

The present invention relates to a process for producing rotundone from α -guaiene, to a use of α -guaiene for producing rotundone, to fragrance or flavor ingredients and to a use of such fragrance or flavor ingredients.

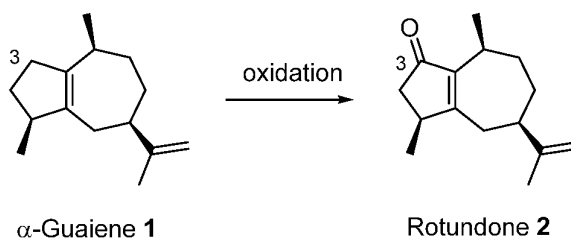
- 5 Rotundone ((3*S*,5*R*,8*S*)-3,8-dimethyl-5-prop-1-en-2-yl-3,4,5,6,7,8-hexahydro-2H-azulen-1-one) is a sesquiterpene originally discovered in the tubers of *Cyperus rotundus*. The compound has a strong spicy peppercorn aroma and a woody odor. It was later also found to be a constituent of black and white pepper, marjoram, oregano, rosemary,
10 basil, thyme, geranium, agarwood, patchouli oil and cypriol oil. Furthermore, rotundone was detected in various wines that exhibit peppery spicy notes, mainly Syrah (Shiraz) wines. The sesquiterpene has an aroma detection threshold in water of 8 ng/L, which is amongst the lowest for any natural product yet discovered (*J. Agric. Food Chem.*
15 **2008**, 56, 3738-3744 and references cited therein).

Moreover, an investigation of the aromas of grapefruit, orange, apple, and mango revealed the presence of rotundone. Sensory analyses showed that the compound, when added at even subthreshold levels to model beverages of these fruits, did not confer directly a woody odor,
20 but had significant effects on the overall flavors of the beverages, helping them to better approximate the natural flavors of the fruits (*J. Agric. Food Chem.* **2017**, 65, 4464-4471).

Despite these highly attractive properties, rotundone has not been used as an ingredient in the fragrance and flavor industry thus far. A main
25 reason for this is the fact that there is no reliable process for the production of sufficient amounts of this material in the desired olfactive quality.

It is surmised that in nature rotundone is formed from α -guaiene by allylic oxidation of the C(3) position, either by aerial oxidation, reactive

oxygen species (ROS) or enzymatic oxidation (*J. Agric. Food Chem.* **2014**, *62*, 10809–10815; *J. Nat. Prod.* **2015**, *78*, 131-145; *J. Exp. Bot.* **2016**, *67*, 787-798). This transformation can also be achieved by means of chemical synthesis.



α -Guaiene is a constituent of various essential oils, such as guaiacwood oil or patchouli oil. Although it is widely employed in the field of fragrances and flavors, it hitherto could not be used as a precursor for the industrial production of rotundone. First of all, there are serious
10 limitations in the supply of plant materials, from which α -guaiene can be extracted, as many of these are harvested from endangered species, the exploitation of which is under strict control. Furthermore, the separation of α -guaiene from plant extracts is difficult and a major hurdle to access this precursor. Also, the quality of such extracts often suffers from
15 considerable fluctuations. For example, the odor of guaiacwood has been reported to be accompanied by a "smoked ham"-like odor, conceivably acquired during forced distillation of the guaiacwood in adding mineral acid to the distillation water in order to increase the yield and speed of the distillation (S. Arctander, *Perfume and Flavor Materials of Natural*
20 *Origin* **1994**, Allured Publishing Corporation, Carol Stream, IL, USA). The impurities causing this "smoked ham"-like odor are difficult to separate, either from α -guaiene or from rotundone after conversion.

It is therefore a problem underlying the present invention to overcome the above-mentioned shortcomings in the prior art. In particular, it is a
25 problem underlying the present invention to provide a process for the production of rotundone for use in the fragrance and flavor industry, more specifically in the substantial absence of impurities causing a

disturbing odor, in particular of the above mentioned “*smoked ham*”-like odor. Advantageously, this process is supposed to allow for the production of significant quantities of rotundone. Furthermore, the process should be environmentally friendly, safe and cost-efficient.

5 These problems are solved by a process according to claim 1. In this process, rotundone is produced from α -guaiene, in particular by oxidation of the C(3) position. The α -guaiene is produced from a precursor by a sesquiterpene synthase, wherein the sesquiterpene synthase is produced in a microorganism.

10 In the context of the present invention, the term “*sesquiterpene synthase*” refers to a polypeptide capable of effecting the synthesis of the sesquiterpene α -guaiene from a precursor.

Furthermore, that “*the α -guaiene is produced from a precursor by a sesquiterpene synthase*” is to be understood that the precursor and the
15 sesquiterpene synthase are brought in contact with each other in order to effect the formation of α -guaiene.

Another aspect of the present invention refers to a process for producing rotundone comprising the steps of:

- Producing a sesquiterpene synthase in a microorganism;
- 20 – Producing α -guaiene by bringing the sesquiterpene synthase obtained into contact with a precursor;
- Producing rotundone from the α -guaiene obtained, in particular by oxidation of the C(3) position.

By use of a sesquiterpene synthase that is produced in a microorganism,
25 α -guaiene can be obtained independently from naturally sourced raw materials, more specifically through a biotechnological process. Without this constraint, significant quantities of rotundone can be produced at industrial scale with no limitations in volumes, using an environmentally

friendly process. This allows for the sustainable production of this compound, in particular as an ingredient in the fragrance and flavor industry. Furthermore, due to the fact that no extraction of plant material is necessary, the α -guaiene required can be furnished under
5 controlled conditions in stable quality and in the substantial absence of impurities causing a disturbing odor, in particular of the above mentioned “*smoked ham*”-like odor.

The microorganism can be cultured under conditions suitable to produce α -guaiene, in particular *in vivo*. This has the advantage that the
10 production of both of the sesquiterpene synthase and the α -guaiene can be effected in the same biotransformation, which makes the overall process more efficient. Furthermore, isolation of the sesquiterpene synthase is avoided.

In a preferred embodiment, the microorganism is cultured under
15 conditions suitable to also produce the precursor, in particular from a sugar. Examples of suitable sugars include, but are not limited to, sucrose, fructose, xylose, glycerol, glucose, cellulose, starch, cellobiose and other glucose containing polymers.

On the other hand, the sesquiterpene synthase can also be isolated from
20 the microorganism prior to the production of α -guaiene. Although an additional transformation is then required, the formation of the α -guaiene can then be effected *ex vivo* under more controlled conditions.

The sesquiterpene synthase required to effect the formation of α -guaiene *ex vivo* can be obtained by extraction from any microorganism
25 expressing it, using standard protein or enzyme extraction technologies. If the microorganism is a cell releasing the sesquiterpene synthase into the culture medium, the sesquiterpene synthase may simply be collected from the culture medium, for example by centrifugation, optionally followed by washing steps and re-suspension in suitable
30 buffer solutions. If the microorganism accumulates the polypeptide

within itself, the sesquiterpene synthase may be obtained by disruption or lysis of the cells and further extraction of the polypeptide from the cell lysate.

The sesquiterpene synthase, either in isolated form or together with
5 other proteins, for example in a crude protein extract obtained from the cultured microorganism, may then be suspended in a buffer solution at optimal pH. If adequate, salts, BSA and other kinds of enzymatic co-factors, may be added in order to optimize enzyme activity. In particular, the enzymatic co-factor can be a Mg^{2+} salt.

10 The precursor may then be added to the suspension or solution, which is then incubated at optimal temperature, for example between 15 and 40 °C, preferably between 25 and 35 °C, more preferably at 30 °C. After incubation, the α -guaiene, and optionally the other sesquiterpene by-products may be isolated from the incubated solution by standard
15 isolation procedures, such as solvent extraction and distillation, optionally after removal of polypeptides from the solution.

The microorganism can be a recombinant microorganism. The term "*recombinant microorganism*" refers to a microorganism that is transformed to express the sesquiterpene synthase, preferably under
20 conditions conducive to the production of α -guaiene. The term "*transformed*" refers to the fact that the microorganism was subjected to genetic engineering. Preferably, the microorganism is heterologously expressing the sesquiterpene synthase or even over-expressing it. There are several methods known in the art for the creation of transgenic
25 microorganisms.

The recombinant microorganism can be a bacterium or a yeast. More specifically, the microorganism can be selected from the group consisting of *Escherichia coli*, *Arxula adeninivorans*, *Candida boidinii*, *Hansenula polymorpha*, *Kluyveromyces lactis*, *Pichia pastoris*,
30 *Saccharomyces cerevisiae* and *Yarrowia lipolytica*.

Preferably, the *Escherichia coli* used is recognized by the industry and regulatory authorities (including but not limited to an *Escherichia coli* K12 or an *Escherichia coli* BL21).

The precursor can be an acyclic precursor, in particular farnesyl
5 pyrophosphate. In a preferred embodiment of the present invention, wherein the α -guaiene is formed *in vivo*, the microorganism is also capable of producing farnesyl pyrophosphate, preferably from a sugar.

The sesquiterpene synthase can have a sequence identity with SEQ ID NO.: 2, SEQ ID NO.: 4 or SEQ ID No.: 6 of at least 70%, preferably at
10 least 80%, more preferably at least 90%, even more preferably at least 95%.

SEQ ID NO.: 2 corresponds to the enzyme VvGuaS, which was obtained from *Vitis vinifera*, as described in *J. Exp. Bot.* **2016**, 67, 799-808. SEQ ID NO.: 1 represents the corresponding nucleic acid sequence. VvGuaS
15 has been shown to produce α -guaiene as a main product with 45% selectivity.

SEQ ID NO.:4 corresponds to the enzyme AcC3, which was obtained from *Aquilaria* plants, as described in *Plant Physiol.* **2010**, 154, 1998-2007. SEQ ID NO.: 3 represents the corresponding nucleic acid
20 sequence. AcC3 has been shown to produce α -guaiene with 45% selectivity.

SEQ ID NO.: 6 corresponds to the enzyme PatTps717, which was obtained from *Pogostemon cablin* (patchouli), as described in *Arch. Biochem. Biophys.* **2006**, 454, 123-136. SEQ ID NO.: 5 represents the
25 corresponding nucleic acid sequence (cf. also NCBI GenBank accession number AY508730 {Version: AY508730.1}). PatTps717 has been shown to produce α -guaiene with 13% selectivity.

The sequence identity between two peptidic or nucleotidic sequences is a function of the number of amino acids or nucleotide residues that are

identical in the two sequences when an alignment of these two sequences has been generated. Identical residues are defined as residues that are the same in the two sequences in a given position of the alignment. The percentage of sequence identity, as used herein, is
5 calculated from the optimal alignment by taking the number of residues identical between two sequences dividing it by the total number of residues in the shortest sequence and multiplying by 100. The optimal alignment is the alignment in which the percentage of identity is the highest possible. Gaps may be introduced into one or both sequences in
10 one or more positions of the alignment to obtain the optimal alignment. These gaps are then taken into account as non-identical residues for the calculation of the percentage of sequence identity.

Alignment for the purpose of determining the percentage of amino acid or nucleic acid sequence identity can be achieved in various ways using
15 computer programs and for instance publicly available computer programs. Preferably, the BLAST program (*FEMS Microbiol Lett.* **1999**, 174, 247-250) set to the default parameters, available from the National Center for Biotechnology Information (NCBI) can be used to obtain an optimal alignment of peptidic or nucleotidic sequences and to calculate
20 the percentage of sequence identity.

In the context of the present invention, another microorganism can be transformed capable of producing the sesquiterpene synthase with at least one nucleic acid encoding the sesquiterpene synthase.

The at least one nucleic acid can have a sequence identity with SEQ ID
25 NO.: 1, SEQ ID NO.: 3 or SEQ ID No.: 5 of at least 70%, preferably at least 80%, more preferably at least 90%, even more preferably at least 95%.

The "nucleic acid" can be defined as including deoxyribonucleotide or ribonucleotide polymers in either single- or double-stranded form (DNA
30 and/or RNA). An important tool for transforming microorganisms cells

suitable to produce the sesquiterpene synthase is an expression vector comprising a nucleic acid. An "*expression vector*" as used herein includes any linear or circular recombinant vector including but not limited to plasmids, phagemids, phages, cosmids, artificial bacterial or
5 artificial yeast chromosomes, and knock-out or knock-in constructs. The skilled person is capable of selecting a suitable vector according to the expression system.

A bacterial or yeast cell may be transformed by exogenous or heterologous DNA when such DNA has been introduced inside the cell.
10 The transforming DNA may or may not be integrated, i.e. covalently linked into the genome of the cell. In prokaryotes, and yeast, for example, the transforming DNA may be maintained on an episomal element such as a plasmid. With respect to eukaryotic cells, a stably transfected cell is one in which the transfected DNA has become
15 integrated into a chromosome so that it is inherited by daughter cells through chromosome replication. This stability is demonstrated by the ability of the eukaryotic cell to establish cell lines or clones comprised of a population of daughter cells containing the transforming DNA.

In the context of the present invention, bacteria (for example
20 *Escherichia coli*) can be transformed with, for example, recombinant bacteriophage DNA, plasmid DNA, bacterial artificial chromosome, or cosmid DNA expression vectors. Yeasts (for example *Saccharomyces cerevisiae*) can be transformed with, for example, recombinant yeast expression vectors containing the polynucleotide molecule of the
25 disclosure. Depending on the microorganism and the respective vector used, the polynucleotide can integrate, for example, into the chromosome or the mitochondrial DNA or can be maintained extrachromosomally like, for example, episomally or can be only transiently comprised.

The suitability of a microorganism for use according to the present invention may be determined by simple test procedures using well known methods. For example, the microorganism to be tested may be propagated in a rich medium (e.g. LB-medium, Bactotryptone yeast
5 extract medium or nutrient medium) at a pH, temperature and under aeration conditions commonly used for propagation of the microorganism. Once a microorganisms is selected that produces the desired products of bioconversion, the products are typically produced by a production cell line on the large scale by suitable expression
10 systems and fermentations, i.e. by microbial production in cell culture.

For cell cultivation, a defined minimal medium such as M9A can be used. The components of M9A medium comprise: 14 g/L KH_2PO_4 , 16 g/L K_2HPO_4 , 1 g/L $\text{Na}_3\text{Citrate}\cdot 2\text{H}_2\text{O}$, 7.5 g/L $(\text{NH}_4)_2\text{SO}_4$, 0.25 g/L $\text{MgSO}_4\cdot 7\text{H}_2\text{O}$, 0.015 g/L $\text{CaCl}_2\cdot 2\text{H}_2\text{O}$, 5 g/L glucose and 1.25 g/L yeast
15 extract. On the other hand, a nutrient rich medium such as LB can be used. The components of LB medium comprise: 10 g/L tryptone, 5 g/L yeast extract and 5g/L NaCl.

The microorganism may be grown in a batch, fed batch or continuous process or combinations thereof. Typically, the microorganism is grown
20 in a fermenter at a defined temperature(s) in the presence of a suitable nutrient source for a desired period of. As used herein, the term "*batch cultivation*" is a cultivation method in which culture medium is neither added nor withdrawn during the cultivation. As used herein, the term "*fed-batch*" means a cultivation method in which culture medium is
25 added during the cultivation but no culture medium is withdrawn.

The process according to the present invention can further comprise the step of purifying the α -guaiene prior to the production of rotundone, in particular by distillation or chromatography. Advantageously, the α -guaiene used for producing rotundone has a purity of 10 to 95%,
30 preferably 20 to 80%, more preferably 30 to 70%.

In a process according to the present invention, rotundone can be produced from α -guaiene by an oxidation selected from the group consisting of transition metal catalysis, organocatalysis, chromium oxidation, selenium oxidation, manganese oxidation, aerial oxidation, enzymatic oxidation, electrochemical oxidation and combinations thereof. This bestows significant flexibility with regard to the means available to effect this transformation.

In order to avoid any ambiguity, in the context of the present invention, "*oxidation of α -guaiene at the C(3) position*", is not only to be understood as a direct oxidation of the methylene group at the C(3) position of α -guaiene to the corresponding carbonyl group. This transformation can also refer to a process, wherein the carbonyl group is formed stepwise via an intermediate, for instance a secondary alcohol. Depending on the method used, this intermediate can be isolated and further transformed into rotundone.

In the context of the present invention "*aerial oxidation*" is to be understood as any oxidation with molecular oxygen (O₂), either in pure or dilute form, for instance as air.

When rotundone is produced from α -guaiene by transition metal catalysis, the transition metal can be selected from the group consisting of iron, copper, vanadium, manganese, molybdenum, cobalt, ruthenium, palladium, iridium, rhodium, titanium, chromium, gold, osmium and combinations thereof. With these transition metals, high selectivities for the product rotundone and good yields can be achieved.

In particular, rotundone can be produced from α -guaiene by iron porphyrin catalysis comprising the steps of:

- Forming a mixture containing α -guaiene and an iron (III)-X porphyrin complex catalyst in a solvent;
- Introducing molecular oxygen into the mixture;

- Effecting production of rotundone by oxidation of the C(3) position of α -guaiene.

Iron porphyrin catalysis provides an efficient method for the transformation of α -guaiene to rotundone with good selectivities and yields. Molecular oxygen (O_2) is a superb stoichiometric oxidant that is readily available, cost-efficient, environmentally friendly and save to handle. Also the iron (III)-X porphyrin complex catalysts show a low toxicity and can be used with a low catalyst loading. Furthermore, the odor profiles of the crude products are such, that the odor of rotundone is not adversely affected by byproducts. As a consequence of this, depending on the application, the products obtained can be used in the perfume and flavor industry without purification of rotundone. If however, the rotundone obtained is to be purified, this can be achieved through a simple distillation or by column chromatography.

In the above-described iron porphyrin catalysis, X can be selected from Cl, Br, I, mesylate, triflate and carboxylates, preferably Cl, Br and I. Especially Cl is preferred, as with this anion, a variety of iron (III)-X porphyrin complex catalysts can be obtained at low costs from commercial sources with different substitution patterns at the porphyrin system.

In the above-described iron porphyrin catalysis, the mixture can additionally contain a base coordination compound, preferably an *N*-heterocycle, more preferably imidazole. This has the advantage that better yields and purities are achieved after short reaction times.

On one hand, the step of introducing molecular oxygen into the mixture can comprise bubbling oxygen gas into the mixture. On the other hand, the step of introducing molecular oxygen into the mixture can also comprise bubbling air into the mixture.

Another option for introducing molecular oxygen into the mixture is to heavily stir the mixture under an oxygen containing atmosphere. It has been found that good results can be achieved in the above-described iron porphyrin catalysis by the introduction of either air or molecular oxygen into the reaction mixture. Air as the source of molecular oxygen has the further advantage that it is abundantly available at low cost. Furthermore it is operationally safe.

Although not required, the process may include exposing the mixture to electromagnetic radiation, preferably UV light radiation or radiation in the visible range of the electromagnetic spectrum. The wavelength range of electromagnetic radiation used to expose the mixture may be in the range of about 200 nm to about 800 nm. Alternatively, the process may be carried out in the dark or under ambient light conditions. The possibility to choose among these options allows the choice of the most suitable setup for industrial production.

In the iron porphyrin catalysis, the solvent can be selected from the group consisting of water, acetone, ethanol, 2-propanol, ethyl acetate, isopropyl acetate, methanol, methyl ethyl ketone, 1-butanol, *tert*-butanol and mixtures thereof, preferably an ethanol/water mixture. These solvents can be either discarded without environmental damage or easily recycled after use. An ethanol/water mixture has the further advantage that rotundone can be obtained in particular good yield and purity. Furthermore, with an ethanol : water ratio of less than 1:1, a non-flammable mixture can be achieved.

On the other hand, the solvent can also be selected from the group consisting of cyclohexane, heptane, toluene, methylcyclohexane, methyl *tert*-butyl ether, isooctane, acetonitrile, xylenes, dimethyl sulfoxide, acetic acid, ethylene glycol and mixtures thereof.

Preferably, the catalyst is an iron (III) porphyrin complex catalyst, having a chloride counter-ion. Furthermore, the porphyrin complex can

be a tetraphenylporphyrin complex. Specifically, the catalyst can be chloro(tetraphenylporphyrinato)iron(III). Using this catalyst, superb results with respect to selectivity, yield and product purity can be achieved. Furthermore, as mentioned above, this catalyst is cost-effective and available from commercial sources. However, catalysts of this type with different substitution patterns at the porphyrin can be easily and nearly quantitatively prepared from even less expensive components Fe(II)Cl₂ and the porphyrine ligand. In addition, chloro(tetraphenylporphyrinato)iron-(III) can be employed with low catalyst loadings. Furthermore, hemine chloride can be used as an iron (III)-X porphyrin complex catalyst.

Alternatively, rotundone can be produced from α -guaiene by cobalt catalysis, in particular comprising the steps of:

- Forming a mixture containing α -guaiene and at least one cobalt (II) complex catalyst, preferably selected from the group consisting of cobalt(II) ethylhexanoate, cobalt(II) acetylacetonate, cobalt(II) naphthenate and mixtures thereof, in particular in the presence of 4-methyl-2-pentanone, in a solvent;
- Introducing molecular oxygen into the mixture;
- Effecting oxidation of the C(3) position of α -guaiene.

As yet another alternative, rotundone can be produced from α -guaiene by chromium oxidation, in particular comprising the steps of:

- Forming a mixture containing α -guaiene and at least one chromium reagent, preferably a chromium (VI) reagent, in particular selected from the group consisting of pyridinium chlorochromate, pyridinium fluorochromate, pyridinium dichromate, chromium trioxide, sodium chromate and mixtures thereof, preferably in the presence of celite, in a solvent;
- Effecting oxidation of the C(3) position of α -guaiene.

With this method, rotundone can be obtained in good yield and purity.

Moreover, rotundone can be produced from α -guaiene by organocatalysis, in particular comprising the steps of:

- Forming a mixture containing α -guaiene, an organocatalyst,
5 preferably selected from the group consisting of *N*-hydroxyphthalimide and tetrachloro-*N*-hydroxyphthalimide, and an oxidant in a solvent;
- Effecting oxidation of the C(3) position of α -guaiene.

Through organocatalysis, production of rotundone from α -guaiene can
10 be achieved without the use of expensive and potentially harmful heavy metal catalysts. This process is therefore cost-efficient, environmentally friendly and operationally safe.

In the organocatalysis, the oxidant can be selected from the group consisting of *tert*-butyl hydroperoxide, hydrogen peroxide, dibenzoyl
15 peroxide, di-*tert*-butyl peroxide, sodium chlorite, molecular oxygen and mixtures thereof. All of these oxidants are bulk chemicals that are readily available and safe in use. Sodium chlorite and molecular oxygen have the further advantage that work-up of the reaction is particularly facile.

20 In the context of the present invention, rotundone can also be produced from α -guaiene by electrochemical oxidation, in particular comprising the steps of:

- Forming a mixture containing α -guaiene, an electrochemical mediator, preferably selected from the group consisting of *N*-
25 hydroxyphthalimide and tetrachloro-*N*-hydroxyphthalimide, and an electrolyte in a solvent;
- Applying an electrical current to the mixture;
- Effecting oxidation of the C(3) position of α -guaiene.

A representative example of electrochemical oxidation is described in *Nature* **2016**, 533, 77-81. It allows for the production of rotundone from α -guaiene in good yield and selectivity. By electrochemical oxidation, no or less stoichiometric oxidants need to be used and the generation of waste products is reduced.

In the above-described electrochemical oxidation, the mixture can additionally contain a base, preferably selected from the group consisting of pyridine, 2,6-lutidine, 2,4,6-collidine, trimethylamine, DBU and mixtures thereof. The solvent can be selected from the group consisting of acetone, acetonitrile, dichloromethane, pyridine and mixtures thereof. The electrolyte can be selected from the group consisting of LiBF₄, LiClO₄ and mixtures thereof.

Furthermore, in the above-described electrochemical oxidation, the mixture additionally contains a co-oxidant, preferably selected from the group consisting of *tert*-butyl hydroperoxide, hydrogen peroxide, dibenzoyl peroxide, di-*tert*-butyl peroxide and mixtures thereof. By use of a co-oxidant increased yields can be achieved.

Apart from chemical synthesis, rotundone can also be produced from α -guaiene by enzymatic oxidation, in particular through an enzyme selected from the group consisting of a cytochrome P450, preferably an α -guaiene 3-oxidase cytochrome P450, a laccase, a Rieske non-heme dioxygenase and combinations thereof. An α -guaiene 3-oxidase cytochrome P450 (referred therein as " *α -guaiene 2-oxidase VvSTO2*") has been described in *J. Exp. Bot.* **2016**, 67, 787-798. This enzyme has been shown to exhibit excellent substrate-specificity and selectivity.

An oxidation of α -guaiene at the C(3) position with the above-mentioned enzymes can also lead to a corresponding secondary alcohol. This intermediate can be further oxidized to rotundone using various methods, for instance oxidation with an alcohol oxidase or an alcohol dehydrogenase.

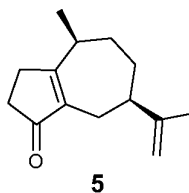
A process according to the present invention can further comprise the step of purifying the rotundone produced. This can be effected by distillation or chromatography. Distillation has the advantage that it can be performed at low cost on large scales. The advantage of
5 chromatography is that material with a particularly high purity can be obtained.

The present invention also refers to a use of α -guaiene for producing rotundone, in particular by oxidation of the C(3) position, wherein the α -guaiene is produced from a precursor, in particular an acyclic precursor,
10 by a sesquiterpene synthase, wherein the sesquiterpene synthase is produced in a microorganism.

A further aspect of the present invention relates to a fragrance or flavor ingredient obtainable by the process as stated hereinabove.

The present invention also refers to a fragrance or flavor ingredient, in
15 particular an ingredient as described hereinabove, wherein the portion of rotundone is in a range of 10 to 95 wt.-%, preferably 20 to 70 wt.-%, even more preferably 25 to 50 wt.-%.

The fragrance or flavor ingredient can additionally contain ketone **5**.



20 In such a fragrance or flavor ingredient, the weight-ratio of rotundone to ketone **5** can be in a range of 20:1 to 1:1, preferably 10:1 to 2:1, even more preferably 5:1 to 3:1.

The present invention also relates to a consumer product containing a fragrance or flavor ingredient as stated herein above and to the use of
25 such a fragrance or flavor ingredient.

The present invention also refers to a process for producing a fragrance or flavor composition and/or a consumer product, the process comprising the production of rotundone from α -guaiene by a process as described herein above.

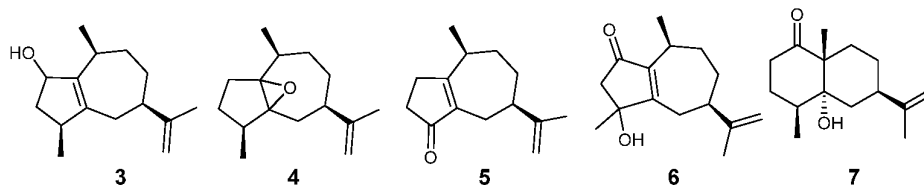
- 5 Further aspects and particular features of the present invention become apparent from the following description of representative embodiments.

Analytical Methods Employed

Polar GCMS:

- 10 35 °C / 2 min, 10 °C / min to 50 °C, 2.5 °C / min to 240 °C, 240 °C / 5 min. Thermo Scientific TSQ8000evo + Trace 1310 system. Polar column: Varian VF-WAX (polar, PEG phase). Column dimensions: 30 m length, 0.25 mm ID, 0.25 μ m film thickness. Injector: splitless. Flow: 1.2 mL / min. Carrier gas: Helium. Injection volume: 1 μ l. Injector
15 temperature: 230 °C. Transfer line: 250 °C. MS-quadrupol: 160 °C. MS-source: 230 °C. Ionization mode: Electron Impact (EI) at 70 eV.

By this method, the products obtained were identified. Minor and unidentified byproducts were neglected and their percentages (usually < 10%) are not given. Apart from α -guaiene **1** and rotundone **2**, side
20 products included rotundol **3**, epoxy-guaiene **4**, ketone **5**, hydroxy-rotundone **6**, and corymbolon **7**.



Components **1**–**7** as defined herein below are literature-known apart from ketone **5** which was isolated and its structure confirmed.

Nonpolar GC:

100 °C / 2 min, 15 °C / min to 240 °C, 240 °C / 5 min. Thermo Focus
GC. Nonpolar column: Agilent Technologies J&W Scientific DB-5
(nonpolar, 5% phenylmethylpolysiloxane). Column dimensions: 30 m
5 length, 0.32 mm ID, 0.25 µm film thickness. Injector: Split. Injector
temperature: 240 °C. Detector: FID. Detector temperature: 270 °C.
Injection volume: 1 µl. Carrier gas: Helium. Split ratio: 1 / 42.3.
Pressure: 70 kPa. Integrator: Hewlett Packard.

By this method, substrate purity, conversion and GC-purities of
10 rotundone **2** after distillation were determined (% rpa).

Source of α -Guaiene

α -Guaiene was isolated from Clearwood™ by repeated distillation with
purities of 37% to 85%. The purities were determined by GC and NMR
15 with internal standard anisaldehyde. The other constituents were
seychellene ($\leq 33\%$), α -patchoulene ($\leq 25\%$), and γ -patchoulene ($\leq$
5%). The purity was determined by GC and NMR with internal standard
anisaldehyde.

Clearwood™ (CAS 1450625-49-6) is a perfumery ingredient in the
20 patchouli, woody family and commercially available from Firmenich. This
mixture of sesquiterpenes, which contains about 14 wt.-% of α -guaiene
1, is obtained by fermentation of sugars (*IP.com Technical Disclosure*
IPCOM000233341D).

Examples for the biotechnological production of α -guaiene **1** are also
25 given in *Plant Physiol.* **2010**, 154, 1998-2007; *Arch. Biochem. Biophys.*
2006, 454, 123-136 and WO 2005/052163 A2.

Preparation of Rotundone **2** from α -Guaiene **1** (Iron Porphyrin Catalysis)

Chloro(tetraphenylporphyrinato)iron(III) (17 mg, 0.024 mmol) and imidazole (6.7 mg, 0.1 mmol) were added to α -guaiene **1** (61 % ex Clearwood™, 1 g, 3 mmol) in a 1:1 ethanol / water mixture (20 mL) under stirring. Oxygen was bubbled into the greenish turbid mixture at 45°C. After 30 min the oxygen inlet was replaced by an oxygen balloon. After 5 hours GC indicated complete conversion to a mixture containing of, rotundone **2** (24%), epoxy-guaiene **4** (3%), ketone **5** (6%), hydroxy-rotundone **6** (4%), seychellene **8** (37%). The dark-brown mixture was evaporated partially under reduced pressure and the residue extracted with *tert*-butyl methyl ether. The combined organic layers were dried over MgSO₄, filtered and evaporated. The residual brown oil (1.22 g) was bulb-to-bulb distilled at 150 - 230°C / 0.03 mbar, giving 0.88 g rotundone **2** of 32% GC-purity (43% corr. yield) as a red-brown oil and 0.18 g of a brown residue.

Preparation of Rotundone **2** from α -Guaiene **1** (Organocatalysis)

In a 100 mL round-bottom two-necked flask equipped with a condenser, α -guaiene **1** (37 % ex Clearwood™, 1.022 g, 1.85 mmol) and NHPI (0.082 g, 0.5 mmol) were dissolved in acetonitrile (30 mL) and water (15 mL) under positive nitrogen flow. The solution was heated to 50 °C, and solid NaClO₂ (0.678 g, 7.5 mmol) was added in portions. The reaction mixture was then allowed to stir at 50 °C for 21 h. Then, the solution was allowed to cool to room temperature and poured onto NaOH (aqueous, 2M). The product was extracted with MTBE and washed with brine. The combined organic layers were dried over MgSO₄, filtered and evaporated. GCMS of the residue (0.92 g) indicated complete conversion to a mixture containing rotundone **2** (6%), rotundol **3** (1%), epoxy-guaiene **4** (1%), ketone **5** (1%), hydroxy-rotundone **6** (2%), seychellene (40%), α -patchoulene (11%), α -patchoulenone (2%) and β -

patchoulone (2%) The residual brown oil (0.92 g) was bulb-to-bulb distilled at 160 - 220°C / 0.01 mbar, giving 0.92 g rotundone **2** of 17% GC-purity (33% corr. yield) as a red-brown oil and 90 mg of a brown residue.

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Olfactory Description of Rotundone **2**

(from iron porphyrin catalysis as described herein above, purified by distillation, dilution 1% in ethanol on blotter dipped freshly, after 4 h and after 1 week)

Time	Olfactory Description
2 minutes	fresh, woody, cedarwood, terpenic, wood fiber, slightly minty and terpinol
4 hour	warm, woody, spicy, cedar wood like, wood fiber, sawdust, straw
1 week	cedar wood like, wood fiber, sawdust, straw

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Synthesis and purification of Ketone **5**

Oxygen was bubbled into a mixture of chloro(tetraphenylporphyrinato) iron(III) (34 mg, 0.05 mmol), imidazole (6.7 mg, 0.1 mmol) and α -guaiene 91% (1 g, 4.5 mmol) in polyethylenglycol (20 mL) under
15 stirring, light irradiation with a 300 W Osram Ultra Vitalux lamp and at 45 °C. After 38 hours, GCMS indicated a quantitative conversion to a mixture of rotundone **2** (27%), epoxy-guaiene **4** (6%), ketone **5** (11%), hydroxy-rotundone **6** (19%), corymbolon **7** (1%). The orange product mixture was extracted with *tert*-butyl methyl ether against water. The
20 combined organic layers were dried over MgSO₄, filtered and evaporated to 0.7 g of an orange oil, which was purified by flash chromatography over 30 g silica gel 15 – 40 μ m using an hexane / ethyl acetate gradient 98:2 – 50:50. After evaporation of the solvents this gave 0.23 g of rotundone **2** with 52-59% GC-purity (13% corr) and 24 mg of Ketone **5**
25 with a GC-purity of 71% (2% corr). Ketone **5** was further purified by

preparative GC to a purity of > 99.5% (containing less than 0.03% of rotundone **2**) and its odor analyzed on blotter and by sniff-GC being woody, cedary, dry, isoraldeine-guaiac, smokey, fruity, spicy.

Analytical data of ketone **5** ((4*S*,7*R*)-4-methyl-7-(prop-1-en-2-yl)-3,4,5,6,7,8-hexahydroazulen-1(2H)-one): ¹H-NMR (benzene-D₆, 400 MHz): 4.85 – 4.9 (2 s, 2 H), 3.1 – 3.14 (2 h), 2.5 – 1.4 (10 H), 1.75 (s, 3 H), 0.9 (d, 3 H) ppm; ¹³C-NMR (benzene-D₆, 100 MHz): 206.5 (s), 176.6 (s), 150.3 (s), 139.0 (s), 108.9 (t), 45.2 (d), 36.4 (d), 33.8 (t), 32.1 (t), 30.9 (t), 29.5 (t), 28.1 (t), 20.4 (q), 16.5 (q) ppm; ¹³C-NMR (CDCl₃, 100 MHz): 209.3 (s), 179.9 (s), 150.6 (s), 139.2 (s), 108.9 (t), 45.3 (d), 36.85 (d), 34.3 (t), 32.3 (t), 31.0 (t), 30.15 (t), 27.2 (t), 20.6 (q), 17.0 (q) ppm; IR (cm⁻¹): 2661 (w), 2922 (m), 2854 (w), 1697 (s), 1642 (m), 1452 (w), 1438 (w), 1375 (w), 1304 (w), 1286 (w), 1260 (w), 1236 (w), 1173 (w), 1154 (w), 1071 (w), 1042 (w), 1023 (w), 992 (w), 886 (m), 532 (w); GCMS (EI, m/z): 204 (2%, [M]⁺), 189 (11%, [M - 15]⁺), 161 (12%), 148 (51%), 147 (48%), 134 (10%), 133 (100%), 121 (18%), 119 (28%), 107 (19%), 106 (11%), 105 (43%), 93 (25%), 91 (18%), 91 (39%), 81 (34%), 81 (17%), 79 (27%), 77 (22%); [α]_D²² = -11.4 (c 0.35, CHCl₃); HRMS (ESI): Calculated for C₁₄H₂₁O [M+H]⁺: 205.1587; Found: 205.1586.

CLAIMS

1. A process for producing rotundone from α -guaiene, by oxidation of the C(3) position, wherein the α -guaiene is produced from a precursor by a sesquiterpene synthase, wherein the sesquiterpene synthase is produced in a microorganism, and wherein the sesquiterpene synthase has a sequence identity with SEQ ID NO.: 2 or SEQ ID NO.: 4 of at least 90%.
2. The process according to claim 1, wherein the microorganism is cultured under conditions suitable to produce α -guaiene.
3. The process according to claim 1, wherein the sesquiterpene synthase is isolated from the microorganism prior to production of α -guaiene.
4. The process according to one of claims 1 to 3, wherein the microorganism is a recombinant microorganism.
5. The process according to one of claims 1 to 4, wherein the precursor is an acyclic precursor, in particular farnesyl pyrophosphate.
6. The process according to one of claims 1 to 5, wherein rotundone is produced from α -guaiene by an oxidation selected from the group consisting of transition metal catalysis, organocatalysis, chromium oxidation, selenium oxidation, manganese oxidation, aerial oxidation, enzymatic oxidation, electrochemical oxidation and combinations thereof.
7. The process according to claim 6, wherein rotundone is produced from α -guaiene by transition metal catalysis and the transition metal is in particular selected from the group consisting of iron, copper, vanadium, manganese, molybdenum, cobalt, ruthenium, palladium, iridium, rhodium, titanium, chromium, gold, osmium and combinations thereof.

8. The process according to one of claims 1 to 7, wherein rotundone is produced from α -guaiene by an oxidation selected from transition metal catalysis or organocatalysis.
9. The process according to claim 8, wherein rotundone is produced from α -guaiene by iron porphyrin catalysis comprising the steps of:
 - Forming a mixture containing α -guaiene and an iron (III)-X porphyrin complex catalyst in a solvent;
 - Introducing molecular oxygen into the mixture;
 - Effecting production of rotundone oxidation of the C(3) position of α -guaiene.
10. The process according to claim 7, wherein rotundone is produced from α -guaiene by organocatalysis, in particular comprising the steps of:
 - Forming a mixture containing α -guaiene, an organocatalyst, preferably selected from the group consisting of *N*-hydroxyphthalimide and tetrachloro-*N*-hydroxyphthalimide, and an oxidant in a solvent;
 - Effecting oxidation of the C(3) position of α -guaiene.
11. Use of α -guaiene for producing rotundone, by oxidation of the C(3) position, wherein the α -guaiene is produced from a precursor, in particular an acyclic precursor, by a sesquiterpene synthase, wherein the sesquiterpene synthase is produced in a microorganism, and wherein the sesquiterpene synthase has a sequence identity with SEQ ID NO.: 2 or SEQ ID NO.: 4 of at least 90%.