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(54) Title: PREPARATION OF VANILLIN FROM MICROBIAL TRANSFORMATION MEDIA BY EXTRACTION BY MEANS SUPERCRITICAL FLUIDS OR GASES

(57) Abstract: Crude solid vanillin-containing material is precipitated from a solution obtained by biotransformation, and purified by a process comprising contacting it with a purification fluid selected from (a) a liquefied gas whose pressure exceeds its critical pressure and whose temperature is below its critical temperature; (b) a supercritical fluid; (c) a gas. The fluid is preferably liquid carbon dioxide. The temperature is maintained below 25°. The product may be further purified by treatment with CO_2 in a fluid bed drier. The crude material is preferably one precipitated from a solution resulting from biotransformation of ferulic acid. A new strain of *Amycolatopsis* capable of generating high concentrations of vanillin with minimal odoriferous by-products (e.g. guaiacol) is also disclosed.

PREPARATION OF VANILLIN FROM MICROBIAL TRANSFORMATION MEDIA BY EXTRACTION BY MEANS SUPERCRITICAL FLUIDS OR GASES

Technical Field

The present invention relates to methods and materials that may be used in the production of vanillin and to vanillin as produced using such methods and materials.

There is a demand for natural vanillin of high flavour quality. This requires the use of raw materials of natural origin, and that all process steps should be compatible with the requirements for natural flavours as recognised by the industry and regulatory authorities.

Background Art

Vanilla is a flavouring material derived from the pods of the vanilla orchid. It has long been known to make vanilla extract by extracting vanilla pods with alcohol (ethanol). More recently, vanilla pods have been extracted with supercritical carbon dioxide, generally in conjunction with a co-solvent such as ethanol. Flavourant components dissolve in the carbon dioxide (and co-solvent), which is then separated from the solid (waste) material.

Because of the expense of vanilla pods, there have long been attempts to produce substitutes. The main

constituent of vanilla flavour is vanillin (3-methoxy-4-hydroxybenzaldehyde). This has been produced from industrial waste materials such as sulphite waste liquors of the wood pulp industry. However it is not possible to make "natural grade" vanillin in this way, and such material is unacceptable to many.

It must be appreciated that the natural vanilla aroma and flavour originating in vanilla pods are due to a complex mixture of compounds, mostly phenolic, of which vanillin is merely the main one in terms of percentage composition. It generally constitutes something less than 3% by weight of vanilla pods. Someone seeking to produce "vanilla extract" from vanilla pods is not seeking to extract vanillin selectively, but to extract a mixture (which may be concentrated to produce a brownish oil). In contrast someone seeking pure vanillin would not consider vanilla pods as a starting material - they are far too expensive, with a low vanillin content - and the technology developed for preparing vanilla extracts would not be considered relevant.

It is known to convert ferulic acid into vanillin using various microorganisms. We have previously disclosed (WO 00/50622) that use of a special strain of *Pseudomonas putida* can lead to a culture medium containing 2.25 gl^{-1} of vanillin, a molar yield of 75%

based on ferulic acid consumed. Vanillin was recovered by separating the culture broth from the cells and extracting it with an organic solvent (butyl acetate).

Haarman & Reimer GmbH have disclosed (US-A-6133003) two strains of *Amycolatopsis*. Using one of them they achieved a culture medium containing up to 11.5gl^{-1} of vanillin and 1gl^{-1} of unreacted ferulic acid. These concentrations were determined by HPLC. There is no disclosure of any work-up technique or the isolation of the product.

Givaudan-Roure (International) S.A. have disclosed (EP-A-0885968) the use of *Streptomyces setonii* to produce "vanillin and several by-products". The concentration of vanillin is said to be 8-16 gl^{-1}, though in the actual examples it ranges from 3.10 to 13.9 gl^{-1}, in the latter case accompanied by 0.4gl^{-1} of guaiacol. The co-production of guaiacol is represented as being advantageous. The products are extracted by solvent extraction using methyl *tert*-butyl ether.

In many fields, the use of organic solvents is now seen as undesirable. This is certainly the case in the production of food-grade materials, especially if they are to be of "organic" quality.

Disclosure of the Invention

We have now developed a process for the production of vanillin which does not require the use of organic solvents. In a first aspect the invention provides:

a method of purifying a crude solid vanillin-containing first material comprising:

(a) purifying said first material by a process comprising contacting it with a purification fluid selected from (a) a liquefied gas whose pressure exceeds its critical pressure and whose temperature is below its critical temperature; (b) a supercritical fluid; (c) a gas; to provide a solid vanillin-containing second material which is purer than said first material in terms of its vanillin content.

The first solid material is preferably produced by (i) a step of carrying out a biotransformation process to generate a biotransformation medium which contains vanillin produced by said biotransformation process; and (ii) a step of precipitating a crude first solid vanillin-containing solid material from a solution which is or is derived from said biotransformation medium.

Desirably at all times the vanillin-containing materials are maintained at temperatures not exceeding 25° and preferably not exceeding 10^0.

Preferably the purification involves the dissolution of the vanillin in the purification fluid, and its separation from undissolved impurities.

Alternatively or additionally, the method involves treating solid vanillin-containing material with a gas (preferably CO_2) in a fluidised bed, which carries away impurities and leaves behind purified solid vanillin material.

The crude first material may be obtained by precipitation from a solution, preferably in a crystalline or microcrystalline state. The solution may be a biotransformation medium, or may be derived from such a medium, e.g. by one or more steps such as removal of biocatalyst (which may be whole cells, cell parts, or immobilised enzyme), pasteurisation and concentration.

The biotransformation medium is generally from a biotransformation process which produces vanillin, usually by the biotransformation of ferulic acid into vanillin.

The ferulic acid is preferably derived from a natural plant source, particularly a food plant source, e.g. rice, maize, sugar beet, wheat or turmeric (*Curcuma longo*), generally waste material such as bran.

Preferably the biotransformation medium is a culture medium, preferably containing *Actinomycetales*

microorganisms such as *Streptomyces setonii* or *Amycolatopsis* organisms, most preferably of the strain deposited under accession number IMI390106 or mutants thereof which are (a) resistant to spectinomycin and (b) capable of producing vanillin substantially free from guaiacol. Preferably the organism is able to produce a medium containing at least 5g/l and preferably at least 10g/l of vanillin, preferably substantially free from odoriferous by-products. Thus it is desirably possible to obtain a crude solid vanillin-containing material which contains not more than 100ppm of guaiacol.

In another aspect the invention provides solid vanillin material having the following characteristics:

(i) absence of solvent residues;

(ii) absence of off-odours;

(iii) colour: white;

(iv) isotope ratio consistent with production from a precursor derived from a natural plant source.

Preferably none of guaiacol, vinyl guaiacol, eugenol and isoeugenol is present at more than 100ppm.

In another aspect the invention provides organisms of the strain deposited under accession number IMI390106 or mutants thereof which are (a) resistant to spectinomycin and (b) capable of producing vanillin substantially free from guaiacol.

Modes for Carrying Out the Invention

a) Novel microorganism

Zyl 926 is a new organism which the present inventors have produced. It has been deposited with CABI Bioscience, Egham TW20 9TY, GB and given the accession number IMI 390106. It has been identified as a strain of *Amycolatopsis*. It has the following characteristics:-

(i) Resistance to spectinomycin (determined by plating strains onto ISPII agar (see below) containing 1g/ℓ spectinomycin, incubating, and observing the growth or non/growth of colonies);

(ii) Morphology:

Media:	ISPII medium, 5 day evaluation
Form:	Irregular
Elevation:	Raised
Margin:	Curled/undulate
Colony Colour:	Yellow/beige
Spore Colour:	White
Surface:	Dull, presporulation

The criteria for selection of the strain were that it be:-

- Genetically stable.
- Safe (Class 1).

- Easy to grow to high biomass concentrations using a cheap carbon source.
- Produce concentrations of vanillin significantly higher than existing strains.
- Convert nearly all the ferulic acid supplied.
- Carry out the conversion in an acceptable time period.
- Produce no significant off-flavour by-products, or by-products that colour the product.

b) Microbiological Process

An organism having a known antibiotic resistance (preferably Zyl 926) is incubated in the presence of the antibiotic to prepare a stock of the organism, essentially free of other organisms. Subsequent processes use this stock material, without added antibiotic.

A sterile medium is inoculated with the organism, which is cultured. Ferulic acid is added to the cultured organism, and undergoes bioconversion to vanillin. The broth, containing the vanillin in solution, is removed and clarified.

c) Downstream Purification

An aqueous solution of vanillin (generally the clarified broth from (b)) is treated (typically by concentration and cooling) to cause solid vanillin to separate. This is collected and purified, preferably by selective extraction into a purification fluid, preferably CO_2, preferably in a liquid state though a supercritical fluid such as CO_2 may be used. The liquid is preferably at a pressure greater than the critical pressure (e.g. at least twice the critical pressure) and at a temperature below the critical temperature (e.g. at least 10^0 below). Using CO_2, we favour pressures around 200 bar (about 3 times Pc which is 74 bar) and temperatures between the freezing point and Tc (31°), preferably at least 10° below Tc. Other possible fluids include nitrous oxide, ethylene and Freons, such as Freon 13.

Extraction with carbon dioxide is favoured because of its good selectivity, ability to deal with variations in feedstock, operation at low temperature and good solvating power. Extraction efficiencies of 95% have been achieved to yield a product with a vanillin content of 98-100%. This product may be milled to aid rapid dissolution in formulation applications. The resulting material may be further purified by fluidised bed "drying" to remove volatile impurities. Indeed this

could be used for the primary purification of the separated solid vanillin.

This form of purification, involving the direct production of solid crude vanillin, requires a starting solution which contains predominantly vanillin, with only small amounts of impurities and unreacted ferulic acid. In particular, odoriferous contaminants (such as guaiacol) are very undesirable. Desirably the concentration of vanillin in a broth from a microbiological process should be at least $5gl^{-1}$ and preferably at least $10gl^{-1}$. The broth obtained from process (b) using Zyl 926 is particularly suitable.

(d) Natural/Organic Vanillin

The vanillin which can be produced can meet the following criteria:

(i) Vanillin content of ≥98% w/w.

(ii) No odorous impurity (off-aroma) such as guaiacol, vinylguaiacol, eugenol, isoeugenol present at more than ca 100ppm in the solid vanillin product.

(iii) Colour. An 'L' value of ≥94 determined using a Minolta chromameter calibrated with propylene glycol and using samples of 6% vanillin in propylene glycol.

(iv) Isotope ratios consistent with the ferulic acid precursor having been entirely derived from a

natural plant source (e.g. maize, sugar beet or rice) as defined by authorities such as the French Ministere de L'Economie des Finances et de L'Industrie (59, Bd Vincent Auriol, 75703, Paris, Cedex 13, France).

Some embodiments of the invention will now be described in greater detail by way of example.

1. Preparation of stock inoculum

ISPVII agar, containing 10g/L malt extract, $4gl^{-1}$ yeast extract, $4gl^{-1}$ glucose and $20gl^{-1}$ agar, was adjusted to pH 7.4, and $1gl^{-1}$ spectinomycin was added as the agar cooled (and before it gelled). Petri dishes containing the sterile ISP II agar were inoculated aseptically with Zyl 926 culture. These petri dishes were incubated for a minimum of 72 hours at 30°C to generate colonies across the plates.

Single colonies were lifted from the agar and used to inoculate 50ml portions of sterile SFG medium containing $1gl^{-1}$ spectinomycin in 250ml Erlenmeyer flasks. The antibiotic was added by sterile filtration. (SFG medium: per litre of water: Soya flour (Nutrisoy) 5g; di-potassium hydrogen orthophosphate 1g; magnesium sulphate heptahydrate 1.64g; glycerol 20g). Flasks were incubated at 30°C and 200rpm for 3 to 5 days in a shaking incubator.

After visual assessment of satisfactory luxuriant growth an equal volume of sterile cryopreservative was added: 20% glycerol / 10% lactose solution in water.

The resulting suspension of cells was then dispensed into sterile vials in appropriate aliquots for inoculation of subsequent stages. Culture stock was preserved by storage at -80°C.

2. Fermentation

0.7ml of culture (thawed) prepared as above was used to inoculate 1 litre of sterile SFG medium in a 1.25l fermenter, configured with two 6 bladed Rushton impellers and static air sparger.

The fermenter was cultured at 37°C and 100rpm with an airflow of 1.7l min^{-1} (1.7vvm) at pH 7.2 for 48 hours prior to using this primary seed stage to inoculate 40l of sterile SFG medium (7gl^{-1} glycerol).

This stage was cultured at 41°C and 55rpm (two Rushton turbines in a 50l fermenter) for 43 hours at an airflow of 40l min^{-1}.

Two litre portions of this culture were used to inoculate 38l of a sterile SFG medium in a 50l fermenter. This stage was cultured at 41°C and 20l min^{-1} airflow with control of dissolved oxygen at 70% of saturation by cascade control of agitator speed.

After 13 hours of incubation the pH in each fermenter was adjusted over the course of 60 minutes to 8.5 by addition of 2M sodium hydroxide. Substrate (ferulic acid) was added as a single charge, dissolved in 10l of 0.5M sodium hydroxide at 41°C, with adjustment of this solution to pH 8.5 with 10M base. The correct concentration was verified by HPLC analysis, as was the subsequent course of reaction. Culture conditions were maintained as above.

Reaction of substrate to product was complete after between 40 and 51 hours.

The amounts of ferulic acid were varied, and the strength of the SFG final stage medium was adjusted according to substrate concentration:

Substrate concentration (gl^{-1})	Soyflour (Nutrisoy) (gl^{-1})	di-Potassium hydrogen orthophosphate (gl^{-1})	Magnesium Sulphate heptahydrate (gl^{-1})	Polypropylene glycol (ml)	Glycerol (gl^{-1})
18	5	1	1.64	0.2	7
25	8.6	1.7	2.8	.35	12
32	8.6	1.7	2.8	.35	12

3. Downstream purification

Extraction: At the conclusion of the biotransformation, the pH of the broth was adjusted to 6.7 +/- 0.1. It was then heat treated at 55°C for 5 minutes and then cooled to 30°C. Heat treated broth, 50l was then clarified either by centrifugation at -11,000 xg or more preferably by filtration using a filter aid, e.g.

Celite 512. The filter press used for clarification, a British Filters PA20M, is pre-coated with 10g of Celite per plate and 12gl^{-1} of bodyfeed or admix added to the broth. The resulting filtrate was then ultrafiltered through any suitable membrane, preferably one made of polysulphone and having a molecular weight cut-off of 10,000 Daltons.

To maximise recovery the ultrafiltrate retentate, 41, was diafiltered three times with an equal volume of water.

The combined ultrafiltrate and diafiltrate, 66l, were then adjusted to pH 6.6 +/- 0.1 and concentrated to approximately 50gl^{-1} vanillin under reduced pressure using a pot still. The concentrate temperature was maintained between 20 and 35°C at a vacuum of 1.3 to 26 KPa. On subsequent cooling of the final concentrate to 5-10°C in a suitable jacketed vessel, a crude vanillin product precipitated. After cooling at 5-10°C for not less than 3 hours the crude product was recovered by any suitable means, but preferably filtration using a basket centrifuge (Broadbent 9 inch type 41) and dried in trays at 30-40°C and 80KPa.

Alternatively, the clarified broth may be concentrated to approximately 40gl^{-1} at a higher temperature suitably 30-35°C, and the resulting

concentrate, after adjustment of pH to 5.9, extracted with an equal volume of n-butyl acetate. After separation of the phases the rich solvent extract is concentrated to 320gl^{-1} vanillin using a pot still and cooled, whereupon a precipitate of crude vanillin is formed which is recovered by vacuum filtration on a Nutsche filter. The filter cake can then be washed with 2 volumes of hexane to remove the n-butyl acetate and then dried in trays under vacuum, 80 KPa and 40°C.

The resulting dry material may be purified by either of the methods outlined under Purification below.

Purification

Dried product (554g, 53% vanillin) from initial downstream processing was charged into an extraction vessel of a carbon dioxide extraction rig. Pressure was raised to 20MPa and temperature set at 5°C. Liquid carbon dioxide rich in vanillin was piped to the evaporator, maintaining the above temperature and pressure conditions. In the evaporator the pressure was reduced to approximately 3MPa whereupon white crystals of vanillin precipitated. Temperature was maintained in the evaporator by circulation of a heat transfer medium in the evaporator jacket at 70°C. Vanillin (278.9g 95% yield) was recovered from the evaporator.

The purified material may be further purified in a fluidised-bed dryer. This example used one produced by Sherwood Scientific, Cambridge, GB. Treatment at 55°C for 2 hours with a flow rate of CO_2 of 14.8-15.3L/sec caused the organoleptic quality to be greatly improved by a method that is simple to use, acceptable as regards 'natural' and 'organic' specifications for flavours, and entails only minor (1-2%) losses consistent with normal handling operation losses. The colour of the product was determined using a Minolta chromameter as explained above. It has an 'L' value of 99.5; and also an 'a' value (red-green hue) of 0.01, and a 'b' value (yellow-blue hue) of 2.84.

Fluidisation with air is also possible, but less preferred than CO_2.

Fluidised bed treatment may also be used instead of the liquid CO_2 extraction method for the initial purification.

Results of some runs are presented in Table 1 below:

Table 1: Production of vanillin using Zyl 926

Ferulic acid added	18	25	31-33
Conc. of vanillin formed (g/l)	10.8	13.8	17.95
Fermentation Time (h)	38.7	51.5	50.5

Residual Ferulic acid cons (g/l)	0.49	1.01	1.52
Volumetric Productivity (gV/L/H)	0.279	0.268	0.347
Yields of vanillin on ferulic acid supplied (% g/g) [% of theoretical yield]	62.17 [79.7%]	55.9 [71.7%]	56.17 [62,9%]

CLAIMS

1. A method of preparing a vanillin material which comprises: (i) a step of carrying out a biotransformation process to generate a biotransformation medium which contains vanillin produced by said biotransformation process; (ii) a step of precipitating a crude first solid vanillin-containing solid material from a solution which is or is derived from said biotransformation medium; and (iii) purifying said first material by a process comprising contacting it with a purification fluid selected from (a) a liquefied gas whose pressure exceeds its critical pressure and whose temperature is below its critical temperature; (b) a supercritical fluid; (c) a gas; to provide a solid vanillin-containing second material which is purer than said first material in terms of its vanillin content.

2. A method according to claim 1 wherein said purification fluid is a liquefied gas.

3. A method according to claim 1 or claim 2 wherein said purification fluid is at a temperature below 25°.

4. A method according to claim 1 wherein said purification fluid is (a) a liquefied gas or (b) a supercritical fluid.

5. A method according to any preceding claim wherein said fluid is carbon dioxide.

6. A method according to any preceding claim including a further step (iv) of treating said second material with a gas in a fluidised bed.

7. A method according to claim 6 in which the fluid and/or the gas is carbon dioxide.

8. A method according to any preceding claim in which said biotransformation process comprises the biotransformation of ferulic acid into vanillin.

9. A method according to claim 8 in which the ferulic acid is derived from a natural plant source.

10. A method according to any preceding claim in which the biotransformation medium is a culture medium.

11. A method according to claim 10 in which the culture medium is a medium containing *Actinomycetales* microorganisms which have generated vanillin therein.

12. A method according to claim 11 wherein said microorganisms are *Streptomyces* species.

13. A method according to claim 12 wherein said species is *S. setonii*.

14. A method according to claim 11 wherein said microorganisms are *Amycolatopsis* species.

15. A method according to claim 11 wherein said microorganisms are organisms of the strain deposited under accession number IMI390106 or mutants thereof which are (a) resistant to spectinomycin and (b) capable of producing vanillin substantially free from guaiacol.

16. A method according to claim 15 which employs a mutant such that the crude solid vanillin-containing material contains not more than 100ppm of guaiacol.

17. Vanillin material as prepared by the method of any preceding claim and having the following characteristics:-

(i) absence of solvent residues;

(ii) absence of off-odours;

(iii) colour: white;

(iv) isotope ratios consistent with production from a precursor derived from a natural plant source.

18. Vanillin material according to claim 17 wherein none of guaiacol, vinyl guaiacol, eugenol and isoeugenol is present at more than 100ppm.

19. Vanillin material according to claim 17 or 18 wherein the colour is such that a 6% w/v solution in propylene glycol has an 'L' value of at least 94.

20. Vanillin material according to claim 17, 18 or 19 wherein the isotope ratios are consistent with production from ferulic acid derived from a natural plant source selected from rice, maize, sugar beet, wheat and curcumin.

21. Organisms of the strain deposited under accession number IMI390106 or mutants thereof which are

(a) resistant to spectinomycin and (b) capable of producing vanillin substantially free from guaiacol.

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INTERNATIONAL SEARCH REPORT

Inte nal Application No
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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 C12P7/24 //(C12P7/24,C12R1:01,1:465)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 C12P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, BIOSIS, EMBASE, CHEM ABS Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	US 6 133 003 A (HOPP RUDOLF ET AL) 17 October 2000 (2000-10-17) cited in the application the whole document ---	1-8,10, 11,14
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[X] Further documents are listed in the continuation of box C. [X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
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Date of the actual completion of the international search	Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT

Int ional Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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