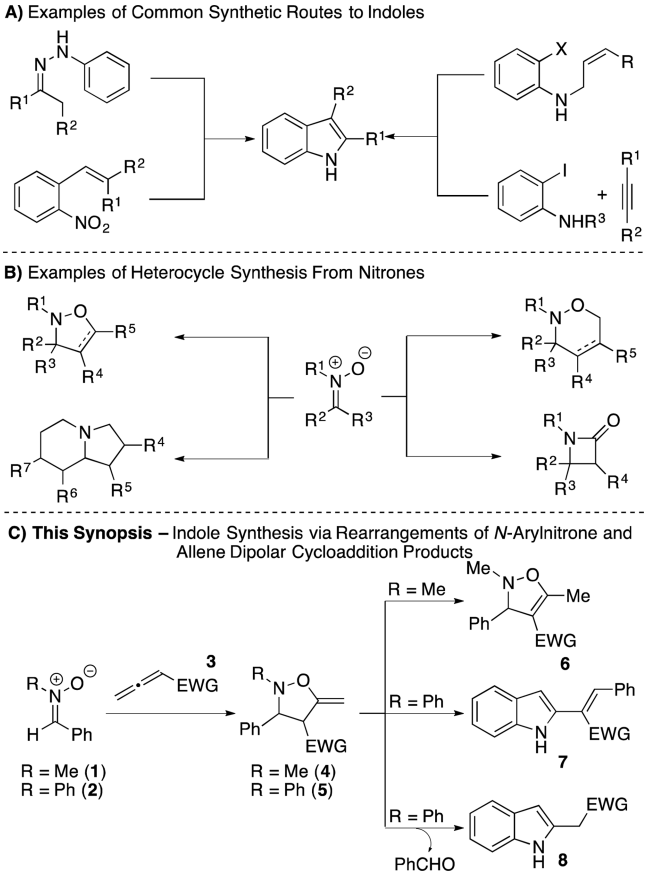
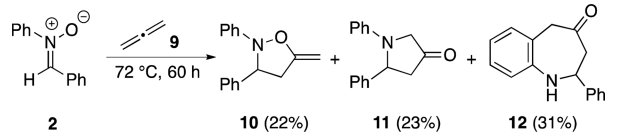
Scheme 1. Rearrangement of *N*-Arylnitrone Dipolar Cycloaddition Products for the Synthesis of Indoles



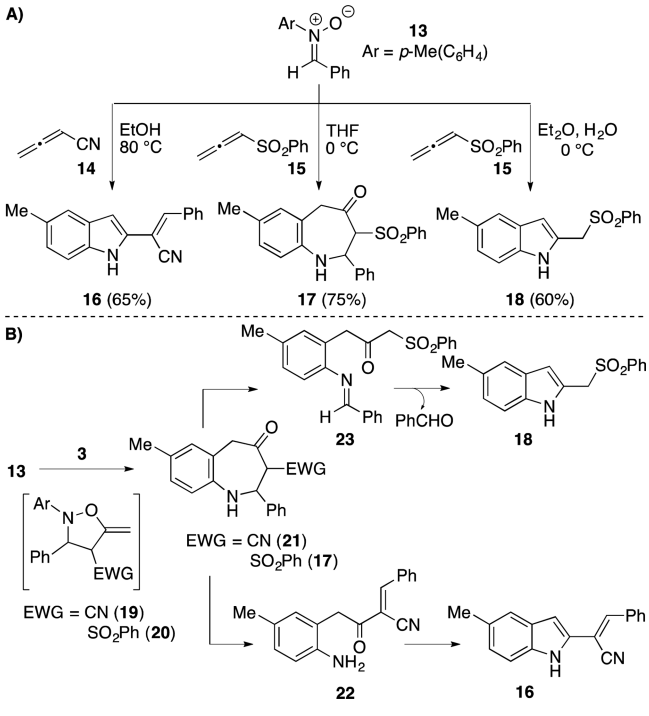
Scheme 2. Initial Observation of Multiple Products Resulting from [3 + 2]-Dipolar Cycloaddition of *N*-Phenylnitrone and Allene[36]



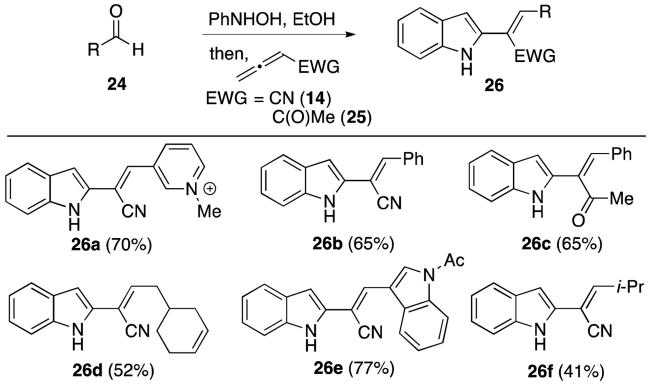
corresponding aldehyde and *N*-phenylhydroxylamine (Scheme 4).[38] A variety of substitution patterns were tolerated for this two-step, single-flask transformation. Further investigation of the scope of the allene reaction partner showed that allenoates behaved similarly to **15** and stalled at an analogous benazepinone intermediate, while ketone-substituted allenes such as **25** behaved similarly to **14** and formed **26c** in good yield.

In work related to Blechert's 2-vinylindole synthesis, Padwa and co-workers also investigated the cycloaddition reactivity of nitrones with allene dipolarophiles but concentrated their efforts on exploring the regioselectivity of the initial [3 + 2]-cycloaddition as well as the subsequent rearrangement reactivity and the dependence of these transformations on the identity of the allene (Scheme 5).[39,40] When nitrone **2** was treated with dimethylallene **27**, a mixture of isoxazoline **28** and benzazepinone **29** was isolated (Scheme 5A). Benzazepinone **29** was proposed to form due to a lack of regioselectivity for the dipolar cycloaddition and a subsequent rearrangement of the transient isoxazoline isomer **30**. Electronic differentiation of the terminal positions of allene **31** favored the formation of isoxazoline **32**, but

Scheme 3. Initial Synthesis of 2-Vinylindoles and 2-Substituted Indoles from *N*-Arylnitrones and Allenes[37]



Scheme 4. Examples of Single-Flask Conversion of Aldehydes and Allenes to 2-Vinylindoles[38]



competing formal [3,3]- and [1,3]-rearrangements gave a mixture of **33** and **34**, respectively (Scheme 5B). Treatment of *gem*-disubstituted allene **35** with nitrone **2** once again gave a mixture of dipolar cycloaddition products; however, isoxazoline **38** was observed to rearrange similarly to **17** to give indole **37** through a benzazepinone intermediate and retro-Mannich ring-opening (Scheme 5C). These results further emphasized the strong dependence of the outcome of these addition and rearrangement reactions on the substituents of the allene and their effect on the reactivity of the benzazepinone intermediate.

EFFECT OF NITRONE SUBSTITUENTS ON REACTION PATHWAY

In 1999, Ishar and co-workers tested the reactivity of benzopyranone nitrones **39** and **40** with allenoates such as **41** and **42** (Scheme 6).[43,44] They discovered that these substrates undergo a similar transformation to the 2-substituted indole synthesis described in Scheme 3; however, due to the *α,β*-

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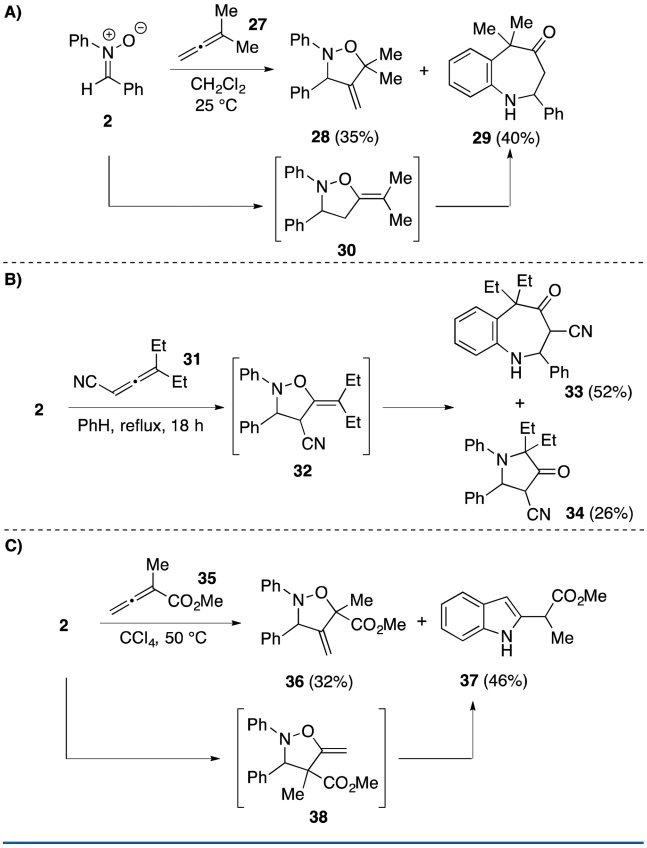
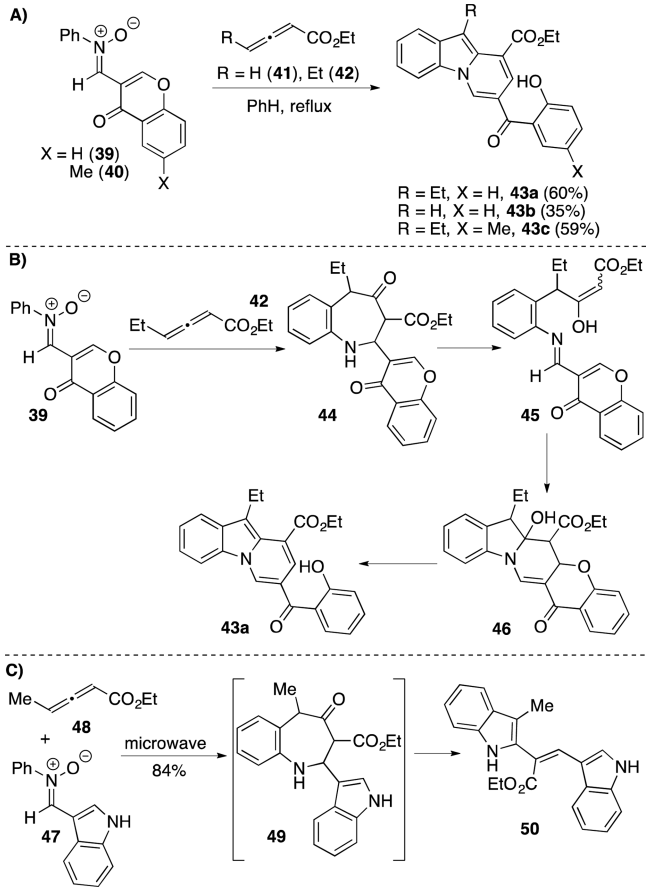
Scheme 5. Effect of Allene Dipolarophiles on Reactive Intermediate and Product Selectivity[39]



Scheme 6. Synthesis of Benzoindolizines by Treatment of Electron-Deficient Allenes with α,β-Unsaturated Nitrones[44]

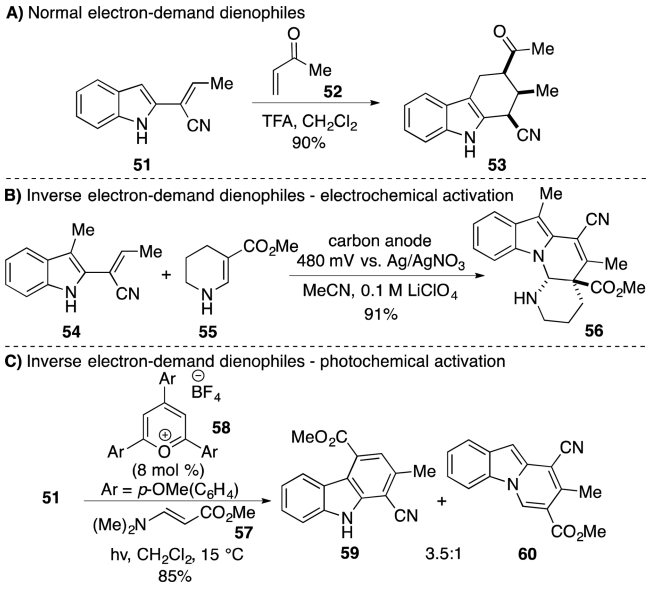


unsaturated functionality of **39**, retro-Mannich intermediate **45** is poised to be intercepted prior to hydrolysis with an intramolecular Diels–Alder reaction to give benzoindolizine **43a** (Scheme 6B). Increased yields were observed for substituted allenoates such as **42** in comparison to **41**. DFT calculations suggested that this improved reactivity was due to conformational effects that favored a closer interaction between the tethered diene and dienophile in **45** for substituted allenoates prior to cycloaddition.[44] Ishar also investigated the reactivity of indole-substituted nitrone **47** with allene **48** under microwave conditions (Scheme 6C).[45] This transformation followed a pathway proceeding through benzazepinone intermediate **49** with a retro-Michael opening and condensation to form indole-substituted vinylindole **50**. These studies further demonstrated the versatility of the addition and rearrangement, branched cascade reaction for forming a variety of different products based on the identity of the allene and nitrone substrates.

APPLICATIONS OF NITRONE AND ALLENE ADDITION AND REARRANGEMENT REACTIONS IN SYNTHESIS

Blechert and co-workers explored the use of 2-vinylindoles, generated from *N*-arylnitrone and allene addition and rearrangement cascade reactions, as dienes in [4 + 2]-cycloaddition reactions for the synthesis of carbazoles and pyridoindoles.[46−48] The following transformations were optimized: (1) acid-promoted conditions for the synthesis of tetrahydrocarbazoles **53** through cycloaddition reactions between 2-vinylindoles such as **51** and electron-deficient dienophiles such as **52** (Scheme 7A);[46] (2) electrolysis conditions for the synthesis of dihydropyridoindoles **56** via cycloaddition reactions between

Scheme 7. Diels–Alder Reactions of 2-Vinylindoles Formed via Nitrone and Allene Addition and Rearrangement Cascade Reactions[46−48]



2-vinylindoles such as **54** and electron-rich dipolarophiles such as **55** (Scheme 7B);[47,48] and (3) photoelectron-transfer conditions for the synthesis of mixtures of carbazoles **59** and pyridoindoles **60** from 2-vinylindoles such as **51** and electron-rich dipolar-

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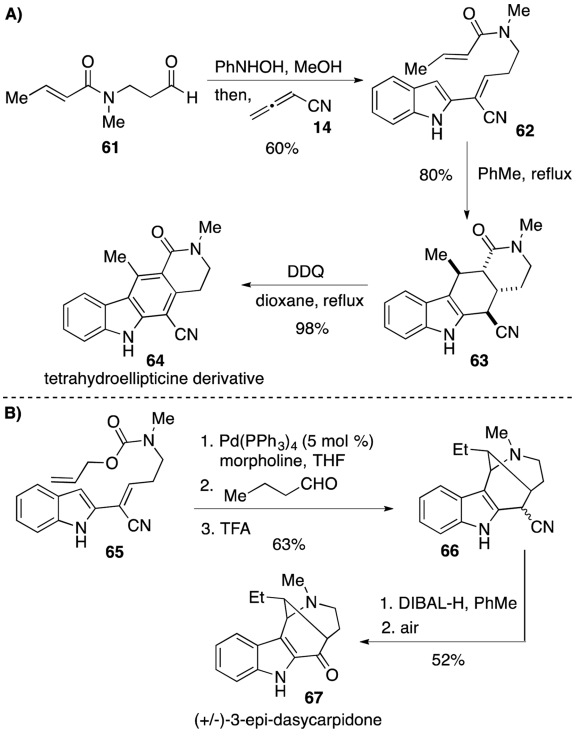
ophiles such as **57** in the presence of a photoelectron transfer catalyst, triarylpyrylium tetrafluoroborate **58** (Scheme 7C).[47,48] Blechert and co-workers further used Diels–Alder reactions with 2-vinylindoles to form compounds related to biologically active targets.[46] As shown in Scheme 8A, a cascade reaction between

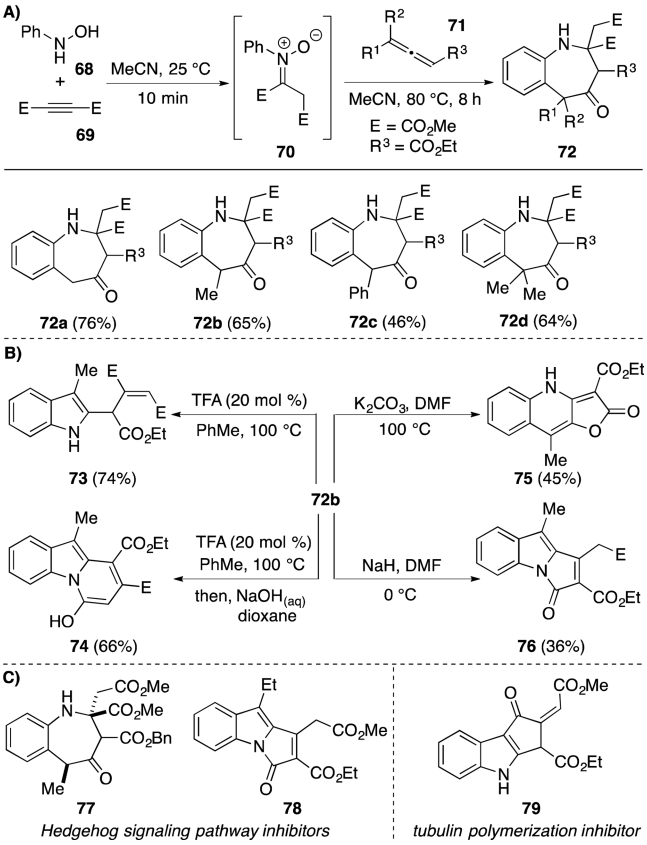
Scheme 8. Applications of Nitrone and Allene Addition and Rearrangement Cascade Reactions Towards the Synthesis of Biologically Active Molecules and Natural Products[47,48]



the *N*-phenylnitrone of **61** and allene **14** gave 2-vinylindole **62**, which was poised to undergo an intramolecular Diels–Alder reaction to give tetrahydrocarbazole **63**. Oxidation of **63** with DDQ then gave carbazole **64**, which is an ellipticine derivative. In addition, deprotection of carbamate **65** and condensation with butyraldehyde initiated an intramolecular 2-vinylindole Diels–Alder reaction with a tethered enamine to give bridged dihydrocarbazole **66**. Conversion of the cyano substituent to a carbonyl group completed the synthesis of the uleine alkaloid, (±)-3-epidasycarpidone **67** (Scheme 8B).

In 2015, Kumar and co-workers investigated the use of nitrone and allene addition and rearrangement reactions to form a new, structurally diverse, heterocyclic library.[49] A key feature of their plan was to access benzazepinone intermediates by the same dipolar cycloaddition and formal [3,3]-rearrangement sequences described above (see Schemes 3–6 for examples) and then to funnel these intermediates down different reaction pathways depending on the reaction conditions (Scheme 9). Nitrone **70** was generated by mixing hydroxylamine **68** with DMAD (**69**), and then treated with allenoates **71** to form a variety of benzazepinones **72** (Scheme 9A). With several benzazepinones in hand, the Kumar group then focused on looking at the reactivity of **72** and testing single-flask reactions to determine which types of benzazepinone rearrangements could be paired with the benzazepinone synthesis in a single-flask, two-step process (Scheme 9B). The Kumar group discovered four new transformations of **72** that they used for building substrate

Scheme 9. Diversity-Oriented Synthesis Using Addition and Rearrangement Cascade Reactions of Nitrones and Allenes[49]



diversity. When treated with substoichiometric quantities of TFA, **72b** was converted to 2-allylindole **73** through a proposed retro-Michael reaction. Indole **73** was then converted to benzoindolizine **74** by treatment with NaOH. Combining these two transformations led to the development of a two-step, single-flask process for the conversion of **72b** to **74**. In contrast, treatment of benzazepinone **72b** with K_2CO_3 gave lactone-fused quinolone **75** through a proposed retro-Michael opening of **72b** followed by addition to the electron-poor Michael acceptor and rearrangement by addition to the ester substituents. Through a related pathway, deprotonation of **72b** by NaH led to an alternative addition and elimination sequence to give indole **76**. The transformations leading to **73**, **75**, and **76** could be performed as two-step, single-flask transformations from a mixture of **68** and **69**. These two-step transformations gave higher overall yields than the independent two-step sequence. This synthetic plan demonstrated the versatility of **72** as an intermediate for the generation of a compound library consisting of 45 heterocycles similar in structure to **73**–**76**. The reactivity of these heterocyclic scaffolds was further investigated in the second phase of the project, and a total of 61 diverse library entries were prepared from **68**, **69**, and **71**. Quantification of the scaffold diversity in this library indicated that it covered both biologically relevant and novel chemical space. High-throughput screening allowed Kumar and co-workers to determine that **77** and **78** are inhibitors of hedgehog signaling pathways and that **79** is a tubulin polymerization inhibitor (Scheme 9C). These studies demonstrate the utility of these branched cascade reactions for forming diverse compound libraries with only simple changes in the structure of the allene reagents and the rearrangement reaction conditions.

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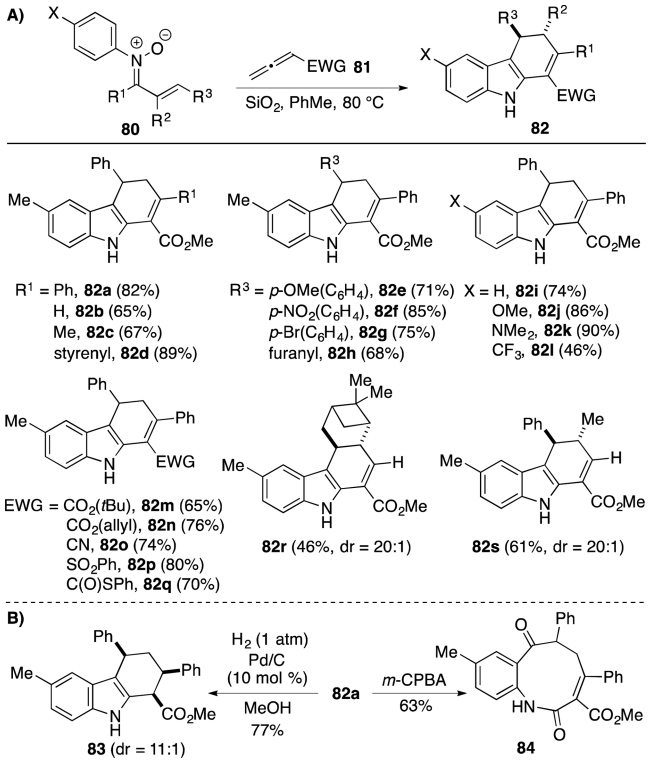
SOLVENT AND CATALYST CONTROL FOR CHEMOSELECTIVE AND ENANTIOSELECTIVE SYNTHESIS OF INDOLE DERIVATIVES

After our recent discovery of Chan−Lam conditions for the synthesis of *N*-aryl- and *N*-alkenylnitrones, we became interested in the reactivity of previously difficult to access examples of these compounds.[50,51] While screening the reactivity of *N*-arylnitrones derived from chalcones, we observed that when nitrones **80** are mixed with allenoates **81** in the presence of SiO_2 at 80 °C dihydrocarbazoles **82** are generated in good yields (Scheme 10).[52] These heterocyclic products had not previously been

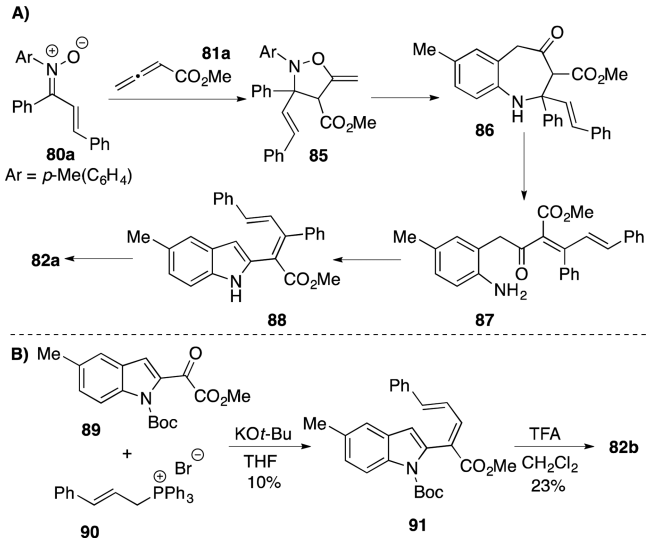
Scheme 10. *N*-Aryl-*α*,*β*-unsaturated Nitrone and Allene Addition and Rearrangement Reactions for the Synthesis of Dihydrocarbazoles[52]



reported for nitrone and allene cascade reactions and were a direct consequence of our ability to access these types of nitrones through a copper-mediated C−N bond coupling. The synthesis of dihydrocarbazoles **82** was shown to be general for a variety of *α*,*β*-unsaturated *N*-arylnitrones. Aryl, alkyl, and styrenyl substituents were tolerated at the R^1 position of **80** and gave **82a**, **82c**, and **82d**. An exchange of silica gel for Na_2SO_4 expanded the substrate scope further to include aldehyde-derived nitrones and the preparation of **82b**. Examples of nitrones with substituents at both the *α*- and *β*-positions were shown to form dihydrocarbazoles such as **82r** and **82s** with high diastereoselectivity. Allenes with different electron-withdrawing groups were shown to be equally effective reaction partners as allenoates and gave dihydrocarbazoles such as **82m−q**. To further enhance the structural complexity gained from the single-step conversion of nitrones **80** to dihydrocarbazoles **82**, reduction and oxidation conditions were tested for subsequent functionalization. As shown in Scheme 10B, hydrogenation of **82a** gave tetrahydrocarbazole **83** in good yield and high diastereoselectivity. Similarly, oxidation of **82a** in the presence of *m*-CPBA gave the ring-expanded product **84**. The variety of heterocyclic compounds illustrated in Scheme 10 illustrates the expanded scope of the addition and rearrangement cascade reaction made possible through access to a broader variety of *N*-arylnitrones and the sensitivity of the cascade process to the substitution patterns of both the allene and nitrone reagents.

While optimizing the synthesis of dihydrocarbazoles **82** from nitrones **80** and electron-deficient allenes **81**, benzazepinone **86** was observed as a reactive intermediate (Scheme 11A).[52] This

Scheme 11. Proposed Mechanism for Dihydrocarbazole Synthesis[52]



observation suggested that the synthesis of **82a** from **80a** and **81a** was proceeding through a pathway similar to that proposed for the synthesis of 2-vinylindole **16** by Blechert and co-workers (Scheme 3). A retro-Michael ring-opening of benzazepinone **86** could give aniline **87**, which could then condense to form 2-dienylindole **88** and cyclize to form **82a** (Scheme 11A). In contrast to the 2-vinylindole synthesis observed by Blechert and co-workers, dienylindole **88** is poised to undergo a subsequent cyclization to dihydrocarbazole **82a**. To test this hypothesis, dienylindole **91** was prepared independently by an olefination reaction and subjected to Boc deprotection conditions (Scheme 11B).[52] Dihydrocarbazole **82b** was isolated as predicted. This experiment supported the proposal of **88** as an intermediate in the cascade reaction for the formation of dihydrocarbazole **82a** as well as the proposed relationship between 2-vinylindole and dihydrocarbazole synthesis via nitrone and allene addition and rearrangement reactions.

While examining the proposed mechanism for the preparation of dihydrocarbazole **82**, we wondered if the same substrate combinations of nitrones and allenes could proceed down a similar but distinct reaction pathway when subjected to a change in reaction medium. As shown in Scheme 12, when the addition and rearrangement of nitrone **80a** and allene **81a** was tested in different solvents, formation of dihydrocarbazole **82a** was shown to compete with the formation of dihydropyridoindole **92a**.[52] The formation of **82a** was strongly favored in PhMe, while the formation of **92a** was strongly favored in EtOAc or *i*-PrOAc. Further optimization of the dihydropyridoindole synthesis showed that the use of 10 mol % thiourea **93** and 4 Å molecular sieves increased the yield, chemoselectivity, and diastereoselectivity of the preparation of **92a**. This change in favored product

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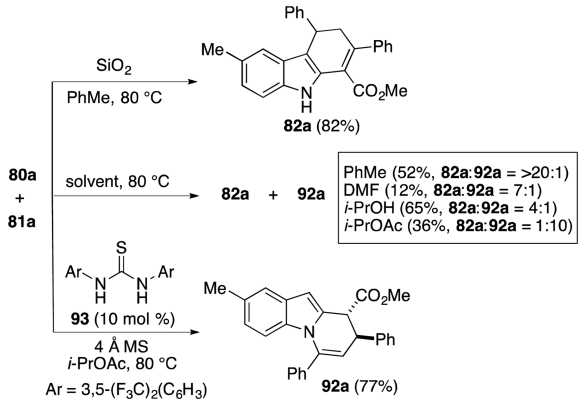
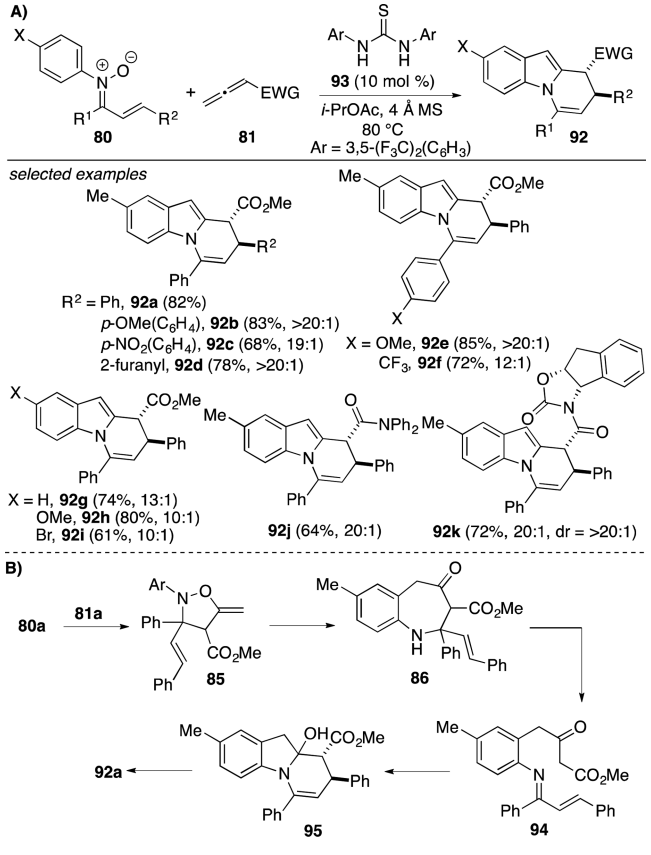
Scheme 12. Solvent-Controlled Bifurcated Cascade Pathway for the Synthesis of Either Dihydrocarbazoles or Dihydropyridoindoles[52]

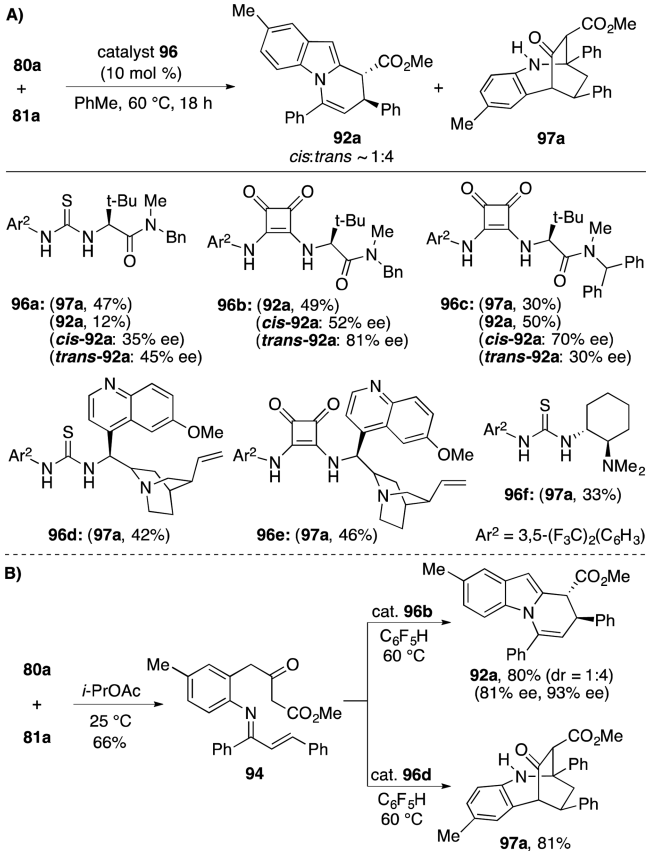


formation observed with the change in reaction conditions was shown to be general for the majority of substrates listed previously for the synthesis of dihydrocarbazoles in Scheme 10. The same substrate combinations were successfully directed along a unique reaction pathway toward the synthesis of dihydropyridoindoles **92** (Scheme 13A). These results suggested that nitrone and allene addition and rearrangement cascade pathways can bifurcate at benzazepinone intermediate **86**, based on the influence of reaction conditions, and favor either retro-Michael opening to form the dihydrocarbazole **82** or retro-Mannich opening to form the dihydropyridoindole **92** (Scheme 13B). While similar pathways had previously been observed for the selective synthesis of 2-vinylindoles and benzoindolizines, these processes were primarily substrate controlled. The sensitivity of the addition and rearrangement cascade to reaction conditions further demonstrated the synthetic versatility of these transformations.

Scheme 13. α,β-Unsaturated *N*-Arylnitrone and Allene Addition and Rearrangement Reactions for the Synthesis of Dihydropyridoindoles − Anderson and coworkers[52]



Scheme 14. Catalytic Asymmetric Synthesis of Dihydropyridoindoles[53]



While studying the synthesis of dihydropyridoindoles **92** from nitrones **80** and allenoates **81** in the presence of thiourea catalyst **93**, we observed that this reaction is diastereoselective for allenes with chiral nonracemic substituents. This prompted us to consider if this transformation could be rendered enantioselective with a chiral thiourea catalyst. As shown in Scheme 14A, several chiral, nonracemic thioureas and squaramides were tested as catalysts for the addition and rearrangement cascade reaction of **80** and **81** with the goal of achieving an asymmetric synthesis of dihydropyridoindoles **92**.[53] Two distinct trends were observed: (1) squaramide **96b** was shown to be the optimal catalyst for the asymmetric synthesis of **92a**, and (2) thioureas and squaramides with nucleophilic tethers such as **96d−f** strongly favored the formation of a new bicyclic product **97a**. These results indicated that these types of cascade reactions have a broad scope of potential pathways and corresponding products that can be controlled by catalyst selection. Preliminary mechanistic experiments suggested that the role of the catalyst is to control and facilitate the conversion of **94** to **92a** since **94** forms spontaneously upon mixing **80a** and **81a** (Scheme 14B). As shown in Scheme 15A, the asymmetric synthesis of **92** was shown to be general, but the diastereoselectivity of this process was low in comparison to the corresponding racemic synthesis

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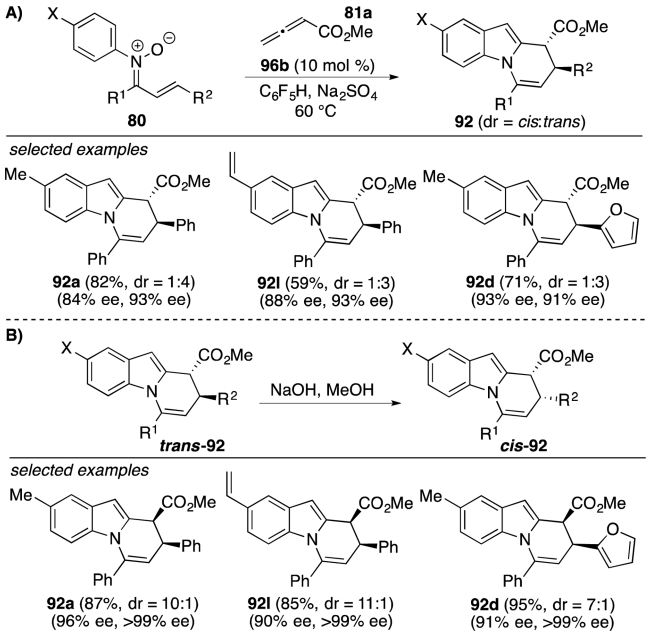
Scheme 15. Scope of Catalytic Asymmetric Synthesis of Dihydropyridoindoles and Epimerization To Improve Diastereoselectivity[53]

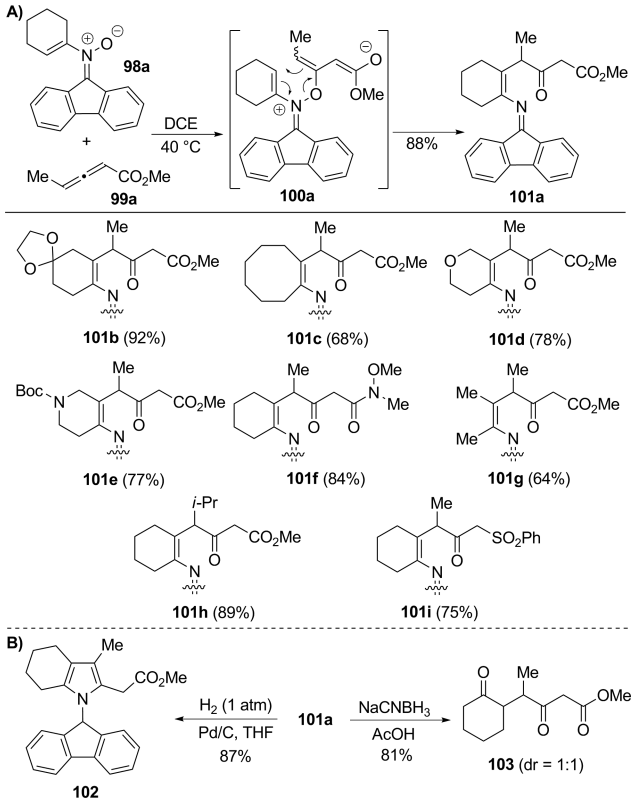


shown in Scheme 13A. To address this limitation, we designed an epimerization reaction to access the corresponding *cis*-**92** in good yield, high diastereoselectivity, and excellent enantioselectivity (Scheme 15B).[53] These results showed that cascade reactions of nitrones and allenes can be rendered chemo- and enantioselective with the appropriate catalyst selection.

EXTENSION OF NITRONE AND ALLENE ADDITION AND REARRANGEMENT CASCADE REACTIONS TO *N*-ALKENYL NITRONES

Using Chan–Lam conditions for the preparation of *N*-alkenylnitrones such as **98a**, we were able to extend our studies of nitrone and allene addition and rearrangement cascade reactions to this new class of substrates. When **98a** was treated with allenoate **99a**, an addition and rearrangement reaction was observed to give enaminoketone **101a** (Scheme 16A).[54] We proposed that this transformation could be occurring through an initial addition of the nitrone to the electrophilic position of the allenoate (see intermediate **100a**) followed by a rearrangement to form the new C–C bond. This reaction is similar to those described above for the synthesis of indole **18**, benzoindolizine **43**, and dihydropyridoindole **92** but provides access to new chemical space through the use of an *N*-alkenyl group in contrast to an *N*-aryl group and does not promote a spontaneous subsequent cyclization due to the identity of imine substituent. The stability of the fluorenone imine-protecting groups of **101** facilitated isolation of a variety of these addition and rearrangement cascade reaction products in good yields. Nitrones with cyclic *N*-alkenyl groups were particularly amenable to the reaction conditions (see **101a–c**), and heterocyclic *N*-alkenyl substituents were also tolerated as shown for **101d** and **101e**. Nitrones with linear *N*-alkenyl groups were smoothly converted to the desired products as shown for **101g**, albeit in somewhat attenuated yield. The scope of the reaction included allenes with a variety of different electron-withdrawing groups and alkyl substituents as shown for **101f**, **101h**, and **101i**. With several

Scheme 16. Addition and Rearrangement Reactions of *N*-Alkenylnitrones and Allenes[54]



enaminoketones **101** in hand, we were also able to investigate the imine deprotection and reactivity of these arrested Paal–Knorr intermediates under controlled conditions. When treated with acidic hydrolysis conditions, removal of the fluorenone protecting group led to the expected pyrrole synthesis and provided access to highly functionalized examples of these privileged motifs. In addition, reduction conditions were tested with **101a** (Scheme 16B). When **101a** was treated with H_2 in the presence of Pd/C, pyrrole **102** was isolated in good yield. In contrast, when **101a** was treated with $NaCNBH_3$, 1,4-dione **103** was isolated in good yield through reduction of the fluorenone imine and hydrolysis of the cyclohexyl enamine, providing the oxidative coupling product of an oxime and an alkenyl boronic acid through a three-step sequence. This new direction for nitrone and allene addition and rearrangement reactions will hopefully encourage the further development of general methods for the preparation of *N*-alkenylnitrones and continue to promote expansion of these multidirectional cascade reactions.

CONCLUSION

Since the seminal work of Tufariello, Blechert, and Padwa, the versatility and selectivity of addition and rearrangement reactions of nitrones and allenes have been explored for the preparation of a variety of indole derivatives and applied in both target- and diversity-oriented synthesis. These transformations are particularly appealing due to both their modularity and their rapid installation of molecular complexity through cascade processes. The pathways of these reactions have been shown to diverge from common intermediates due to a variety of influences including substrate functionalization, reaction conditions, and catalyst control. Future fine-tuning of these transformations will likely involve careful comparison of these influences, and

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continued development of facile methods to access *N*-aryl- and *N*-alkenylnitrones will continue to expand the breadth of these approaches to heterocycle synthesis. Recent work showing that catalyst control is viable in these systems is particularly exciting and will assist in expanding the utility and generally of these divergent methods for the preparation of privileged, unprecedented, and stereodefined heterocyclic structures from simple reagents.

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Notes

The authors declare no competing financial interest.

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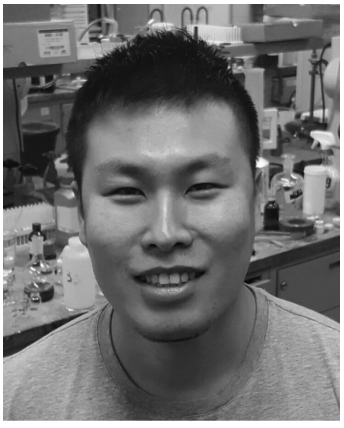
Michelle A. Kroc received a B.S. in Chemistry from the University of Iowa in 2013, where she carried out research in the laboratory of Professor Gregory K. Friestad. In 2013, she began her graduate studies at the University of Illinois at Chicago and joined the research group of Professor Laura L. Anderson. Her current research is focused on the development of new catalyst systems for the cascade conversion of nitrones and allenes to medium-ring heterocycles.

Tyler Reidl received a B.S. in Chemistry and a B.A. in Biology from Quincy University in 2014. He joined the research group of Professor Laura L. Anderson at the University of Illinois at Chicago in 2014. His current research is aimed toward the formation of strained heterocycles via electrocyclizations of *N*-vinylnitrones.



Jongwoo Son received a B.S and a M.S in Chemistry at Chungnam National University in 2009 and 2011 under the supervision of Professor Eul-Kgun Yum. In 2012, he decided to pursue his graduate studies at the University of Illinois at Chicago and joined the research group of Professor Laura L. Anderson. His current research is aimed toward the convenient synthesis of unsaturated oxazines via electrocyclization and exploration of the synthetic utility of these new heterocycles.

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