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Research Advances in the Synthesis of α - and β -Damascone: From an Industrial Application Perspective

Jian Huang^{1,2,3}  | Hua-Chang Wu^{1,2} | Yuheng Yan¹ | Rui Yin¹

¹College of Culinary and Food Science Engineering, Sichuan Tourism University, Chengdu 610100, China | ²Sichuan Provincial Key Laboratory of Culinary Science, Sichuan Tourism University, Chengdu 610100, China | ³Key Laboratory of Sichuan Cuisine Artificial Intelligence, Sichuan Tourism University, Chengdu 610100, China

Correspondence: Jian Huang (jh@sctu.edu.cn)

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ABSTRACT

Damascone, a precious natural fragrance primarily isolated from rose essential oil, is widely distributed in the flowers, leaves, or essential oils of various aromatic plants such as *Rosa damascena*, *Osmanthus fragrans*, *Camellia sinensis*, and *Viola odorata*. It exerts distinctive olfactory notes reminiscent of rose, strawberry, apple, and fresh sweet florals and serves as a key aroma component in numerous food matrices. Owing to its unique sensory profile, damascone is extensively employed in the flavor and fragrance industries. This review systematically summarizes and evaluates the synthetic routes toward α -damascone and β -damascone—the most widely used compounds of the damascone family—from an industrial-application perspective and critically analyzes emerging synthetic strategies, offering insights into future research directions.

1 | Introduction

Damascone, also known as dihydrodamascene [1], with the molecular formula $C_{13}H_{20}O$, is a colorless to pale yellow liquid compound [2]. It is recognized as a safe food flavor by the Flavor and Extract Manufacturers Association of the United States. Initially discovered by the fragrance chemists Ohloff and Demole from Firmenich in the 1960s and 1970s [3, 4], damascone was isolated from Bulgarian rose essential oil. Depending on the position of the double bonds in their chemical structures, damascone can be categorized into several isomers, including α -damascone, β -damascone, δ -damascone, γ -damascone, and damascenones [5]. Damascone compounds are closely associated with the food industry, with studies indicating that they serve as primary contributors to the floral aroma in various wine varieties [6]. They are also recognized as one of the key volatile compounds responsible for the floral scent in green tea [7, 8]. Currently, the most significant application of damascone-type fragrance compounds lies in the cosmetics and perfumery

industries [9, 10]. Their core functions include providing a rich and layered aroma, masking unpleasant odors, adding a sweet and mellow feel, and creating a natural atmosphere.

Due to its extremely low natural content in plants [11, 12], damascone is difficult to produce on a large scale through plant extraction, resulting in high costs and limited availability in the flavor market. Therefore, the synthesis of damascone through artificial methods has become an essential alternative. Since the 1960s and 1970s, researchers from Firmenich have conducted extensive studies and developed synthetic processes for damascone fragrances, which have been successfully commercialized. As a result, Firmenich has become the primary global supplier of damascone fragrances. However, due to commercial considerations, the company's synthetic processes remain highly confidential and have not been publicly disclosed.

The demand for damascone fragrances has been increasing annually [13]. However, due to their high thermal sensitivity and

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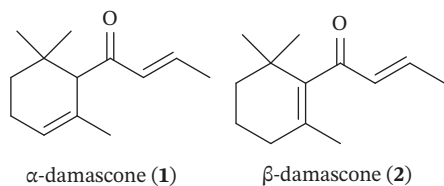


FIGURE 1 | Chemical structure of α -damascone and β -damascone.

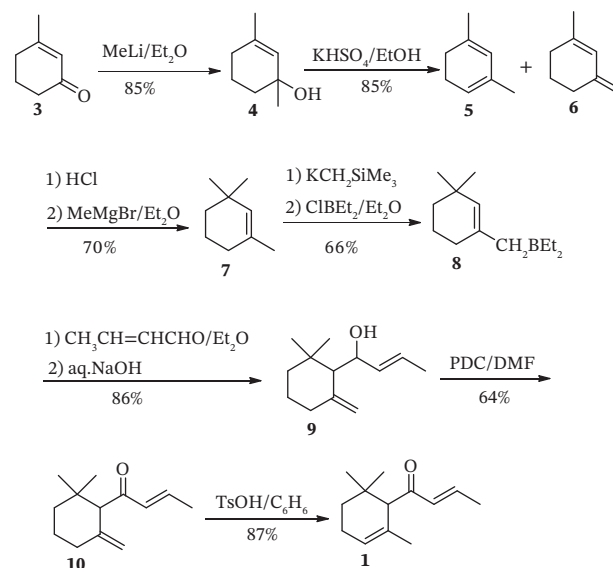
the close relationship between aroma and product purity, even minor impurities can affect the fragrance. Therefore, the production and purification technologies are highly complex. Currently, other than Firmenich, only a few companies are capable of producing these fragrances, and their production technologies are relatively outdated. Thus, exploring a synthetic route with large-scale production potential is of great significance.

To date, several synthetic routes for damascone fragrances have been reported by scientists worldwide, with continuous improvements in synthetic methods. This review, from the perspective of industrial application, provides a detailed strategic analysis and summary evaluation of the industrially potential synthetic routes for α -damascone and β -damascone, which are the most widely used in damascone fragrances. α -Darnascone exhibits a floral-fruity, green, apple-like odor, accompanied by a harsh camphoraceous cork note, whereas β -damascone presents a floral-woody, slightly tobacco-like aroma [14]. α -Damascone **1** and β -damascone **2** are isomers of each other. Their chemical structures are shown in Figure 1. Theoretically, α -damascone and β -damascone can be transformed each other. α -Damascone contains a chiral carbon atom in its structure, thereby existing as two chiral enantiomers, namely, (S)-(-)- α -damascone and (R)-(+)- α -damascone. Due to the higher synthetic cost of chiral α -damascone and its absence in commercial applications [14], the synthesis of enantiomeric α -damascone is not covered in this review. Interested readers are referred to the relevant literature [15–21] for further details.

This paper is divided into three main sections: Section 2 and Section 3 describe the distinct synthetic routes and methods for α -damascone and β -damascone, respectively, while Section 4 summarizes the synthetic strategies applicable to both compounds. The first two sections are primarily intended for scientists with research interests in the synthesis of damascone-based fragrances, whereas Section 4 is targeted at those focused on developing novel synthetic strategies for natural products. Section 5 provides an evaluation of the current synthetic strategies and offers valuable insights into the design of more efficient and optimized synthetic routes.

2 | Synthetic Routes for α -Damascone

The chemical structure of α -damascone mainly consists of a trimethylcyclohexene core and a butenone side chain. The synthesis of α -damascone is mainly focused on the construction of these two parts. The reported synthetic routes mainly include the following strategies: (1) using compounds with a cyclohexene core as raw materials to synthesize target compounds through side-chain structural modifications, (2) constructing the cyclohexene core through a Diels–Alder reaction, and (3) obtaining



SCHEME 1 | Zaidlewicz's synthetic route.

the trimethylcyclohexene core by catalytic cyclization of 2,6-disubstituted dienes. The construction of the four-carbon side chain is mainly achieved through nucleophilic addition reactions, such as C0 + C4, C1 + C3, and C2 + C2 carbon chain extension strategies.

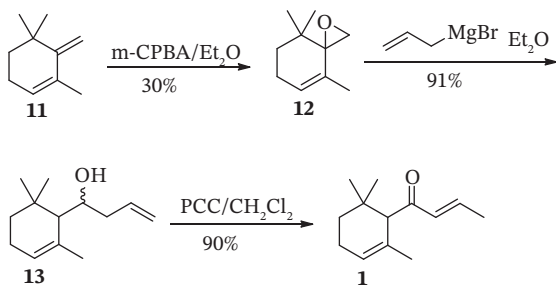
2.1 | Utilizing Compounds With a Cyclohexene Core as Starting Materials

Cyclohexenone, which possesses the basic core structure of α -damascone, has been used as a starting material for its synthesis.

Zaidlewicz's route: Zaidlewicz [22] used seudenone **3** as the starting material. The nucleophilic addition of methyl lithium yielded tertiary alcohol **4**. Subsequently, dehydration with potassium hydrogen sulfate afforded a mixture of dienes **5** and **6**. Acidification of this mixture generated a tertiary carbocation, which then underwent addition with methylmagnesium bromide to introduce a gem-dimethyl group, yielding trimethylcyclohexene **7** as a single constituent. The side-chain methyl group of **7** underwent boronation under the action of a potassium reagent to afford **8**. After selective nucleophilic addition to crotonaldehyde, the diethylboron group in **8** was removed under basic conditions, yielding alcohol **9** possessing an exocyclic double bond, which was oxidized to ketone **10** by PDC [23]. Finally, the exocyclic double bond was isomerized by p-toluenesulfonic acid to obtain α -damascone **1**. The reaction route is shown in Scheme 1.

This route has the advantage of not requiring column chromatography throughout the entire process, although it involves lengthy reaction steps and complex reagents.

Boulin's route: Boulin et al. [24] synthesized α -damascone from γ -pyronene **11**, a monoterpene derived from geraniene. The epoxidation of γ -pyronene **11** yielded epoxy pyronene **12** with a yield of only 30%, likely due to the formation of more byproducts from the oxidation of the double bond on the ring. Subsequently, the treatment of **12** with allylmagnesium bromide resulted in a mixture of diastereomers **13**. An epoxy rearrangement process leading to the formation of cyclocitral was



SCHEME 2 | Boulin's synthetic route.

involved in this reaction. Finally, α -damascone **1** was prepared in a one-pot reaction through PCC oxidation and isomerization (Scheme 2).

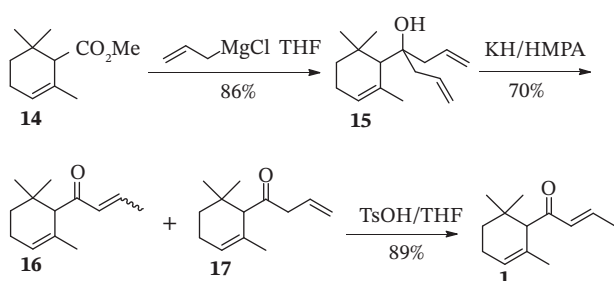
This synthesis is concise and uses easily available raw materials, but alumina column chromatography makes it unsuitable for industrial application.

Snowden's route: Snowden et al. [25, 26] developed a synthetic route for α -damascone using cyclogeranate **14** as the starting material. Depending on the starting material used, this synthetic route can produce either α -damascone or β -damascone. As shown in Scheme 3, when methyl α -cyclogeranate **14** is used as the starting material, α -damascone **1** is obtained. Initially, the nucleophilic addition of allylmagnesium chloride to methyl α -cyclogeranate **14** introduces two allyl groups to form tertiary alcohol **15**. Subsequently, in the presence of hexamethylphosphoramide (HMPA) and strong base potassium hydride (KH), **15** is cleaved to yield a mixture of isomers **16** and **17** (with a ratio of approximately 1:0.6). Without separation, the mixture is isomerized to α -damascone **1** under the catalysis of *p*-toluenesulfonic acid.

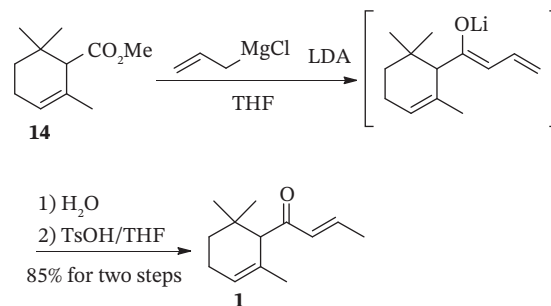
This synthetic route is concise, and the product does not require column chromatography. However, the use of hazardous potassium hydride limits its industrial application.

Fehr's route: Fehr and Galindo [27] improved Snowden's method (Scheme 4). The use of allylmagnesium chloride in combination with an equimolar amount of lithium diisopropylamide (LDA) for nucleophilic addition to **14** forms a lithium enolate intermediate, which prevents further attack by the Grignard reagent to form a tertiary alcohol. The lithium enolate intermediate is then hydrolyzed and acid-catalyzed isomerized to yield α -damascone **1**.

This improvement reduces the reaction steps and significantly increases the overall yield. The product does not require column chromatography, which is beneficial for industrialization. However, the high cost of LDA limited its industrial-scale application.



SCHEME 3 | Snowden's synthetic route.



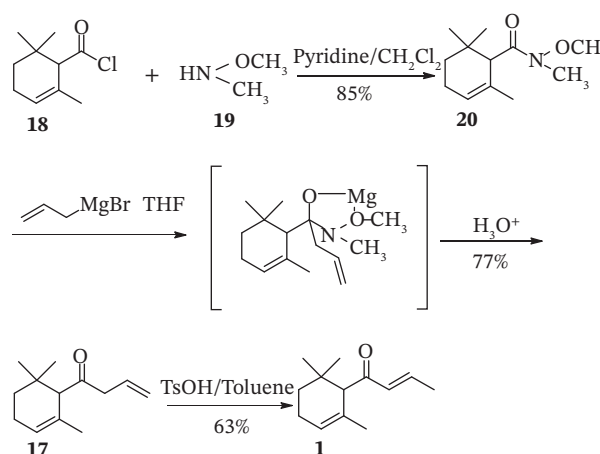
SCHEME 4 | Fehr's synthetic route.

Apple Flavor & Fragrance Group Co., Ltd's Route: Apple Flavor & Fragrance Group [28] developed a synthetic process for α -damascone using cyclohexyl acyl chloride **18** as the starting material through the Weinreb ketone synthesis method [29]. Initially, cyclohexyl acyl chloride **18** reacts with *N,O*-dimethyl hydroxylamine **19** to form *N,O*-dimethyl cyclohexyl amide **20**, which then reacts with allylmagnesium bromide to generate iso- α -damascone **17** through a five-membered ring intermediate. Finally, α -damascone **1** is obtained through acid-catalyzed isomerization of the double bond by *p*-toluenesulfonic acid, as shown in Scheme 5.

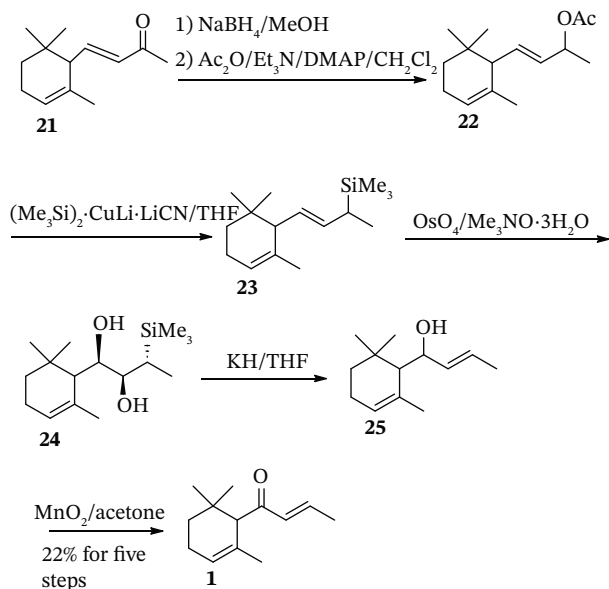
This synthetic route avoids the use of environmentally unfriendly chemical oxidants such as chromium trioxide [30] or hazardous strong bases like LDA or KH. Instead, it uses relatively safe and easily available raw materials and easily controlled reactions to synthesize the product. This approach reduces reaction hazards, simplifies operations, increases reaction yield, and allows the product to be obtained through vacuum distillation without the need for column chromatography, making it more suitable for large-scale production.

α -Ionone and α -damascone are isomers. The difference between their structures lies in the positions of the carbonyl group and the double bond in the side chain. Therefore, α -ionone is also used as a raw material to synthesize α -damascone through the modification of the side-chain structure.

Taddei's route: Azzari et al. [31] synthesized α -damascone from ionone through allylsilane chemistry (Scheme 6). Initially, ionone **21** was reduced with sodium borohydride and acetylated



SCHEME 5 | Synthetic route of Apple Flavor & Fragrance Group.

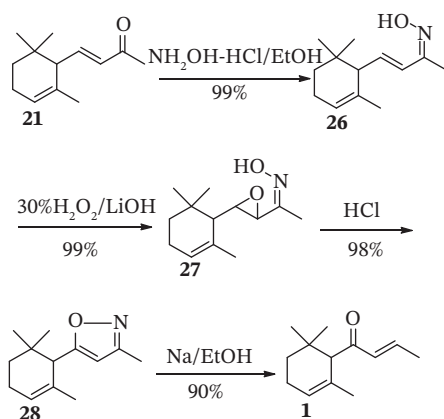


SCHEME 6 | Taddei's synthetic route.

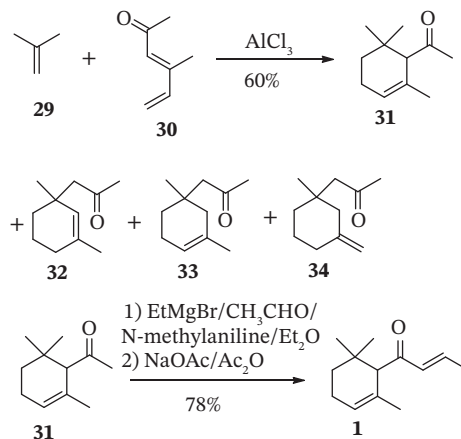
with acetic anhydride to form ester **22**. Subsequently, (trimethylsilyl)lithium copper (prepared from (trimethylsilyl)lithium and copper cyanide) was used for regioselective substitution at the C-3 position of the side chain to generate (E)-allylsilane **23**. The side-chain double bond of **23** was oxidized to diol **24** by osmium tetroxide. Under the action of strong base potassium hydride, **24** underwent Peterson elimination [32, 33] to yield α -damascone alcohol **25**, which was finally oxidized to α -damascone **1** by manganese dioxide with a total yield of 22%.

This procedure can be used not only for the synthesis of α -damascone **1** but also for β -damascone **2**. However, due to the complex synthesis steps, the need for column chromatography, it is limited to laboratory-scale preparation.

Hu's route: Based on the synthetic route of Büchi and Vederas [34], Hu et al. [35–37] improved the synthesis of α -damascone (Scheme 7). α -Ionone **21** reacted with hydroxylamine hydrochloride [38] to form ionone oxime **26**. Subsequently, hydrogen peroxide oxidation [39] yielded epoxide **27**, which underwent dehydration cyclization [40] in concentrated hydrochloric acid to form isoxazole derivative **28** [41]. Finally, α -damascone **1** was



SCHEME 7 | Hu's synthetic route.



SCHEME 8 | Cookson's synthetic route.

obtained through reduction by sodium/ethanol system [34]. Wei [42] also used the same synthetic route and conducted detailed studies on the reaction conditions.

This route cleverly rearranges the double bond and carbonyl group in α -ionone **21** through isoxazole intermediate to synthesize α -damascone **1**. The reaction steps are simple, no column chromatography is required, and the yield is high, showing good potential for industrialization.

Additionally, Dupuy and Luche [43] synthesized α -damascone from α -ionone with Wharton rearrangement [44, 45] as the key reaction. However, the required ultra-low-temperature reaction conditions of -85°C and Dess–Martin oxidation [46] reagent make it unsuitable for industrial production.

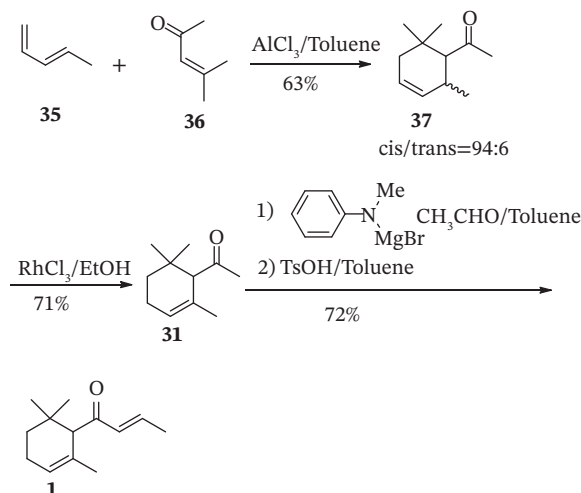
2.2 | Construction of Cyclohexene Core Through Diels–Alder Reaction

The Diels–Alder reaction [47] is a classic method for constructing a six-membered ring, and it is also an ideal choice for constructing the cyclohexene core of α -damascone.

Cookson's route: Cookson and Tuddenham [48, 49] used isobutene **29** and conjugated dienone **30** as raw materials to construct α -cyclohexenyl methylketone **31** and its derivatives **32**, **33**, and **34** through a Diels–Alder reaction. After separation, **31** was subjected to nucleophilic addition in the presence of Grignard reagent and elimination reactions to extend the carbon chain and obtain α -damascone **1**, as shown in Scheme 8.

Though the process is simple, but the first Diels–Alder reaction has poor regioselectivity, resulting in a mixture that is difficult to separate.

Watanabe's route: Watanabe et al. [50] developed a synthetic process for α -damascone using 1,3-pentadiene and mesityl oxide as raw materials through a Diels–Alder reaction (Scheme 9). Under the catalysis of aluminum chloride, 1,3-pentadiene **35** and mesityl oxide **36** reacted to form cyclohexenone **37** (cis/trans = 94:6). This reaction has good regioselectivity. The double bond of cyclohexenone **37** was isomerized by rhodium chloride to obtain α -cyclohexenone **31**. Subsequently, in the presence of N-methylphenylmagnesium bromide, **31** underwent aldol condensation with acetaldehyde and acid-catalyzed dehydration to yield α -damascone **1**.



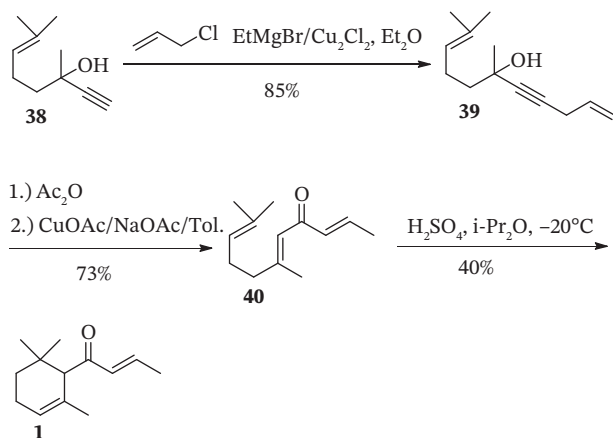
SCHEME 9 | Watanabe's synthetic route.

This synthesis is concise and easy to operate, with cheap and easily available raw materials. The method for preparing cyclohexenone **37** is particularly efficient and can be applied to the synthesis of other compounds [51]. The product can be obtained through distillation without the need for column chromatography.

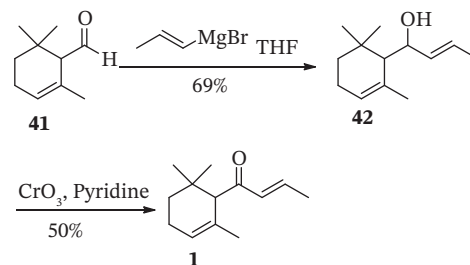
2.3 | Construction of Cyclohexene Core Through Catalytic Cyclization

Ohloff's route: Three years after the structural elucidation of the damascones, the first technical process to α -damascone was established by Schulte-Elte et al. [52], which started from dehydrolinalool **38** via a Cu^+ -catalyzed Claisen rearrangement (Scheme 10). Coupling of **38** with allyl chloride led to alkenyne **39**, which was transformed by Cu^+ -catalyzed Claisen rearrangement [53] of the acetylenecarbinol acetate and isomerization to conjugated enone **40**. Finally, acid-catalyzed cyclization of **40** gave α -damascone **1**.

Although Ohloff's synthetic route utilizes expensive dehydrolinalool as the starting material, resulting in relatively high costs, it nevertheless provides a valuable approach for constructing conjugated enones.



SCHEME 10 | Ohloff's synthetic route.



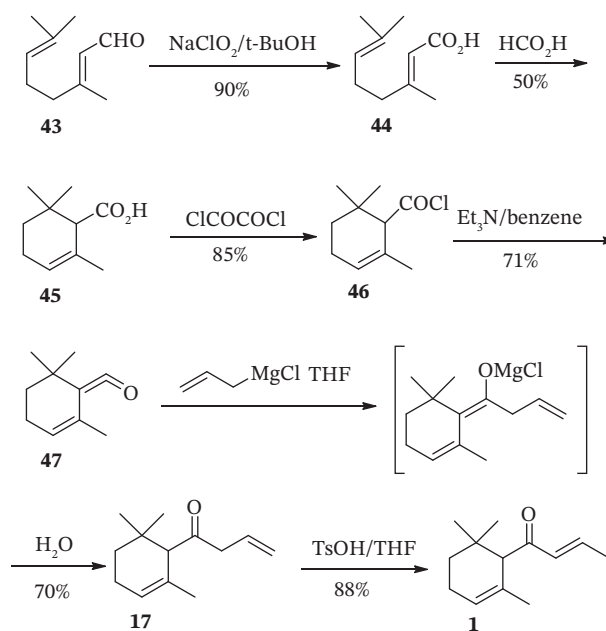
SCHEME 11 | Demole's synthetic route.

Citral, a natural product with a 2,6-disubstituted diene structure and three methyl groups, can rapidly construct the damascone core through catalytic cyclization [54, 55]. Therefore, citral is also a good choice for the synthesis of damascone.

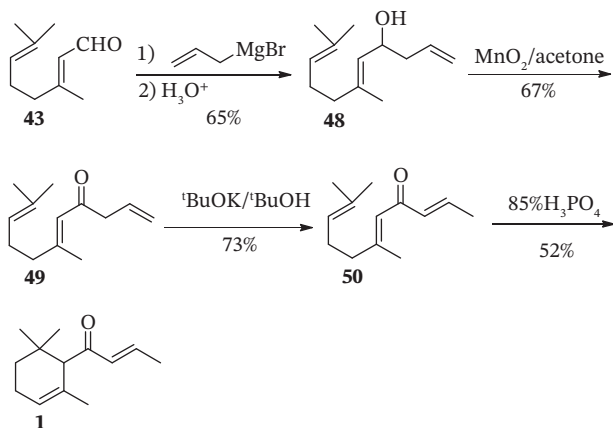
Demole's route: Demole et al. [4] synthesized α -damascone **1** from α -cyclocitral **41**, as shown in Scheme 11. α -Cyclocitral **41** was added to propenylmagnesium bromide to obtain α -iso-ionol **42**, which was then oxidized to α -damascone **1** using the Sarrett reagent. The raw material α -cyclocitral **41** can be obtained by acid-catalyzed cyclization of Schiff base derived from citral and aniline [56].

With only two reaction steps and easily available raw materials, Demole's procedure has significant potential for industrial application.

Naef's route: Naef and Decorzant [57] developed a process for synthesizing α -damascone **1** from citral **43** (Scheme 12). Initially, citral **43** was oxidized by sodium hypochlorite [58] to form geranic acid **44**, which was then cyclized under acid catalysis [59] to obtain α -cyclogeranic acid **45**. Subsequently, **45** was converted to chloride **46** [60] using oxalyl chloride. In the presence of the organic base triethylamine, an elimination reaction occurred to form enone **47**. Finally, the side chain was extended through nucleophilic addition with allylmagnesium bromide, followed by acid-catalyzed isomerization to yield α -damascone **1**.



SCHEME 12 | Naef's synthetic route.



SCHEME 13 | Li's synthetic route.

This route uses cheap and easily available citral as the raw material and does not involve hazardous reagents. The product does not require column chromatography for purification, showing potential for industrial application.

Li's route: Based on Nakatani et al. [61], Mori et al. [15], and Kazunori [62], Li et al. [63] improved the process for synthesizing α -damascone from citral. Initially, citral **43** reacted with allylmagnesium bromide to construct the side chain, forming alcohol **48**. Subsequently, manganese dioxide oxidation yielded ketone **49**. Potassium tert-butoxide catalyzed double bond isomerization to form conjugated enone **50**. Finally, acid-catalyzed cyclization produced α -damascone **1**, as shown in Scheme 13.

With cheap and easily available raw materials, this procedure could produce many cis-trans isomers. Additionally, the use of manganese dioxide as an oxidant generates a significant amount of waste. In our opinion, this synthetic route shows potential for industrial application after a further improvement.

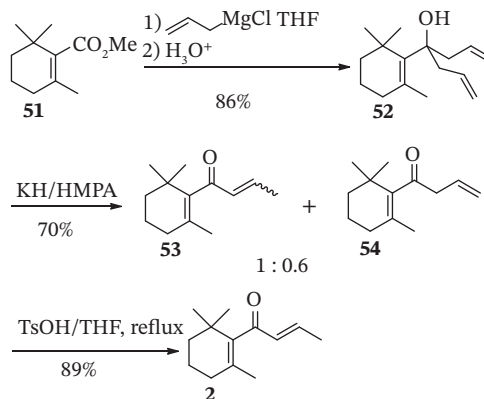
3 | Synthetic Routes for β -Damascone

Similar to the synthesis of α -damascone, the synthesis of β -damascone mainly focuses on the construction of the trimethylcyclohexene core and the butenone side chain in its structure. The main strategies employed include (1) using compounds with a cyclohexene core as raw materials to synthesize target compounds through side-chain structural modifications, (2) obtaining the trimethylcyclohexene core through catalytic cyclization of 2,6-disubstituted dienes. The construction of the four-carbon side chain is mainly achieved through nucleophilic addition strategies such as C0 + C4, C1 + C3, and C2 + C2.

3.1 | Structural Modification of Existing Cyclohexene Core

β -cyclogeranate, which have a trimethylcyclohexene core similar to β -damascone, are a rational choice for synthesizing β -damascone.

Snowden's route: Snowden et al. [25, 26] also developed a method for synthesizing β -damascone, as shown in Scheme 14. Methyl β -cyclogeranate **51** underwent nucleophilic addition with two molecules of allylmagnesium chloride to form tertiary alcohol **52**. Subsequently, with the presence of strong base potassium hydride in hexamethylphosphoramide, **52** was cleaved to



SCHEME 14 | Snowden's synthetic route.

yield a mixture of isomers **53** and **54** (with a ratio of approximately 1:0.6). Without separation, the mixture was isomerized to β -damascone **2** under the catalysis of *p*-toluenesulfonic acid.

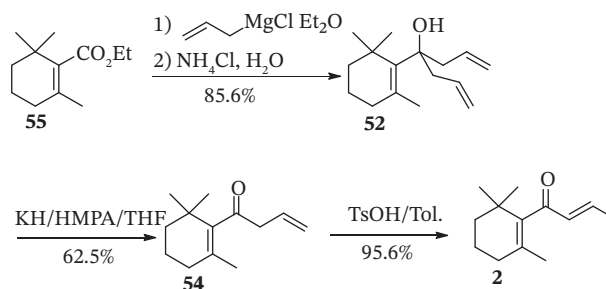
The synthetic route is relatively concise, and the product does not require column chromatography for purification.

Li's route: Based on Snowden's route, Li et al. [64] improved the synthesis of β -damascone (Scheme 15). Ethyl β -cyclogeranate **55** underwent a Grignard reaction with allylmagnesium chloride to form tertiary alcohol **52**. Subsequently, in the presence of strong base potassium hydride, **52** was cleaved to yield ketone **54**. Finally, acid-catalyzed double bond isomerization produced β -damascone **2**. Later, Li et al. [65] improved the second step reaction by using a phase-transfer catalyst and strong base sodium hydroxide as cleavage reagents, avoiding the use of hazardous potassium hydride.

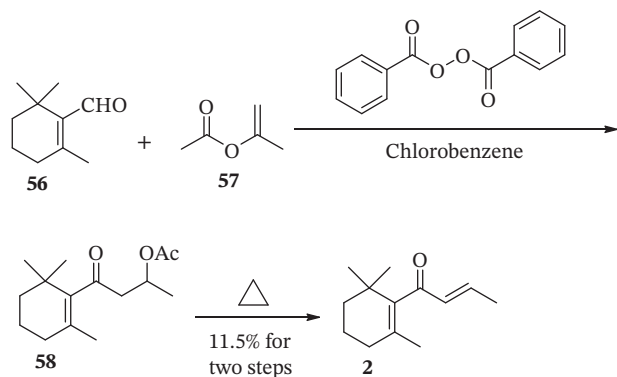
The total yield of the three-step reaction in this route reaches 51.1%, with minimal waste. The crude product can reach the required purity through simple distillation, and the fragrance fully meets the requirements of perfumers.

Cyclocitral also possesses a trimethylcyclohexene moiety similar to that of damascone, which makes it a good choice to use as a starting material for the synthesis of damascone.

Shanghai Wanxiang Flavours & Fragrances Co., Ltd.'s Route: Shanghai Wanxiang Flavours & Fragrances Co., Ltd. developed a synthetic route for β -damascone from β -cyclocitral **56** [66], as shown in Scheme 16. β -Cyclocitral **56** generated acyl radicals in the presence of peroxides such as benzoyl peroxide, which then underwent radical addition with isopropenyl acetate **57** to form



SCHEME 15 | Li's synthetic route.



SCHEME 16 | Synthetic route of Shanghai Wanxiang Flavours & Fragrances Co., Ltd.

ester **58**. Finally, β -damascone **2** was synthesized through a thermal elimination reaction of **58**.

The advantage of this route is its simplicity and ease of control. However, it is difficult to obtain a high-purity product, making it unsuitable for industrial application.

Wu's route: Wu and Xiao [67] also developed a similar synthetic route for β -damascone **2** from β -cyclocitral **56**. However, the use of manganese dioxide as an oxidant in this route generates serious environmental pollution, making it unsuitable for large-scale industrial production.

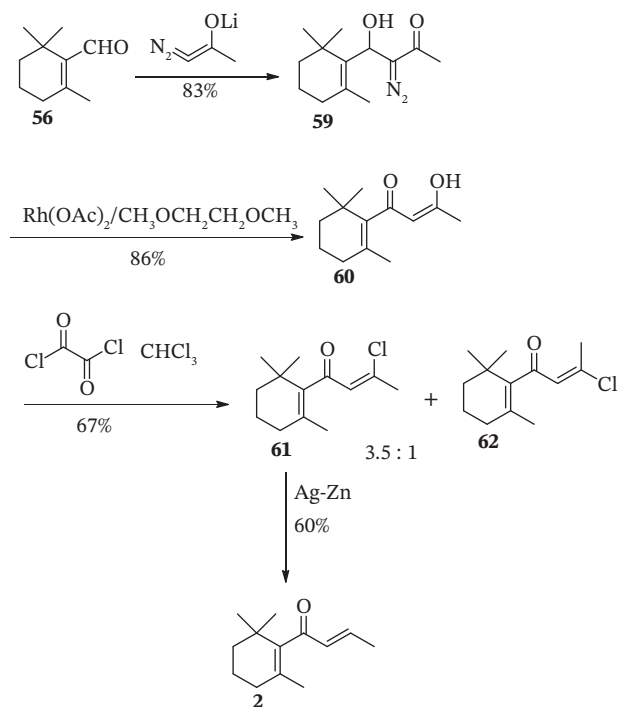
Pellicciari's route: Pellicciari et al. [68] synthesized β -damascone from β -cyclocitral **56**, as shown in Scheme 17. The key step involves the condensation of β -cyclocitral **56** with lithium propionate to form α -diazobutanone derivative **59**. Subsequently, **59** was treated with rhodium acetate to generate key intermediate β -dione **60**. Finally, β -damascone **2** was synthesized through chlorination with oxalyl chloride and silver-zinc reductive elimination.

The reagents used in this route, such as lithium propionate and rhodium acetate, are not readily available and are expensive; thus, it has less industrial value.

Barker's route [69]: To access d_6 - β -damascone, Barker and co-workers devised a concise sequence commencing from β -cyclocitral **56** (Scheme 18). Grignard addition of allylmagnesium bromide to β -cyclocitral **56** furnished the secondary allylic alcohol **63** in a 57% yield. Subsequent Dess–Martin periodinane (DMP) oxidation delivered the corresponding ketone **54**. Base-mediated (DBU) allylic rearrangement of **54** proceeded smoothly to afford β -damascone **2**.

Barker's route furnishes β -damascone in a concise and efficient manner by using cyclocitral as the starting material. Furthermore, Mosaferi et al. reported the preparation of β -cyclocitral **56** from acetone via a nine-step sequence with an overall yield of 5.5% [70].

Mianyang Simaiergu Biotech. Co. Ltd's route: Guo et al. from Mianyang Simaiergu Biotechnology Co., Ltd. published a patent [71] describing the synthesis of β -damascone starting from β -cyclocitral **56**. As illustrated in Scheme 19, the reaction pathway resembles Barker's route. β -Cyclocitral **56** was reacted with allyl chloride or allyl bromide in the presence of catalyst A to yield the secondary allylic alcohol **63**, which was subsequently oxidized with oxygen under catalysis by catalyst B to afford the



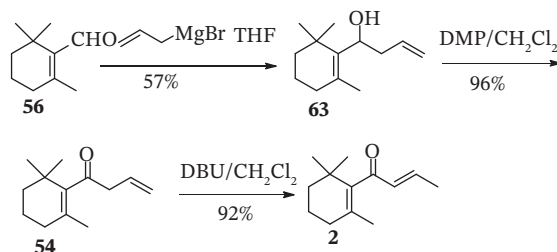
SCHEME 17 | Pellicciari's synthetic route.

corresponding ketone **54**. Finally, isomerization of **54** catalyzed by *p*-toluenesulfonic acid produced β -damascone **2**. The overall yield of this three-step process reached up to 97.5%. Catalyst A was prepared by adsorption of tungsten and chromium metals onto modified porous silica nanospheres, while catalyst B was constructed through deposition of cobalt ferrite onto modified porous titanium oxide nanospheres.

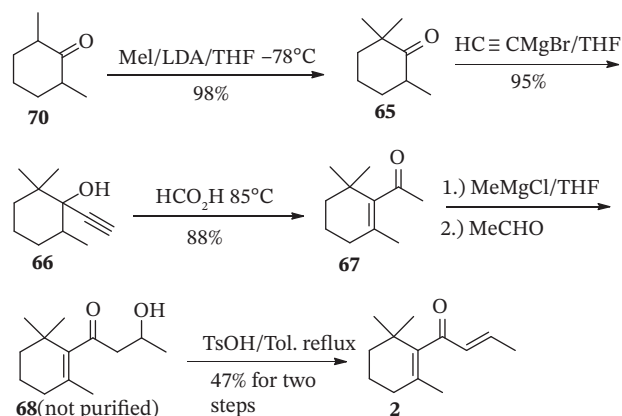
This synthetic route is straightforward and efficient, achieving a remarkably high overall yield, which demonstrates its potential for industrial application. However, the preparation processes for catalyst A and catalyst B are relatively complex and cumbersome. Moreover, the patent literature does not disclose the number of recycling times feasible for these catalysts, and their catalytic efficiency requires further experimental validation.

Trimethylcyclohexenone, which has a core moiety similar to that of damascone, can be used as a starting material for the synthesis of β -damascone by appropriately constructing a four-carbon side chain.

IFF's Route: International Flavors & Fragrances Inc. (IFF) developed a synthetic route [72] starting from trimethylcyclohexenone **64**, as shown in Scheme 20. **64** was hydrogenated over palladium on carbon to yield trimethylcyclohexenone **65**.



SCHEME 18 | Barker's synthetic route.



SCHEME 23 | Cossy's synthetic route.

elimination were carried out to yield damascenol **75**. Finally, β -damascone **2** was synthesized through oxidation and acid-catalyzed isomerization.

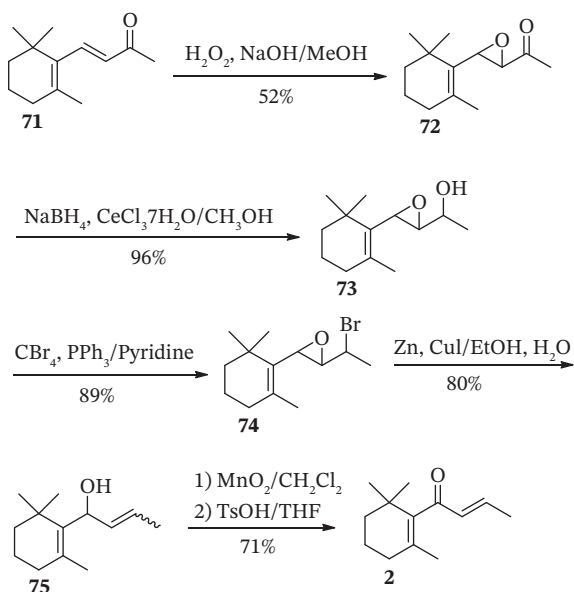
The need for column chromatography and expensive raw materials make it unsuitable for industrial application.

Zong's route: Zong et al. [79] synthesized β -damascone from β -ionone, as shown in Scheme 25. Initially, β -ionone **71** reacted with hydroxylamine to form β -ionone oxime **76**. Subsequently, **76** was cyclized in the presence of iodine to yield β -ionone isoxazole derivative **77**. Finally, β -damascone **2** was obtained through reduction by metallic sodium.

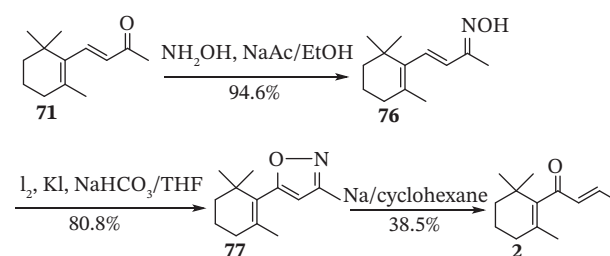
This procedure does not require column chromatography for purification, but the purity of the final product is only 91%. So, it requires further improvement.

3.2 | Construction of Cyclohexene Core Through Catalytic Cyclization

Citral, a natural product with a 2,6-disubstituted diene structure and three methyl groups, can rapidly construct the β -damascone core through catalytic cyclization. Therefore, citral is also a good choice for the synthesis of β -damascone.



SCHEME 24 | Sarandeses's synthetic route.

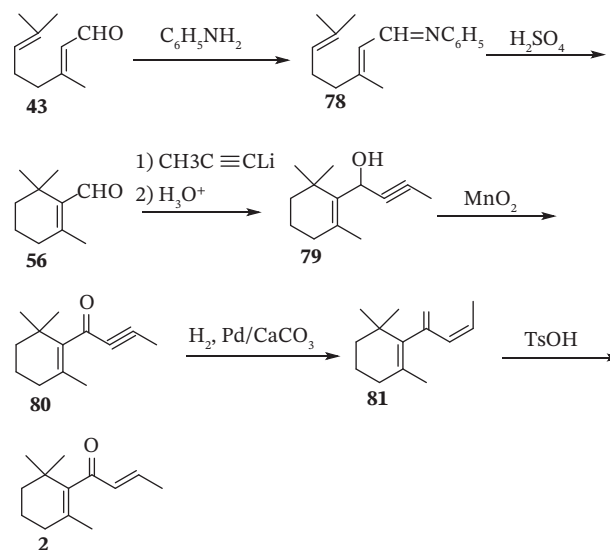


SCHEME 25 | Zong's synthetic route.

Tang's route: Tang [80] introduced a synthetic route for β -damascone starting from citral, as shown in Scheme 26. Initially, citral **43** underwent nucleophilic addition with aniline to form Schiff base **78**. Subsequently, **78** was cyclized under the catalysis of concentrated sulfuric acid to yield β -cyclocitral **56**. This reaction has fewer side reactions for double bond isomerization. β -cyclocitral **56** underwent addition with propynyllithium and hydrolysis to yield propargyl alcohol **79**, which was oxidized to ketone **80** by manganese dioxide. Hydrogenation of **80** by Lindlar catalyst yielded *cis*- β -damascone **81**. Finally, β -damascone **2** was obtained through acid-catalyzed isomerization by *p*-toluenesulfonic acid.

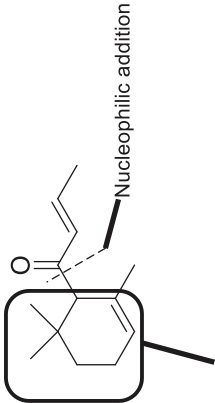
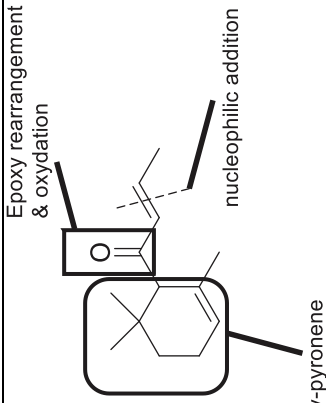
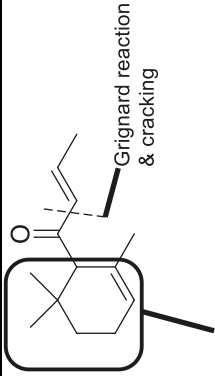
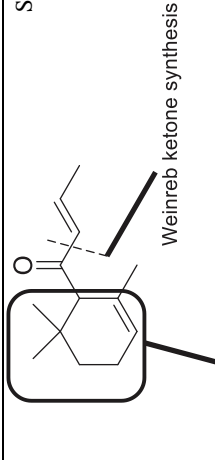
The original paper of this synthetic route does not provide yield information. However, the lengthy reaction steps and the waste pollution problems caused by the use of manganese dioxide limit its industrial application value.

Zhou and Chen from Kunshan Asia Aroma Corp., Ltd. improved this method [81] by extracting citral from mountain pepper oil and then acid-catalyzed cyclization to yield β -cyclocitral. β -Cyclocitral directly reacted with allyl chloride and preactivated magnesium to form an intermediate, which then underwent double bond rearrangement and cyclization to yield β -damascone. This method avoids the waste pollution caused by the use of oxidants but requires column chromatography for purification of the intermediate β -cyclocitral, which renders it unsuitable for large-scale production.



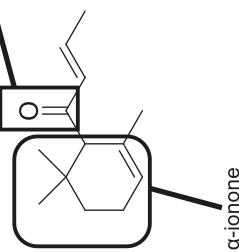
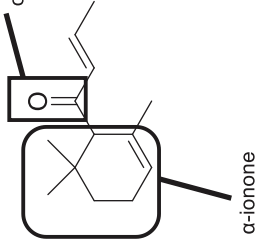
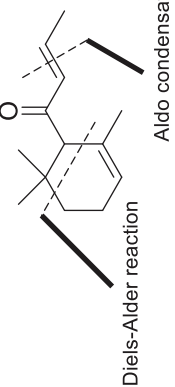
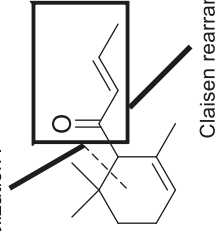
SCHEME 26 | Tang's synthetic route.

TABLE 1 | Analysis of α -damascone synthesis strategies.

Synthetic route	Synthetic strategy	Advantages	Drawbacks
Zaidlewicz's route	 Cyclohexenone Nucleophilic addition	No need for column chromatography	Lengthy reaction steps and complex reagents
Boulin's route	 γ-pyrone nucleophilic addition Epoxy rearrangement & oxydation	Easily available raw materials	Low yield, environmentally unfriendly
Snowden's route	 α-methyl cyclohexanone Grignard reaction & cracking	Concise reaction route and highly operable	Use of hazardous reagent potassium hydride
Apple Flavor & Fragrance Group's route	 α-cyclogeranic acid chloride Weinreb ketone synthesis	Short reaction route and easy to operate	Low product purity

(Continues)

TABLE 1 | (Continued)

Synthetic route	Synthetic strategy	Advantages	Drawbacks
Taddei's route	 oxidation reductive cleavage of isoxazole α-ionone	Readily available raw materials	Lengthy process and complex reagents required
Hu's route	 reductive cleavage of isoxazole α-ionone	Short reaction route and high yield	Use of hazardous metallic sodium
Watanabe's route	 Diels-Alder reaction Aldol condensation	Short reaction route and cheap raw materials	Low yield
Ohloff's route	 acid-catalyzed cyclization I Claisen rearrangement	Readily available reagents and straightforward procedure	Expensive raw material

(Continues)

TABLE 1 | (Continued)

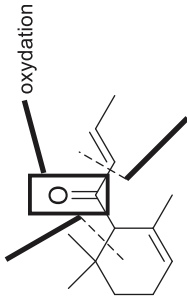
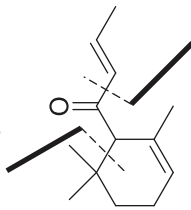
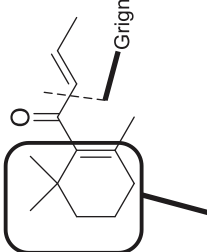
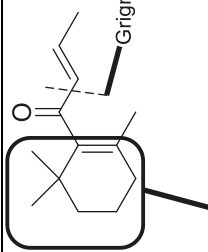
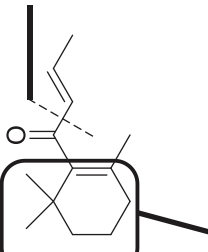
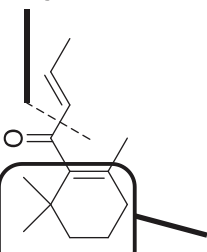
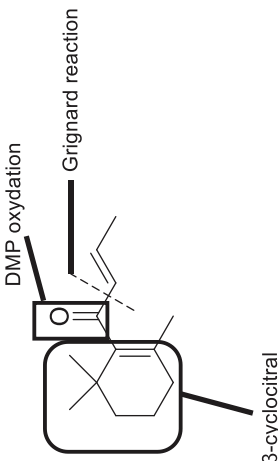
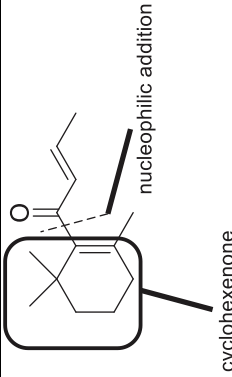
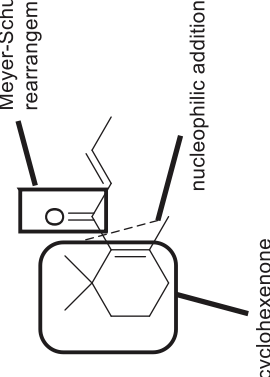
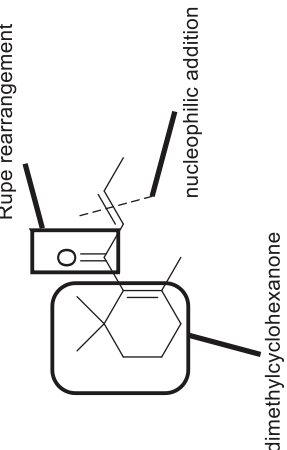
Synthetic route	Synthetic strategy	Advantages	Drawbacks
Demole's route	acid-catalyzed cyclization of citral  nucleophilic addition	Inexpensive and readily available raw materials, concise reaction route	Low yield and environmentally unfriendly
Naef's route	cyclization of geranic acid  nucleophilic addition	Inexpensive and readily available raw materials, high reliability, and operability	Lengthy reaction steps
Li's route	acid-catalyzed cyclization  oxidation	Inexpensive and readily available raw materials	Low yield, high waste

TABLE 2 | Analysis of β -damascone synthesis strategies.

Synthetic route	Synthetic strategy	Advantages	Drawbacks
Snowden's route	 β -methyl cyclogeraniol	Concise synthetic route and simple operation	High raw material costs and use of hazardous KH
Li's route	 β -ethyl cyclogeraniol	Concise synthetic route and high product purity	High raw material costs
Shanghai Wanxiang Flavours & Fragrances Co., Ltd. 's route	 β -cyclocitral	Concise synthetic route	Low overall yield
Pellicciari's route	 β -cyclocitral	Easily available raw materials	Not readily available and expensive reagents

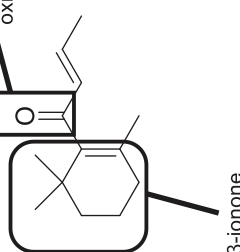
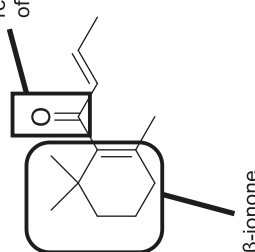
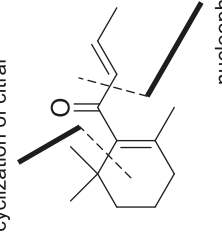
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TABLE 2 | (Continued)

Synthetic route	Synthetic strategy	Advantages	Drawbacks
Barker's route	 β-cyclocitral DMP oxidation Grignard reaction cyclohexenone	Concise synthetic route	Costly oxidant
The IFF's route	 cyclohexenone nucleophilic addition dimethylcyclohexanone	High yield	Use of sodium amide and stringent reaction conditions
Wanhua Chemical Group Co., Ltd.'s route	 cyclohexenone Meyer-Schuster rearrangement nucleophilic addition dimethylcyclohexanone	High overall yield, high product purity	High-pressure reaction conditions
Cossy's route	 dimethylcyclohexanone Rupe rearrangement nucleophilic addition cyclohexenone	Cheap raw materials	Low reaction temperature of -78°C

(Continues)

TABLE 2 | (Continued)

Synthetic route	Synthetic strategy	Advantages	Drawbacks
Sarandases's route	 epoxy ring-opening oxidation β-ionone	Simple reagents and good operability	High raw material costs and high waste
Zong's route	 reductive cleavage of isoxazole β-ionone	Concise synthetic route	Use of hazardous metallic sodium
Tang's route	 cyclization of citral nucleophilic addition	Cheap and easily available raw materials	Use of hazardous propargyl lithium and high waste

4 | Analysis of Synthetic Strategies

The synthetic strategies for α -damascone reported so far have been systematically analyzed. The synthetic strategies and their advantages and drawbacks of each synthetic route are summarized in Table 1.

As an isomer of α -damascone, β -damascone differs from α -damascone only in the position of the double bond in the cyclohexene structure. Its synthesis also focuses on the construction of the cyclohexene core and the conjugated butenone side chain. The strategies and their advantages and drawbacks of each synthetic route are summarized in Table 2.

5 | Conclusions

In recent years, α -damascone and β -damascone, as high-value natural fragrances, have been increasingly widely applied in perfumery and daily chemical industries. Going forward, with the expansion of their applications in the tobacco industry, a rapid surge in the global consumption volume of α -damascone and β -damascone is expected to be driven. It is projected that their global annual consumption will reach thousands of tons, with a corresponding market scale amounting to billions of US dollars—this growth trajectory underscores their rising strategic importance in the global fine chemical and fragrance supply chain.

Since their content in natural plants is extremely low, most of the demand is met through artificial synthesis, which also provides new impetus for the development of the fragrance industry. With the application of new organic synthesis technologies in the fragrance industry, new synthetic routes and processes are continuously being developed. Compared with traditional synthetic methods, the current synthetic schemes are more focused on environmental protection, safety, and atom economy. It is necessary for researchers to develop concise, efficient, low-cost, and industrializable synthetic routes. Through the above analysis of the reported synthetic strategies for α -damascone and β -damascone, it can be seen that their synthesis mainly focuses on the construction of the trimethylcyclohexene core and the butenone side chain. The construction of the trimethylcyclohexene core mainly includes two methods: (1) structural modification of compounds with an existing cyclohexene core, such as α -ionone, β -ionone, and cyclohexenone; (2) catalytic cyclization of 2,6-disubstituted dienes to obtain the trimethylcyclohexene core, such as cyclization of citral and geranic acid to form corresponding cyclocitral or cyclogeranic acid. Other methods include the use of the Diels–Alder reaction to construct the cyclohexene core. Due to the three special methyl groups in the damascone core, to our knowledge, the catalytic cyclization of cheap and readily available citral or geranic acid to construct the damascone core is a better choice. Ionone is not advantageous due to its high cost. The Diels–Alder reaction can also be considered to construct the core, but it is necessary to overcome the shortcoming of low selectivity and yield. The construction of the butenone side chain includes strategies such as C0 + C4, C1 + C3, and C2 + C2. The most efficient method is the nucleophilic addition with the Grignard reagent, which is atom-economic and more competitive in terms of cost. In summary, the synthesis of damascone fragrance is

a challenge for both academia and industry. It is believed that more efficient synthetic routes suitable for large-scale industrial production will be developed in the future.

Author Contributions

Jian Huang conceived and coordinated the study, wrote Chapters 4 and 5, and critically revised the manuscript; Hua-Chang Wu performed the literature search and wrote Chapter 1; Yuheng Yan contributed to the literature search and wrote Chapter 2; Rui Yin wrote Chapter 3.

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Disclosure

All authors have read and agreed to the final version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available in the China National Knowledge Infrastructure at <https://www.cnki.net/>. These data were derived from the following resources available in the public domain: China National Knowledge Infrastructure, <https://www.cnki.net/>.

References

1. R. H. Zhu, Q. C. Xue, and Z. C. Li, in *Synthesis of Food Flavorings Manual* (China Light Industry Press, 1986), Chinese.
2. G. D. Huang and T. Xu, “Advances in the Synthesis of Damascone Fragrances,” *Chemical Industry Times* 15, no. 3 (2001): 14–16, Chinese.
3. G. Ohloff and G. Uhde, “Über eine Ungewöhnliche Cyclisationsreaktion bei der Umsetzung von (+)-Epoxy- α -Dihydrojonon Mit Hydrazinhydrat,” *Helvetica Chimica Acta* 53, no. 3 (1970): 531–541, <https://doi.org/10.1002/hlca.19700530309>.
4. E. Demole, P. Enggist, U. Sauberli, M. Stoll, and S. Kovats, “Structure et Synthèse de la Damascénone (Triméthyl-2,6,6-Trans-Crotonoyl-1-Cyclohexadiène-1,3), Constituant Odorant de l'essence de Rose Bulgare (*Rosa damascena* Mill.),” *Helvetica Chimica Acta* 53, no. 3 (1970): 541–551, <https://doi.org/10.1002/hlca.19700530310>.
5. P. Kraft, in *Advances in Flavours and Fragrances*, ed. K. A. D. Swift (Royal Society of Chemistry, 2002).
6. B. Pineau, J.-C. Barbe, C. Van Leeuwen, and D. Dubourdieu, “Which Impact for β -Damascenone on Red Wines Aroma?” *Journal of Agricultural and Food Chemistry* 55, no. 10 (2007): 4103–4108, <https://doi.org/10.1021/jf070120r>.
7. N. Liu, S. Shen, L. Huang, et al., “Revelation of Volatile Contributions in Green Teas With Different Aroma Types by GC–MS and GC–IMS,” *Food Research International* 169 (2023): 112845, <https://doi.org/10.1016/j.foodres.2023.112845>.
8. T. Kumazawa and H. Masuda, “Identification of Potent Odorants in Different Green Tea Varieties Using Flavor Dilution Technique,” *Journal*

- of *Agricultural and Food Chemistry* 50, no. 20 (2002): 5660–5663, <https://doi.org/10.1021/jf020498j>.
9. G. Ohloff, W. Pickenhagen, and P. Kraft, in *Scent and Chemistry: The Molecular World of Odors* (Wiley-VCH, 2012).
10. M. Campagnole and B. Delmond, “New Straightforward Synthesis of β -Damasenone and β -Damascone Derivatives From β -Ionone via Retro-Ionol,” *Synthetic Communications* 37, no. 7 (2007): 1077–1090, <https://doi.org/10.1080/00397910701196546>.
11. G. A. Zhang and L. T. Tang, “Synthesis of β -Damasenone and β -Damascone,” *Liaoning Chemical Industry* no. 2 (1989): 20–24, Chinese.
12. A. L. Zuo, B. G. Cai, Q. Li, Y. X. Li, and H. F. Mao, “Proceedings of the 7th China Academic Symposium on Flavors, Fragrances and Cosmetics,” (Hangzhou, 2008), Chinese.
13. Green Biological Technology Co.Ltd., *Prospectus for Initial Public Offering and Listing on the ChiNext Board* (2023), https://reportdocs.static.szse.cn/UpFiles/rasinfodisc1/202306/RAS_202306_C988E9B2AD6F4B068AEB51D389CA52F8.pdf.
14. G. Fráter, J. A. Bajgrowicz, and P. Kraft, “Fragrance Chemistry,” *Tetrahedron* 54, no. 27 (1998): 7633–7703, [https://doi.org/10.1016/S0040-4020\(98\)00199-9](https://doi.org/10.1016/S0040-4020(98)00199-9).
15. K. Mori, M. Amaike, and M. Itou, “Synthesis of (S)- α -Damascone,” *Tetrahedron* 49, no. 9 (1993): 1871–1878, [https://doi.org/10.1016/S0040-4020\(01\)80543-3](https://doi.org/10.1016/S0040-4020(01)80543-3).
16. K. Mori, “Biochemical Methods in Enantioselective Synthesis of Bioactive Natural Products,” *Synlett* 11 (1995): 1097–1109, <https://doi.org/10.1055/s-1995-5191>.
17. M. Bovolenta, F. Castronovo, A. Vadala, G. Zanoni, and G. Vidari, “A Simple and Efficient Highly Enantioselective Synthesis of α -Ionone and α -Damascone,” *Journal of Organic Chemistry* 69, no. 25 (2004): 8959–8962, <https://doi.org/10.1021/jo049012j>.
18. S. Serra and C. Fuganti, “Synthesis of the Enantiomeric Forms of α - and γ -Damascone Starting From Commercial Racemic α -Ionone,” *Tetrahedron: Asymmetry* 17, no. 10 (2006): 1573–1580, <https://doi.org/10.1016/j.tetasy.2006.05.024>.
19. C. Fehr and J. Galindo, “Synthesis of (R)-(+)- and (S)-(–)- α -Damascone by Tandem Grignard Reaction-Enantioselective Protonation: Evidence for the Intermediacy of a Chiral Complex,” *Journal of the American Chemical Society* 110, no. 20 (1988): 6909–6911, <https://doi.org/10.1021/ja00228a064>.
20. C. Fehr, “Catalytic Enantioselective Tautomerization of Isolated Enols,” *Angewandte Chemie International Edition* 46, no. 37 (2007): 7119–7121, <https://doi.org/10.1002/anie.200701428>.
21. C. Fehr, I. Stempf, and J. Galindo, “Highly Enantioselective Protonation of Thiol Ester Enolates,” *Angewandte Chemie International Edition* 32, no. 7 (1993): 1042–1044, <https://doi.org/10.1002/anie.199310421>.
22. M. Zaidlewicz, “Synthesis With Organoboranes. Synthesis of α - and γ -Damascone,” *Tetrahedron Letters* 27, no. 42 (1986): 5135–5138, [https://doi.org/10.1016/S0040-4039\(00\)85153-9](https://doi.org/10.1016/S0040-4039(00)85153-9).
23. J. W. Terpstra and A. M. Van Leusen, “A New Synthesis of Benzo[B] Thiophenes and Benzo[C]Thiophenes by Annulation of Disubstituted Thiophenes,” *Journal of Organic Chemistry* 51, no. 2 (1986): 230–238, <https://doi.org/10.1021/jo00352a019>.
24. B. Boulin, M. Taran, B. Arreguy-San Miguel, and B. Delmond, “New Preparation Methods for α -Damascone, γ -Damascone, and β -Damasenone Using Pyronenes,” *Synthetic Communications* 37, no. 15 (2007): 2579–2591, <https://doi.org/10.1080/00397910701462898>.
25. R. L. Snowden, S. M. Linder, B. L. Muller, and K. H. Schulte-Elte, “ β -Cleavage of Bis(Homoallylic) Potassium Alkoxides. Two-Step Preparation of Propenyl Ketones From Carboxylic Esters. Synthesis of Ar-Turmerone, α -Damascone, β -Damascone, and β -Damasenone,” *Helvetica Chimica Acta* 70, no. 7 (1987): 1858–1878, <https://doi.org/10.1002/hlca.19870700721>.
26. R. L. Snowden, B. L. Muller, and K. H. Schulte-Elte, “Fragmentation of Homoallylic Alkoxides. Synthesis of Propenyl and 2-Methylpropenyl Ketones From Carboxylic Esters,” *Tetrahedron Letters* 23, no. 3 (1982): 335–338, [https://doi.org/10.1016/S0040-4039\(00\)86824-0](https://doi.org/10.1016/S0040-4039(00)86824-0).
27. C. Fehr and J. Galindo, “Diastereocontrolled Synthesis of Functionalized Trans-Decalins via Electrocyclic Reaction of Trienol Ethers,” *Helvetica Chimica Acta* 69, no. 1 (1986): 228–235, <https://doi.org/10.1002/hlca.19860690127>.
28. E. Z. Chen, G. Xu, and H. C. Wang, “Novel Method for Synthesizing Alpha-Damasenone,” Chinese Patent CN117105755A, 2023-08-24 [Chinese].
29. S. Nahm and S. M. Weinreb, “N-Methoxy-N-Methylamides as Effective Acylating Agents,” *Tetrahedron Letters* 22, no. 38 (1981): 3815–3818, [https://doi.org/10.1016/S0040-4039\(01\)91316-4](https://doi.org/10.1016/S0040-4039(01)91316-4).
30. M. J. Ma, Y. X. Jia, and Y. H. Zhang, “Research of a New Experimental Technology to Prevent Second Pollution Caused by Atmosphere Monitoring Experiment,” *Research and Exploration in Laboratory* 25, no. 1 (2006): 47–48&104, Chinese.
31. E. Azzari, C. Faggi, N. Gelsomini, and M. Taddei, “Transformation of α - and β -Ionones into α - and β -Damascone and β -Damasenone Using Allylsilane Chemistry,” *Journal of Organic Chemistry* 55, no. 3 (1990): 1106–1108, <https://doi.org/10.1021/jo00290a057>.
32. D. J. Peterson, “Carbonyl Olefination Reaction Using Silyl-Substituted Organometallic Compounds,” *Journal of Organic Chemistry* 33, no. 2 (1968): 780–784, <https://doi.org/10.1021/jo01266a061>.
33. Z. H. Li and C. F. Zhu, “Peterson Reaction: A Novel Method for the Synthesis of Alkenes,” *Chemical Reagents* 17, no. 2 (1995): 91–94&81, Chinese.
34. G. Büchi and J. C. Vederas, “Interchange of Functionality in Conjugated Carbonyl Compounds Through Isoxazoles,” *Journal of the American Chemical Society* 94, no. 26 (1972): 9128–9132, <https://doi.org/10.1021/ja00781a023>.
35. J. Y. Hu, L. L. Wang, Y. Q. Xu, et al., “Preparation Process of α -Damascone,” *Journal of University of Science and Technology Liaoning* 42, no. 3 (2019): 197–201, Chinese.
36. Y. Q. Xu, J. Y. Hu, G. Y. Xiao, J. Y. Liu, X. F. Wei, and L. L. Wang, “Method for Preparing α -Damascone,” Chinese Patent CN108558623B, 2018-09-21 [Chinese].
37. J. Y. Hu, A. Q. Guo, Y. Q. Xu, et al., “Preparation of α -Damascone,” *Polish Journal of Chemical Technology* 21, no. 1 (2019): 50–51, <https://doi.org/10.2478/pjct-2019-0009>.
38. T. Banerjee and P. Dureja, “Synthesis of 4’-(2,6,6-Trimethyl-2-Cyclohexen-1-yl)-3’-Buten-2’-Ketoxime-O-Alkyl Ethers,” *Molecules* 10, no. 8 (2005): 990–999, <https://doi.org/10.3390/10080990>.
39. J. Aleu, E. Brenna, C. Fuganti, and S. Serra, “Lipase-Mediated Synthesis of the Enantiomeric Forms of 4,5-Epoxy-4,5-Dihydro- α -Ionone and 5,6-Epoxy-5,6-Dihydro- β -Ionone. A New Direct Access to Enantiopure (R)- and (S)- α -Ionone,” *Journal of the Chemical Society, Perkin Transactions 1* 3, no. 24 (1999): 271–278, <https://doi.org/10.1039/A808780F>.
40. J. C. Cherton, M. Lanson, D. Ladjama, Y. Guichon, and J. J. Basselier, “Synthesis of Isoxazoles Substituted α to Nitrogen by an Alkyl or Alkenyl Side Chain,” *Canadian Journal of Chemistry* 68, no. 8 (1990): 1271–1276, <https://doi.org/10.1139/v90-196>.
41. A. Barco, S. Benetti, G. P. Pollini, P. G. Baraldi, M. Guarneri, and C. B. Vicentini, “1,4-Diketones via Isoxazole Intermediates,” *Journal of Organic Chemistry* 44, no. 1 (1979): 105–106, <https://doi.org/10.1021/jo01315a023>.
42. X. F. Wei, “Study on the Preparation of α -Damasenone,” (Anshan, China: University of Science and Technology Liaoning, 2018), Master’s thesis Chinese.

43. C. Dupuy and J. L. Luche, "New Developments of the Wharton Transposition," *Tetrahedron* 45, no. 11 (1989): 3437–3444, [https://doi.org/10.1016/S0040-4020\(01\)81022-X](https://doi.org/10.1016/S0040-4020(01)81022-X).
44. P. S. Wharton and D. H. Bohlen, "Hydrazine Reduction of α,β -Epoxy Ketones to Allylic Alcohols," *Journal of Organic Chemistry* 26, no. 9 (1961): 3615–3616, <https://doi.org/10.1021/jo01067a117>.
45. P. S. Wharton, "Stereospecific Synthesis of 6-Methyl-Trans-5-Cyclodecenone," *Journal of Organic Chemistry* 26, no. 12 (1961): 4781–4782, <https://doi.org/10.1021/jo01069a609>.
46. D. B. Dess and J. C. Martin, "Readily Accessible 12-I-5 Oxidant for the Conversion of Primary and Secondary Alcohols to Aldehydes and Ketones," *Journal of Organic Chemistry* 48, no. 22 (1983): 4155–4156, <https://doi.org/10.1021/jo00170a070>.
47. W. Oppolzer, "Vinylketenes," in *Comprehensive Organic Synthesis*, ed. B. M. Trost and I. Fleming, 5 (Oxford, UK: Pergamon, 1991), 315–399.
48. R. C. Cookson and R. M. Tuddenham, "Synthesis of α -Damascone [Trans-1-(2,6,6-Trimethylcyclohex-2-enyl)but-2-en-1-one] by a Catalysed Diels–Alder Reaction With Inverse Electron Demand," *Journal of the Chemical Society, Perkin Transactions 1* 1, no. 6 (1978): 678–680, <https://doi.org/10.1039/P19780000678>.
49. R. C. Cookson and R. M. Tuddenham, "A Lewis Acid Catalysed Diels–Alder Reaction With Inverse Electron Demand; An Alternative Synthesis of α -Damascone," *Journal of the Chemical Society, Chemical Communications* no. 19 (1973): 742, <https://doi.org/10.1039/C39730000742>.
50. S. Watanabe, H. Ujihara, T. Yamamoto, and T. Hagiwara, "Production Process of Cyclohexenyl Ketones," US Patent US20020004615A1, 2002-01-10.
51. K. Turner, "A Review of U.S. Patents in the Field of Organic Process Development Published During November and December 2004," *Organic Process Research & Development* 9, no. 2 (2005): 235–243, <https://doi.org/10.1021/op050031k>.
52. K. H. Schulte-Elte, H. Strickler, F. Gautschi, et al., "Synthesen und Cyclisierungsreaktionen der Pseudodamascone ein Neuer Zugang zu α -Damasconverbindungen," *Liebigs Annalen der Chemie* 1975, no. 3 (1975): 484–508, <https://doi.org/10.1002/jlca.197519750312>.
53. G. Saucy, R. Marbet, H. Lindlar, and O. Isler, "Über eine Neue Synthese von Citral und Verwandten Verbindungen," *Helvetica Chimica Acta* 42, no. 6 (1959): 1945–1955, <https://doi.org/10.1002/hlca.19590420624>.
54. L. Colombi, A. Bosshard, H. Schinz, and C. F. Seidel, "Cyclocitral, Dihydro-Cyclocitral, Dihydro-Jonon," *Helvetica Chimica Acta* 34, no. 1 (1951): 265–273, <https://doi.org/10.1002/hlca.19510340129>.
55. Y. Wang, X. H. Chen, and Z. M. Cui, "Synthesis of Cyclocitral," *Chemical World* 10 (2005): 614–616&620, Chinese.
56. R. P. Shen, S. P. Hu, X. H. Song, et al., "Synthesis of β -Ionone From α -Cyclocitral Directly by Condensation Reaction," *Journal of Chemical Engineering of Chinese Universities* 25, no. 3 (2011): 538–542, Chinese.
57. F. Naef and R. Decorzant, "Grignard and Hydride Addition to a Ketene Intermediate: A Novel Access to α -Damascone and α -Cyclocitral," *Tetrahedron* 42, no. 12 (1986): 3245–3250, [https://doi.org/10.1016/S0040-4020\(01\)87388-9](https://doi.org/10.1016/S0040-4020(01)87388-9).
58. B. S. Bal, W. E. Childers, and H. W. Pinnick, "Oxidation of α,β -Unsaturated Aldehydes," *Tetrahedron* 37, no. 11 (1981): 2091–2096, [https://doi.org/10.1016/S0040-4020\(01\)97963-3](https://doi.org/10.1016/S0040-4020(01)97963-3).
59. L. Ruzicka, H. Schinz, and I. X. Veilchenriechstoffe, "Über die Synthese der Kernmethylierten Jononhomologen 1,1,3,6-Tetramethyl-2-(Buten-2¹-ylon-2³)-Cyclohexen-(2 bzw. 3)," *Helvetica Chimica Acta* 23, no. 1 (1940): 959–974, <https://doi.org/10.1002/hlca.194002301123>.
60. J. D. Wuest, A. M. Madonik, and D. C. Gordon, "Vinylketenes. Synthesis of (+)-Actinidine," *Journal of Organic Chemistry* 42, no. 12 (1977): 2111–2113, <https://doi.org/10.1021/jo00432a019>.
61. Y. Nakatani, K. Ni, K. Kubota, R. Tahara, and Y. Shigematsu, "Nouvelle Synthèse de l' α -Damascone," *Agricultural and Biological Chemistry* 38, no. 7 (1974): 1351–1354, <https://doi.org/10.1271/bbb1961.38.1351>.
62. W. Kazunori, "Method of Producing Damascone or Damascenone," JP Patent JP200060171, 2001-09-11.
63. W. M. Li, Z. C. Wang, and H. L. Chen, "The Improvement Synthesis of α -Damascone," *Huaxue Shiji* 28, no. 11 (2006): 699–700, Chinese.
64. Q. Li, Y. W. Huang, X. Lu, and X. M. He, "Synthesis of β -Damascone From Ethyl Cyclogeranate," *Chemistry Bulletin* 74, no. 3 (2011): 275–279, Chinese.
65. Q. Li, Y. W. Huang, X. Lu, and X. M. He, "A Synthetic Method for β -Damascone," CN Patent CN101698636B, 2009-10-28 [Chinese].
66. Z. A. Huang, F. Hou, Z. G. Qian, J. H. Fei, and C. Z. Zhang, "A Synthetic Approach to β -Damascone," CN Patent CN106496004B, 2016-09-06 [Chinese].
67. J. H. Wu and Y. J. Xiao, "Studies on the Synthesis of β -Damascone," *Special Bulletin From the Research Institute of Fragrance and Flavor Industry* (Beijing, China: Ministry of Light Industry, 1982), Chinese.
68. R. Pellicciari, E. Sisani, and R. Fringuelli, "A New Synthesis of β -Damascone," *Tetrahedron Letters* 21, no. 41 (1980): 4039–4042, [https://doi.org/10.1016/S0040-4039\(00\)92865-X](https://doi.org/10.1016/S0040-4039(00)92865-X).
69. S. Mosafari, R. E. Jelley, B. Fedrizzi, and D. Barker, "Synthesis of d₆-Deuterated Analogues of Aroma Molecules: B-Damascenone, β -Damascone, and Safranal," *Results in Chemistry* 4, no. 1 (2022): 100264, <https://doi.org/10.1016/j.rechem.2021.100264>.
70. S. Mosafari, R. E. Jelley, B. Fedrizzi, and D. Barker, "Scalable Synthesis of the Aroma Compounds d₆- β -Ionone and d₆- β -Cyclocitral for Use as Internal Standards in Stable Isotope Dilution Assays," *Tetrahedron Letters* 61, no. 51 (2020): 152642, <https://doi.org/10.1016/j.tetlet.2020.152642>.
71. X. D. Guo, J. H. Li, Z. Y. Yu, et al., "Damascone and Preparation Method Thereof," CN Patent CN118771961A, 2024-07-08[Chinese].
72. R. W. Trenkle, B. D. Mookherjee, J. B. Hall, et al., "Process for Preparing Acyl Trimethyl Cyclohexene Derivatives and Use of Intermediates Therefor in Augmenting or Enhancing the Aroma or Taste of a Consumable Material," US Patent US4250332A, 1981-02-10.
73. H. Rupe and E. Kambli, "Ungesättigte Aldehyde aus Acetylen-Alkoholen," *Helvetica Chimica Acta* 9, no. 1 (1926): 672, <https://doi.org/10.1002/hlca.19260090185>.
74. Y. Y. Bao, Y. Z. Zhang, and Y. Li, "A Synthetic Method for β -Damascone," CN Patent CN111440055A, 2020-04-24 [Chinese].
75. K. H. Meyer and K. Schuster, "Umlagerung Tertiärer Äthynyl-Carbinole in Ungesättigte Ketone," *Berichte der Deutschen Chemischen Gesellschaft* 55, no. 5 (1922): 819–820.
76. S. Swaminathan and K. V. Narayanan, "The Rupe and Meyer-Schuster Rearrangements," *Chemical Reviews* 71, no. 5 (1971): 429–438, <https://doi.org/10.1021/cr60273a001>.
77. P. Chaumont-Olive, K. Plevová, A. M. Collado Pérez, J. Sánchez-Quesada, R. Šebesta, and J. Cossy, "Synthesis of β -Damascone From 2,6-Dimethylcyclohexanone," *ARKIVOC* 10 (2021): 140–150, <https://doi.org/10.24820/ark.5550190.p011.687>.
78. L. A. Sarandeses and J. L. Luche, "A New Synthesis of α - and β -Damascones From the Ionones," *Journal of Organic Chemistry* 57, no. 9 (1992): 2757–2760, <https://doi.org/10.1021/jo00035a045>.
79. Y. L. Zong, X. X. Qi, and L. N. Luo, "Study on the Synthesis of β -Damascone and Its Effects on Tobacco Flavor," *Acta Tabacaria Sinica* 3, no. 3 (1997): 26–29, Chinese.
80. J. Tang, "Development of β -Damascone," *Hebei Chemical Industry* 36, no. 1 (2013): 49–50&56, Chinese.
81. J. X. Zhou and Q. Chen, "Method for Synthesizing β -Damasenone," CN Patent CN113816840A, 2021-10-21 [Chinese].