

(12) PATENT
(19) AUSTRALIAN PATENT OFFICE

(11) Application No. AU 200011639 B2
(10) Patent No. 762575

(54) Title Nitrocoumarins for detecting all micro-organisms

(51)⁶ International Patent Classification(s)
C12Q 001/04 C12Q 001/26
C07D 311/16

(21) Application No: 200011639 (22) Application Date: 1999 . 11 . 05

(87) WIPO No: WO00/28073

(30) Priority Data

(31) Number 98/14101	(32) Date 1998 . 11 . 05	(33) Country FR
(43) Publication Date :	2000 . 05 . 29	
(43) Publication Journal Date :	2000 . 07 . 27	
(44) Accepted Journal Date :	2003 . 06 . 26	

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PCT

ORGANISATION MONDIALE DE LA PROPRIETE INTELLECTUELLE
Bureau international

DEMANDE INTERNATIONALE PUBLIEE EN VERTU DU TRAITE DE COOPERATION EN MATIERE DE BREVETS (PCT)

(51) Classification internationale des brevets⁷ : C12Q 1/04, C07D 311/16, C12Q 1/26		A1 (11) Numéro de publication internationale: WO 00/28073 (43) Date de publication internationale: 18 mai 2000 (18.05.00)
(21) Numéro de la demande internationale: PCT/FR99/02704 (22) Date de dépôt international: 5 novembre 1999 (05.11.99) (30) Données relatives à la priorité: 98/14101 5 novembre 1998 (05.11.98) FR (71) Déposant (pour tous les Etats désignés sauf US): BIOMERIEUX S.A. [FR/FR]; Chemin de l'Orme, F-69280 Marcy l'Etoile (FR).		(81) Etats désignés: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TI, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW, brevet ARIPO (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), brevet eurasien (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), brevet européen (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), brevet OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).
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(54) Titre: NITROCOUMARINS FOR DETECTING ALL MICRO-ORGANISMS (54) Titre: NITROCOUMARINES POUR LA DETECTION DE TOUS MICRO-ORGANISMES		
(57) Abstract <p>The invention concerns a compound for detecting the presence or absence of at least a micro-organism. The invention also concerns the use of a compound in a detection and/or diagnostic test. The invention further concerns a method for isolating a nitroaryl-reductase activity in a bacteria culture medium. Finally, the invention concerns the use of such a compound, methods for isolating and detecting micro-organisms in a sample likely to contain them, and various applications thereof. The invention is characterised in that the compound consists of a nitrocoumarin molecule or one of its derivatives, which is fluorescent in reduced state. The invention is particularly applicable in the field of diagnosis.</p>		
(57) Abrégé <p>La présente invention concerne un composé de détection de la présence ou de l'absence d'au moins un micro-organisme. L'invention propose également l'utilisation d'un composé dans un test de détection et/ou de diagnostic. Ladite invention a encore pour objet un procédé de mise en évidence d'une activité nitroaryl-réductase dans un milieu de culture de bactéries. L'invention a enfin trait à l'utilisation d'un tel composé, à des procédés de mise en évidence et de détection d'un micro-organisme ou d'un groupe de micro-organismes dans un échantillon susceptible de les contenir, et enfin à différentes applications. Elle se caractérise par le fait que le composé est constitué par une molécule de nitrocoumarine ou un de ses dérivés, qui est fluorescent à l'état réduit. L'invention trouve une application préférentielle dans le domaine du diagnostic.</p>		

ABSTRACT

“Detection of all microorganisms in a sample”

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5 This invention concerns a compound for detecting the presence or absence of at least one microorganism. The invention also concerns the use of a compound in a detection and/or diagnostic test. The said invention further concerns a method for detecting nitroaryl reductase activity in a bacteria culture medium. Finally, the invention concerns the use of such a compound, methods for isolating and detecting 10 microorganisms or a group of microorganisms in a sample likely to contain them, and various applications thereof.

The invention is characterized in that the compound consist of a nitrocoumarin molecule or one of its derivatives, which is fluorescent in reduced state.

The invention is particularly applicable in the field of diagnosis.

DESCRIPTION

This invention concerns a nitro-aromatic compound which can be reduced by microorganisms to produce an amino-aromatic compound.

5 The invention also relates to the use of a compound in a detection and/or diagnostic test for microorganisms.

The invention further relates to a method for demonstrating the presence of nitroaryl reductase activity in a culture medium containing microorganisms.

10 Finally, the invention covers a method for the detection of single microorganisms or groups of microorganisms in samples which may contain them.

15 *The article "Syntheses of coumarin derivatives. V. Syntheses of coumarin-3-carboxylic acid derivatives" CHEMICAL ABSTRACTS, vol. 50, 1956, page 10715, XP-002109446, describes the synthesis of nitrocoumarin derivatives including the 7-nitrocoumarins. The only application specified is based on their hypnotic and sedative activities. Moreover, their toxicity is dealt with. The article "Syntheses of coumarin derivatives. XIV. Preparation of 5-hydroxy-7-nitro-3-coumarincarboxylic acid" CHEMICAL ABSTRACTS, vol. 59, 1963, page 2757, XP-002109447, only describes the synthesis of 5-hydroxy-7-nitrocoumarin carboxylic acid.*

20 20 The possibility of using these molecules to detect the presence or absence of microorganisms has never been addressed. Therefore, no bacteriological application has ever been contemplated. Moreover, the toxicity results did not encourage those skilled in the art to think about using this type of compound in culture media being used to support the growth of microorganisms.

25 25 *Certain products synthesized above may have therapeutic applications, in particular those endowed with antibacterial activity. This is documented in the two following articles: the article "Studies on Synthesis of Coumarin Derivatives. XX. Synthesis and Antibacterial Activity of Derivatives of N-Substituted 3-Coumarincarboxamide" CHEMICAL AND PHARMACEUTICAL BULLETIN, vol. 16, no. 11. November 1968 (1968-11) pages 2093-2100, XP-002109448, describes the use*

of nitrocoumarins as antibacterial agents as does also the article "Synthesis of Coumarin Derivatives. XV. On the Preparation of Ethyl Pyranobenzoxazole carboxylates" CHEMICAL AND PHARMACEUTICAL BULLETIN, vol. 14, 1966, pages 1162-1167, XP-002109449.

5 However, in our invention, the essential property is that nitrocoumarins—and particularly the 7-nitrocoumarins—fluoresce when they are in the reduced state. This fluorescence depends on whether certain microorganisms are present or not. It should be noted that the toxicity and antibacterial activity of these compounds could only discourage those skilled in the art from contemplating their use in the detection of
10 microorganisms.

 The object of this patent application is completely different. It is not in any way associated with detecting a potentially therapeutic activity such as the inhibition of bacterial growth but, in contrast, is a way of detecting microorganisms through an enzyme activity, namely nitroaryl reductase activity which reduces the non-fluorescent
15 7-nitrocoumarin (or one of its derivatives) into the fluorescent 7-aminocoumarin (or the corresponding derivative). It therefore concerns a fluorescent test for the universal detection of microorganisms in samples which may contain them and in which the inhibition of bacterial growth is not an issue.

*Certain bacteria have been known for many years to be able to reduce aromatic nitro-compounds. From E. coli extracts, Asnis (1957) isolated a flavoprotein which could reduce p-nitrobenzoic acid. Since this seminal finding, nitroaryl reductase activities have been described in various types of microorganism, including obligate aerobes such as Pseudomonas spp. (Won et al. 1974) and Nocardia spp. (Villanueva 1964), obligate anaerobes such as Clostridium spp. (Ancermaier & Simon 1983) and
20 25 Veillonella spp. (McCormick et al. 1976), fungi (Masuda & Ozaki 1993) and eukaryotic parasites (Douch 1975). A whole range of substrates is known as being reducible by bacterial nitroaryl reductases, especially aromatic nitro-compounds such as p-nitrobenzoic acid, p-nitrophenol, p-nitroaniline and 2, 4, 6-trinitrotoluene (McCormick et al. 1976).*

Although a wide range of different substrates is available, none are suitable for the direct detection of nitroaryl reductase through the production of a fluorescent product.

Therefore, this enzyme activity has to be assayed by indirect methods, e.g. by

5 *measuring the disappearance of the substrate or some cofactor. Kitamura et al. (1983),*
investigating the reduction of methyl p-nitrobenzoate and a series of other aromatic
*nitro-compounds by *E. coli* extracts, showed that three distinct and well-defined*
enzyme activities could be chromatographically isolated on a DEAE-cellulose column,
and that each of these distinct three fractions required different cofactors for its

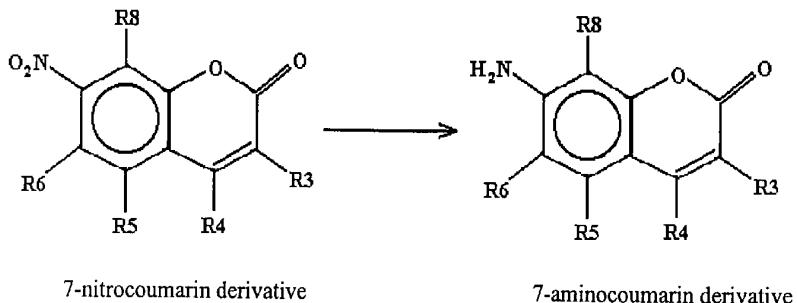
10 *activity: the first required NADH; the second required NADPH; and the third required*
both. Enzyme reactivity was assayed by following the change in optical density (OD) at
340 nanometers (nm) due to the consumption of the NADH and/or the NADPH.
Consumption of the NADH and/or the NADPH was associated with the formation of
two reaction products, namely methyl p-aminobenzoate and methyl p-

15 *hydroxylaminobenzoate. Bryant et al. (1981) also studied *E. coli* nitroaryl reductases,*
using nitrofurazone as the substrate. In order to assay enzyme activity, they were able
to follow changes in OD at 375 nm (the absorption maximum [λ max] of
nitrofurazone). Using this method, they detected three distinct activities capable of
reducing nitrofurazone. The ability of bacteria to reduce nitrofuranes is of great

20 *interest in the field of antibacterial chemotherapy (Peterson et al. 1979, Wentzell &*
*McCalla 1980) and it has been shown that the major *E. coli* nitroaryl reductase (which*
is NADPH-dependent) is absent in nitrofurazone-resistant mutants (Bryant et al. 1981).

The object of this invention is a fluorescent substrate based on nitrocoumarin

25 which is suitable for the direct detection of nitroaryl reductase activity. When reduced, this type of aromatic nitro-compound gives a product which is fluorescent and therefore easy to detect. The reaction (I) is shown below:



Unexpectedly, it was found that the vast majority of microorganisms contain 5 nitroreductase activity and are therefore capable of reducing 7-nitrocoumarin derivatives to give a fluorescent product—this is not true of any of the substrates which have been investigated hitherto. Therefore, these derivatives represent a class of universal indicators which make it possible to detect the presence or absence of microorganisms in any given sample.

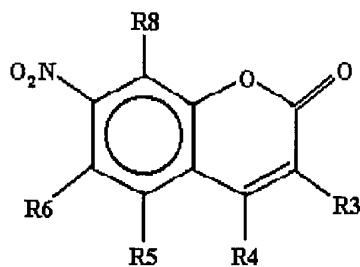
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To this end, this invention concerns a compound for detecting the presence or absence of at least one microorganism. The invention is characterized in that the compound is a nitrocoumarin or one of its derivatives which gives a fluorescent product on reduction.

15

Particularly, said compound is 7-nitrocoumarin or one of its derivatives.

The compound is characterized by the following structural formula:



in which R₃ is either H or COZ, where Z is conducive to the generation of a ketone, an acid or an ester group, or any other aliphatic group,

and in which R_4 is either H or a trifluoromethyl (CF_3) group or any aliphatic group.

According to a modification, R_3 consist of $COOCH_3$, $COOC_2H_5$, $COOH$, COC_3H_7 , $CONC_4H_9O$ or $COCH_3$ group, and R_4 is either H or a CH_3 group.

According to another modification, the compound is made up of 7-nitrocoumarin-3-carboxylic acid.

The concentration of 7-nitrocoumarin-3-carboxylic acid ranges from 0.05 to 0.3 mmol/l.

According to a potentially interesting embodiment, the compound described above can be used in a formulation or in combination with one or more other 10 nitrocoumarin compounds or derivatives.

The invention also concerns the use of a compound as defined above in a detection and/or diagnostic test for the presence or absence of microorganisms.

The invention further concerns a first method for detecting single 15 microorganisms or groups of microorganisms in samples which may contain them. This method consists in:

- adding to a culture medium containing the sample, at least one nitrocoumarin-based compound, preferably 7-nitrocoumarin or one of its derivatives, and
- monitoring for the production of a fluorescent product—the presence or absence of a fluorescent signal corresponding to the presence or absence of the suspected 20 microorganism or group of microorganisms.

The invention further concerns a second method for identifying at least one microorganism in a sample which may contain such microorganisms, comprising the following steps:

- adding, in a series of wells, a culture medium containing a single carbon source, such 25 as lactose, glucose, sucrose, etc., an aliquot of the test sample and at least one nitrocoumarin-based compound, preferably 7-nitrocoumarin or one of its derivatives, and
- searching each well for the production of a fluorescent product—the presence or 30 absence of this fluorescence over all of the wells enabling the microorganism to be identified. This second method is also called an assimilation test.

Finally, the invention concerns various applications associated with the detection of microbial growth using at least one compound, as defined above, for:

- performing a sterility test,
- counting the microorganisms present in the sample,
- 5 - testing the susceptibility of a microorganism to an antimicrobial agent, and
- detecting the presence of at least one microorganism.

The Figures shown are given for reference and explanatory purposes only and are not intended to be in any way limiting. They are designed to make the invention 10 easier to understand.

Figure 1 is a graph showing the effect of a series of different nitrocoumarins (all at a concentration of 0.105 mmol/l) on the growth of *E. coli* (NCTC 10418) in Mueller-Hinton broth.

15 Figure 2 is a graph showing the fluorescent signal generated by *E. coli* (NCTC strain 10418) growing in Mueller-Hinton broth in the presence of a series of different nitrocoumarin derivatives (all at a concentration of 0.105 mmol/l).

Figure 3 is a graph showing the growth of *E. coli* (NCTC strain 10418) in Mueller-Hinton broth in the presence of a series of different concentrations of 7-nitrocoumarin-3-carboxylic acid.

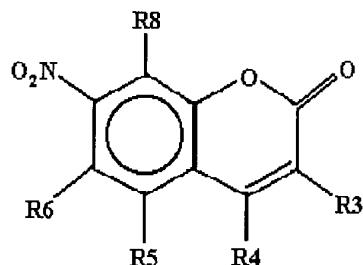
20 Figure 4 is a graph showing the fluorescent signal generated by *E. coli* (NCTC strain 10418) growing in Mueller-Hinton broth in the presence of a series of different concentrations of 7-nitrocoumarin-3-carboxylic acid.

Figure 5 is a graph showing the growth of a series of wild strains of *Enterobacteriaceae* species in Mueller-Hinton broth in the presence of 7-nitrocoumarin-3-carboxylic acid at a concentration of 0.17 mmol/l.

25 Figure 6 is a graph showing the reduction of 7-nitrocoumarin-3-carboxylic acid at a concentration of 0.17 mmol/l by the same wild strains of *Enterobacteriaceae* species as in Figure 5.

This invention concerns a series of compounds based on 7-nitrocoumarin which acts as a fluorogenic substrate for the direct detection of nitroaryl reductase activity.

The general structure of nitrocoumarins is illustrated by formula II:



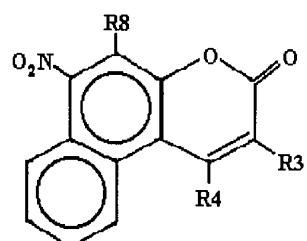
5 The number of possible substituted derivatives is large so the experiments focused on each of the substitutions and on the various possibilities. The alternatives are listed in Table 1 below. This list mainly concern radicals R₃, R₄ and R₈, which represent the most important substituents.

Nevertheless, groups R₅ and R₆ are not usually substituted, as it is the case in
 10 Table 1. They are made up of hydrogen atoms (H). However, substitution can take place here with the following possibilities:

- at least one of the groups R₅ and/or R₆ is a CH₃ group or another small alkyl group (with fewer than 5 carbon atoms), or
- at least one of the groups R₅ and/or R₆ is a halide (F, Cl, Br or I), or
- 15 - at least one of the groups R₅ and/or R₆ is a CH₃O group or another small alkoxy group (with fewer than 5 carbon atoms), or
- at least one of the groups R₅ and/or R₆ is a phenyl (aryl) or an aralkyl group.

Whenever only one of the groups R₅ or R₆ is one of those specified above, there is an H atom at the other position.

20 Furthermore, it is possible that R₅ and R₆ participate together in an aromatic ring (a benzenoid or heterocyclic ring). The structure of this type of molecule is shown opposite.



	R3	R4	R8
7-nitrocoumarin	H	H	H
4-methyl-7-nitrocoumarin	H	CH ₃	H
methyl-7-nitrocoumarin-3-carboxylate	COOCH ₃	H	H
ethyl-7-nitrocoumarin-3-carboxylate	COOC ₂ H ₅	H	H
7-nitrocoumarin-3-carboxylic acid	COOH	H	H
3-butyryl-7-nitrocoumarin	COC ₃ H ₇	H	H
3-acetyl-4-methyl-7-nitrocoumarin	COCH ₃	CH ₃	H
7-nitrocoumarin-3-carboxymorpholide	CONC ₄ H ₄ O	H	H

Table 1: Substitutions of the nitrocoumarin core and the resultant compounds

5

1°) Materials

A – Culture medium

10 The media used were Mueller-Hinton and Trypticase Soy broths and agars obtained from Unipath Ltd, Basingstoke, Great Britain.

B – Substrates and chemical reagents

15 The following substrates were synthesized: 7-nitrocoumarin, 4-methyl-7-nitrocoumarin, methyl-7-nitrocoumarin-3-carboxylate, ethyl-7-nitrocoumarin-3-

carboxylate, 7-nitrocoumarin 3-carboxylic acid, 3-butyryl-7-nitrocoumarin, 3-acetyl-4-methyl-7-nitrocoumarin, 7-nitrocoumarin-3-carboxy-morpholide.

C – Apparatus

5 The following apparatus was used:

- an Anthos 2001 microtiter plate spectrophotometer obtained from Labtech International Limited, Uckfield, Great Britain, and
- a Labtech Biolite F1 microtiter plate fluorescence reader obtained from Labtech International Limited, Uckfield, Great Britain.

10

D – Nitrocoumarin synthesis

All chemical reagents used in the synthesis of the nitrocoumarins were obtained from the Aldrich Chemical Company Ltd, Gillingham, Great Britain.

The synthetic pathway for 7-nitrocoumarin has been described by

15 LIEBERMANN, M, *et al.* (1951) *Académie des Sciences* **232**, 2027-2029. It involves heating together under reflux: 12 g nitro-4-salicylic aldehyde, 18 g of anhydrous sodium acetate and 27 g of acetic anhydride. After three hours of refluxing, the reaction mixture is transferred into a mortar and pounded to a paste. Then it is centrifuged and washed, first with small volumes of acetic anhydride and then with water. The resultant

20 material is heated under reflux together with 13 g of Na_2CO_3 and 320 cm^3 of water. After two hours, the mixture is filtered while still hot and precipitated—still hot—using hydrochloric acid. After cooling, the mixture is centrifuged and the product is recrystallized from 300 cm^3 of 50 % acetic acid. A second cycle of recrystallization gives a product which melts at 198-200°C.

25 Synthesis of the various nitrocoumarin derivatives involves the preliminary synthesis of 4-nitrosalicylaldehyde which was performed using a modification of the method described by SEGESSER, J.R., and CALVIN, M. (1942) *J. Am. Chem. Soc.* **64**, 825-826. This involves initial acetylation of 2-methyl-5-nitrophenol followed by two bromine addition steps using N-bromosuccinimide in the presence of benzoyl peroxide

30 as catalyst. This reaction is carried out in carbon tetrachloride as the solvent and yields

2-acetoxy-4-nitrobenzale bromide. The crude dibromide is recrystallized from 1-butanol before conversion to nitrosalicylaldehyde in the following series of reactions.

A mass of 11 g of the pure dibromide is dissolved in 50 ml of anhydrous methanol and the resultant solution is gradually added to 250 ml of a 1 % (m/v) 5 solution of sodium in boiling methanol. After refluxing for 45 min, the resultant dark orange solution is allowed to cool before the addition of 100 ml of water. After boiling for a further 15 min, the solution is allowed to cool and its pH is adjusted to 3. The methanol is evaporated off (in a rotary evaporator) and the precipitated 4-nitrosalicylaldehyde is recovered by vacuum filtration. The residue is then 10 recrystallized from dilute ethanol.

Three of the nitrocoumarin derivatives were synthesized using similar methods which are based on Knoevenagel condensation with 4-nitrosalicylaldehyde. Dimethylmalonate (1.45 g, 11 mM) and 4-nitrosalicylaldehyde (1.67 g, 10 mM) are dissolved in 15 ml of ethanol. Then 100 mg of piperidine and 100 μ l of cold acetic acid 15 are added and the mixture is refluxed for two hours. The product—methyl-7-nitrocoumarin-3-carboxylate—precipitates out either during the reaction or as the solution cools down. The precipitate is recovered by vacuum filtration and recrystallized from ethanol. For the synthesis of ethyl-7-nitrocoumarin-3-carboxylate and 3-butyryl-7-nitrocoumarin, the dimethyl malonate is replaced with diethyl malonate 20 or ethyl-butyrylacetate respectively.

7-nitrocoumarin-3-carboxylic acid is obtained by refluxing ethyl 7-nitrocoumarin-3-carboxylate (2.63 g, 10 mM) with excess potassium hydroxide solution and aqueous ethanol for one hour. The deep yellow-colored potassium salt is then acidified using hydrochloric acid and, after recovery, the product is washed in a 25 small volume of water and recrystallized from boiling water.

7-nitrocoumarin-3-carboxymorpholide is prepared in the following way. 7-nitrocoumarin-3-carboxylic acid (1.17 g, 5 mM) is dissolved in a mixture of 25 ml of anhydrous tetrahydrofuran and 10 ml of dimethylformamide. This mixture is thoroughly mixed and then 5 mmol of N-methylmorpholine (0.5 g, 5 mM) is added. 30 After cooling to a temperature of below 12 °C, isobutyl chloroformate (0.68 g, 5 mM)

is added. After 10 min, the morpholide (0.64 g, 7.5 mM) is added. The reaction is allowed to proceed for 30 min at a temperature rigorously maintained at 0 °C. Then the mixture is allowed to come to room temperature and left for a further 5 hours. The N-methylmorpholine hydrochloride is removed by filtration and the filtrate transferred 5 into 10 ml of a mixture of ice and water. The solid which precipitates out is then recrystallized in liquid methanol.

Both 4-methyl-7-nitrocoumarin and 3-acetyl-4-methyl-7-nitrocoumarin are synthesized using an alternative procedure based on the oxidation of 7-aminocoumarin. 7-amino-4-methylcoumarin (1.75 g, 10 mM) is resuspended in 10 ml of 75 % (m/m) of 10 sulfuric acid and thoroughly mixed. Keeping the temperature below 5 °C, a 2.5 ml volume of 7 M sodium nitrite solution is gradually added by means of a long delivery tube pushed down to the bottom of the test tube. The diazonium solution is then mixed for 15 min until the temperature has risen from 2 °C to 5 °C. An aliquot of 5 l of ice 15 water containing 2.4 g of sodium tetrafluoroborate is then added to the cold diazonium solution. The ice water at 0 °C is added slowly until a crystalline aggregate of the tetrafluoroborate forms. This precipitate is recovered by vacuum filtration and then washed, first with a small volume of ice water, then with methanol and finally with ether. After rapid air-drying, the yield of the product is 2.2 g.

20 A mass of 3 g of copper powder and a suspension of cupric oxide (prepared by reducing cupric sulfate with glucose) are added to a cold 4.1 M solution of sodium nitrite. A mass of 2.2 g of the diazonium salt is resuspended in 10 ml of water and the resultant mixture is added stepwise over a period of 20 min, keeping the temperature at between 5 and 15 °C and stirring throughout. The nitrogen is then removed which 25 entails the addition of a small volume of ether in order to prevent foaming. After continuous mixing for 5 hours, the suspension is filtered, washed with water, and then extracted with hot ethyl acetate. The aqueous solution is extracted in the same way. The two extracts are then pooled, washed with water and dried with anhydrous magnesium sulfate. The solvent is evaporated off in a rotary evaporator to yield a yellow residue.

Recrystallization of the latter from hot acetic acid gives 0.62 of a lemon yellow-colored product, i.e. 4-methyl-7-nitrocoumarin.

The 3-acetyl-4-methyl-7-nitrocoumarin is prepared using a similar method starting with 3-acetyl-4-methyl-aminocoumarin which is prepared in a similar way to 5 that used for 7-amino-4-methylcoumarin except that ethyl acetoacetate is used instead of ethyl diacetoacetate.

E – Making up the substrate solutions

A sample of the 7-nitrocoumarin derivative is dissolved in 4 ml of hot, distilled 10 water. The mass dissolved to make the stock solution is such that the final concentration of the compound in the assay is 0.105 mmol/l. This solution is added to 96 ml of Mueller-Hinton broth and the mixture is sterile-filtered.

F – Microorganisms tested

15 All strains tested were either wild strains or were obtained from international collections (NCTC and ATCC)

2°) Methods and results

20

A - Evaluation of the usefulness of different nitrocoumarin derivatives as indicators for *Escherichia coli* growth (NCTC 10418):

1°) Method

25 A preliminary experiment was conducted using one strain of *Escherichia coli* (NCTC 10418) and the eight nitrocoumarins listed in Table 1, i.e.:
• 7-nitrocoumarin,
• 4-methyl-7-nitrocoumarin,
• methyl-7-nitrocoumarin-3-carboxylate,
30 • ethyl-7-nitrocoumarin-3-carboxylate,

- 7-nitrocoumarin 3-carboxylic acid,
- 3-butyryl-7-nitrocoumarin,
- 3-acetyl-4-methyl-7-nitrocoumarin, and
- 7-nitrocoumarin-3-carboxymorpholide.

5

The *E. coli* was grown for 24 hours at 35 °C on Columbia agar supplemented with sheep blood. The bacteria were then resuspended in sterile, distilled water and their density was adjusted to 0.5 on the MacFarland scale (i.e. about 10⁸ cells/ml). This suspension was then diluted 100-fold in sterile Mueller-Hinton broth (i.e. to a final density of about 10⁶ cells/ml).

Fifty microliters of each nitrocoumarin solution plus 50 µl of bacterial suspension were then added to the wells of a microtiter plate. The plates were incubated at 35°C and the optical density and fluorescence of each well was read every 30 min for 15 a total of 4 hours. Optical density (690 nm) readings were made using an Anthos 2001 spectrophotometer (Labtech International Limited), and fluorescence (excitation at 365 nm and emission at 440 nm) readings were made on a Biolite F1 2001 fluorometer (Labtech International Limited).

20

2°) Results

Figure 1 shows the effect of each of the eight nitrocoumarins (at 0.105 mmol/l) on the growth of *E. coli* (NCTC 10418). It is clear that chemical substitution of the coumarin nucleus has significant effects on the inhibitory activity of the 7-nitrocoumarin. For example, in the presence of 0.105 mmol/l of 7-nitrocoumarin-3-carboxylic acid, no retarded growth is noted. On the other hand, in the presence of the same concentration of methyl-7-nitrocoumarin-3-carboxylate, the OD readings are reduced by a factor of 92 % compared with the untreated control. These inhibitory effects correlate with the rate of reduction of the substrate as measured by the generation of a fluorescent signal.

In Figure 2, it can be clearly seen that the two most powerful inhibitors—methyl-7-nitrocoumarin-3-carboxylate and 3-butyryl-7-nitrocoumarin—are the least reduced at the end of the four-hour assay. Moreover, 7-nitrocoumarin-3-carboxylic acid (the only compound which does not inhibit *E. coli* growth) is reduced to a far greater extent than any of the other nitrocoumarins with a fluorescent signal which is more than twice as high as that given by any of the other substrates.

In order to make Figures 1 and 2 easier to understand, the readings on which they are based are given in the following Tables (Tables 2 and 3).

10

Compound\Time(min)	0	30	60	90	120	150	180	210	240
7-nitrocoumarin	0.000	-0.002	0.000	0.002	0.009	0.025	0.072	0.133	0.211
4-methyl-7-nitrocoumarin	0.000	0.000	0.002	0.004	0.010	0.024	0.055	0.113	0.175
methyl-7-nitrocoumarin-3-carboxylate	0.000	-0.001	-0.001	0.000	0.000	0.002	0.006	0.014	0.032
ethyl-7-nitrocoumarin-3-carboxylate	0.000	-0.005	-0.008	-0.008	-0.006	0.000	0.018	0.046	0.116
7-nitrocoumarin-3-carboxylic acid	0.000	0.000	0.002	0.008	0.026	0.068	0.164	0.227	0.416
3-butyryl-7-nitrocoumarin	0.000	0.001	0.005	0.007	0.009	0.012	0.015	0.039	0.096
3-acetyl-4-methyl-7-nitrocoumarin	0.000	-0.003	-0.002	-0.001	0.002	0.008	0.023	0.051	0.110
7-nitrocoumarin-3-carboxymorpholide	0.000	-0.002	-0.001	0.001	0.005	0.014	0.037	0.068	0.109
Control	0.000	-0.002	0.000	0.005	0.019	0.085	0.169	0.246	0.400

Table 2: Readings corresponding to Figure 1

Compound\Time(min)	0	30	60	90	120	150	180	210	240
7-nitrocoumarin	0	77	519	1447	2915	4713	7160	10182	14189
4-methyl-7-nitrocoumarin	0	15	302	974	2008	3299	5097	7545	11125
methyl-7-nitrocoumarin-3-carboxylate	0	174	702	1297	2035	2905	3946	5005	6668
ethyl-7-nitrocoumarin-3-carboxylate	0	173	814	1703	2813	4126	5646	7370	10859
7-nitrocoumarin 3-carboxylic acid	0	-67	4	181	586	1694	6724	17495	31314
3-butyryl-7-nitrocoumarin	0	64	387	894	1538	2344	3329	4642	6845
3-acetyl-4-methyl-7-nitrocoumarin	0	40	390	992	1804	2811	4090	5576	8017
7-nitrocoumarin-3-carboxymorpholide	0	180	665	1376	2414	3796	5817	8454	12263
Control	0	-214	-159	-205	-174	-177	-131	-104	-101

Table 3: Readings corresponding to Figure 2

5

B – The inhibitory effect of different concentrations of 7-nitrocoumarin 3-carboxylic acid on the growth of *Escherichia coli* (NCTC strain 10418)

1°) Method

10 The effect of the concentration of 7-nitrocoumarin-3-carboxylic acid on the sensitivity of the assay to detect *E. coli* (NCTC strain 10418) was investigated at concentrations of the indicator ranging from 0 to 0.262 mmol/l. All other conditions were identical to those described in section A above.

2°) Results

It can be clearly seen from Figure 3 that the concentration of 7-nitrocoumarin 3-carboxylic acid has no significant effect on *E. coli* growth since the growth curves measured at different concentrations are similar to one another and even similar to that of the control. The fact that this compound has no growth inhibitory activity is reflected by the level of the fluorescent signal resulting from reduction of the nitro groups.

Figure 4 shows that the fluorescent signal increases with the substrate concentration until saturation at a concentration of about 0.157 mmol/l (36.9 µg/ml). Beyond this point, the sensitivity of the fluorescent reaction is not enhanced.

In order to make Figures 3 and 4 easier to read, the readings on which they are based are given in the following Tables (Tables 4 and 5).

Compound\Time(min)	0	30	60	90	120	150	180	210	240
0.262 mmol/l	0.000	0.000	0.002	0.009	0.027	0.069	0.144	0.213	0.346
0.210 mmol/l	0.000	0.000	0.003	0.010	0.027	0.072	0.138	0.187	0.346
0.157 mmol/l	0.000	-0.001	0.002	0.009	0.027	0.073	0.151	0.205	0.372
0.105 mmol/l	0.000	0.000	0.002	0.008	0.026	0.068	0.164	0.227	0.416
0.052 mmol/l	0.000	0.001	0.003	0.011	0.031	0.082	0.153	0.225	0.408
0.026 mmol/l	0.000	0.001	0.004	0.011	0.032	0.079	0.201	0.290	0.436
0.013 mmol/l	0.000	0.000	0.003	0.011	0.032	0.088	0.149	0.233	0.371
0.005 mmol/l	0.000	0.000	0.003	0.011	0.034	0.090	0.155	0.246	0.411
Control	0.000	0.002	0.005	0.011	0.025	0.061	0.174	0.241	0.332

Table 4: Readings corresponding to Figure 3

Compound\Time(min)	0	30	60	90	120	150	180	210	240
0.262 mmol/l	0	3	131	446	1190	3037	9721	22066	37949
0.210 mmol/l	0	-6	88	354	979	2588	9000	21589	37823
0.157 mmol/l	0	-74	48	280	811	2231	8264	21022	36517
0.105 mmol/l	0	-67	4	181	586	1694	6724	17495	31314
0.052 mmol/l	0	-83	-76	33	241	861	4004	10584	19530
0.026 mmol/l	0	-91	-110	-39	71	467	2311	6028	11387
0.013 mmol/l	0	-113	-141	-76	-22	174	1068	3073	5902
0.005 mmol/l	0	-134	-164	-122	-94	-9	406	1307	2466
Control	0	-296	-159	-168	-149	-156	-131	-110	-119

Table 5: Readings corresponding to Figure 4

5 C – The usefulness of 7-nitrocoumarin 3-carboxylic acid as an indicator of the growth of various different *Enterobacteriaceae*

1°) Method

This experiment was designed to investigate whether or not it would be possible 10 to detect *Enterobacteriaceae* other than *E. coli* using 7-nitrocoumarin-3-carboxylic acid. The conditions for this experiment were similar to those described for the first experiment (section A).

Five wild strains belonging to the species *Citrobacter diversus*, *Enterobacter agglomerans*, *Hafnia alvei*, *Morganella morganii* and *Shigella sonnei* were tested

15

2°) Results

Figure 6 shows how 7-nitrocoumarin-3-carboxylic acid is reduced by wild strains belonging to five different species of *Enterobacteriaceae*. All the strains tested were found to be able to reduce this compound. Comparison of the kinetics of

fluorescence (Figure 6) and the growth curves (Figure 5) reveal close correlation between the fluorescent signal and the rate of growth. This suggests that 7-nitrocoumarin-3-carboxylic acid is a very reliable indicator for growth.

In order to make Figures 5 and 6 easier to read, the readings on which they are based are given in the following Tables (Tables 6 and 7).

Compound\Time(min)	0	30	60	90	120	150	180	210	240
<i>C. diversus</i>	0.000	0.000	0.005	0.011	0.020	0.050	0.092	0.143	0.250
<i>E. agglomerans</i>	0.000	-0.002	0.002	0.006	0.027	0.057	0.155	0.225	0.323
<i>H. alvei</i>	0.000	-0.001	0.004	0.009	0.016	0.034	0.092	0.149	0.246
<i>M. morganii</i>	0.000	-0.010	-0.010	-0.005	0.003	0.020	0.064	0.116	0.187
<i>S. sonnei</i>	0.000	-0.001	0.000	0.002	0.013	0.042	0.097	0.159	0.246
Control	0.000	-0.002	-0.002	0.003	-0.002	0.005	-0.003	-0.001	0.003

Table 6: Readings corresponding to Figure 5

Compound\Time(min)	0	30	60	90	120	150	180	210	240
<i>C. diversus</i>	0	3	3	34	92	281	546	1209	5393
<i>E. agglomerans</i>	0	-15	-3	9	74	199	501	1246	4099
<i>H. alvei</i>	0	-24	-30	0	40	122	260	775	2048
<i>M. morganii</i>	0	-42	-24	-15	31	95	403	2170	8128
<i>S. sonnei</i>	0	-9	15	52	162	434	1108	3095	8567
Control	0	9	0	24	21	34	43	24	61

Table 7: Readings corresponding to Figure 6

Although the results will not be presented here, it has been confirmed that similar kinetic profiles are obtained with most microorganisms, not only the *Enterobacteriaceae*, but also non-fermenting Gram-positive bacilli, *Staphylococcus*

spp., *Streptococcus* spp., *Listeria* spp. and yeasts. All were capable of reducing nitrocoumarin derivatives (in particular 7-nitrocoumarin-3-carboxylic acid) to give a fluorescent signal. This shows the broad applicability of this method of detecting growth, as illustrated by the results of the following series of experiments.

5

D- The usefulness of 7-nitrocoumarin-3-carboxylic acid as a growth indicator for a wide variety of different types of microorganism

10 1°) Method

This experiment was performed to test 7-nitrocoumarin-3-carboxylic acid on sixteen (16) different types of microorganism, including one yeast species. A list of all the species tested is given in Table 8 below.

15 A mass of 10 mg of the indicator was dissolved in 4 ml of hot, distilled water and this solution was then added to 96 ml of Trypticase Soy broth. The resultant mixture was sterile-filtered.

20 All the microorganisms were grown for 24 hours in Trypticase Soy broth at 35 °C. Each culture was then diluted 1,000-fold in Trypticase Soy broth and then serial 10-fold dilutions were made in more Trypticase Soy broth until the test aliquot contained no more microbial cells.

The resultant dilutions ranged from 10^{-3} to 10^{-13} .

Fifty microliters of each dilution plus 50 μ l of Trypticase Soy broth were added to wells of a microtiter plate with or without 7-nitrocoumarin-3-carboxylic acid.

25 The plates were read (T zero) and then incubated at 35 °C before being read again after 24 hours. Two different readings were made at each time point:

- of the optical density (690 nm), using an Anthos 2001 spectrophotometer (Labtech International Limited) for wells without any 7-nitrocoumarin-3-carboxylic acid, and
- of the fluorescence (excitation at 365 nm and emission at 440 nm), using a Biolite F1 2001 fluorometer (Labtech International Limited), for wells containing 7-nitrocoumarin-3-carboxylic acid.

In order to check the correlation between growth and the fluorescence results, the contents of each well were seeded on Columbia agar supplemented with sheep blood.

5 2°) Results

7-nitrocoumarin-3-carboxylic acid was tested against sixteen different microorganisms which represented a broad variety of different bacterial species plus one yeast, as shown in Table 8 below.

Fluorescence readings (the first line for each strain) and optical density readings
10 (the second line for each strain) obtained after 24 hours of culture are shown in Table 8. In order to check the correlation between growth and the fluorescence results, and to confirm that the indicator was non-toxic, the contents of each well were seeded on Columbia agar supplemented with sheep blood. The data points corresponding to wells which grew out colonies are shown in italics in the Table.

15 The results shown in the Table demonstrate that the fluorescence readings (due to reduction of the indicator) correlate closely with microbial growth patterns for all the species tested. The odd minor differences observed can be explained by small variations in the number of viable cells in the microtiter plate wells, especially when it comes to the limiting dilutions where the inoculum might contain only one single
20 microorganism. Therefore, a fluorescence-based test can be used instead of a growth assay. Using 7-nitrocoumarin-3-carboxylic acid as a fluorescent indicator of growth would seem to make for a very sensitive test which is capable of detecting very small numbers of microorganisms; it can be judged that, when limiting dilution methods such as those adopted in this experiment are practiced, this assay is capable of detecting a
25 single viable cell.

It should be noted that the yeast species tested here (*Candida albicans*) gave only a faint fluorescent signal in comparison to that given by the bacteria. This is due to the use of Trypticase Soy broth which is not an ideal medium for the propagation of yeast. Although the results are not presented here, if a medium which is more suitable

for yeast such as RPMI is used, the fluorescent signal is comparable to that generated by the bacteria.

The results are presented in Table 8 below. Because the number of dilutions is so high (eleven dilutions from 10^{-3} to 10^{-13} plus a twelfth "blank" reading used as the control) and in order to make the results easier to assess, the Table has been divided into two sections: the first section covers the dilutions between 10^{-3} and 10^{-9} ; and the second covers the dilutions between 10^{-10} and 10^{-13} and the control.

Dilution factor for suspension	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}
<i>Acinetobacter baumanii</i> (ATCC 19606)	27016	11695	12525	8912	6953	1651	1705
<i>Acinetobacter baumanii</i> (ATCC 19606)	0.447	0.307	0.240	0.085	0.071	0.017	0.002
<i>Acinetobacter calcoaceticus</i> (ATCC 7844)	29657	18288	12311	12223	11635	14858	13353
<i>Acinetobacter calcoaceticus</i> (ATCC 7844)	0.522	0.714	0.669	0.565	0.290	0.404	0.208
<i>Acinetobacter haemolyticus</i> (ATCC 17906)	19231	17403	12614	9727	4236	1981	1938
<i>Acinetobacter haemolyticus</i> (ATCC 17906)	0.063	0.055	0.061	0.047	0.016	-0.003	-0.001
<i>Brevundimonas vesicularis</i> (ATCC 11426)	2543	1962	1861	1941	1928	1889	1929
<i>Brevundimonas vesicularis</i> (ATCC 11426)	0.112	0.037	0.006	-0.012	-0.001	0.005	-0.002
<i>Burkholderia cepacia</i> (ATCC 25416)	16978	16719	16808	15800	11973	1969	1996
<i>Burkholderia cepacia</i> (ATCC 25416)	0.594	0.637	0.536	0.602	0.571	-0.001	0.000
<i>Listeria ivanovii</i> (wild strain)	16246	44910	13185	44865	9251	8137	44425
<i>Listeria ivanovii</i> (wild strain)	0.312	0.269	0.384	0.295	0.298	0.178	0.001
<i>Moraxella nonliquefaciens</i> (ATCC 19975)	28160	27889	28439	27648	27385	27196	1974
<i>Moraxella nonliquefaciens</i> (ATCC 19975)	0.828	0.693	0.666	0.693	0.708	0.697	0.000
<i>Moraxella osloensis</i> (ATCC 19976)	11426	9949	7700	5875	1925	1941	1977
<i>Moraxella osloensis</i> (ATCC 19976)	0.056	0.044	0.051	0.059	0.000	0.001	0.000
<i>Pseudomonas fluorescens</i> (ATCC 13525)	8985	1774	1657	1625	1716	1690	1736
<i>Pseudomonas fluorescens</i> (ATCC 13525)	0.005	-0.002	-0.002	-0.004	-0.001	-0.003	-0.002
<i>Pseudomonas putida</i> (ATCC 12633)	12589	9810	7670	6806	5714	1715	1664
<i>Pseudomonas putida</i> (ATCC 12633)	0.567	0.483	0.431	0.465	0.483	-0.002	0.000
Dilution factor for suspension	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}
<i>Serratia marcescens</i> (NCTC 10211)	47178	49470	45804	45454	45637	43088	48320
<i>Serratia marcescens</i> (NCTC 10211)	0.543	1.001	0.464	0.487	1.240	0.549	1.051
<i>Shewanella putrefaciens</i> (ATCC 8071)	40277	37262	34890	32034	31793	1911	1902
<i>Shewanella putrefaciens</i> (ATCC 8071)	0.364	0.267	0.139	0.106	0.108	-0.003	-0.001
<i>Shigella sonnei</i> (NCTC 8586)	51755	50254	50166	50278	49882	47370	1816
<i>Shigella sonnei</i> (NCTC 8586)	0.183	0.209	0.207	0.269	0.215	0.050	0.000
<i>Staphylococcus aureus</i> (NCTC 6571)	46607	45207	44544	43559	41437	1678	1666
<i>Staphylococcus aureus</i> (NCTC 6571)	0.507	0.484	0.497	0.507	0.444	-0.003	-0.001
<i>Streptococcus mitis</i> (NCTC 12261)	20988	21541	19899	19619	17228	1682	1676
<i>Streptococcus mitis</i> (NCTC 12261)	0.209	0.367	0.325	0.300	0.257	-0.002	0.000
<i>Candida albicans</i> (ATCC 90028)	2847	2609	2335	2041	1693	1745	1693
<i>Candida albicans</i> (ATCC 90028)	0.49	0.419	0.308	0.403	-0.003	0.001	0.000

Control with no microorganism	1785	1727	1779	1755	1786	1724	1712
Control with no microorganism	0.003	0.001	0.000	-0.003	-0.005	-0.002	-0.001

Dilution factor for suspension	10 ⁻¹⁰	10 ⁻¹¹	10 ⁻¹²	10 ⁻¹³	"blank"
<i>Acinetobacter baumanii</i> (ATCC 19606)	1718	1678	1687	1660	1671
<i>Acinetobacter baumanii</i> (ATCC 19606)	-0.001	0.000	-0.001	0.002	0.000
<i>Acinetobacter calcoaceticus</i> (ATCC 7844)	10862	1712	1654	1699	1704
<i>Acinetobacter calcoaceticus</i> (ATCC 7844)	0.200	-0.001	-0.001	-0.001	0.000
<i>Acinetobacter haemolyticus</i> (ATCC 17906)	2005	1947	1904	1938	1907
<i>Acinetobacter haemolyticus</i> (ATCC 17906)	-0.002	0.000	-0.001	-0.002	-0.001
<i>Brevundimonas vesicularis</i> (ATCC 11426)	1910	1938	1919	1877	1840
<i>Brevundimonas vesicularis</i> (ATCC 11426)	0.000	-0.001	-0.001	-0.003	0.006
<i>Burkholderia cepacia</i> (ATCC 25416)	1950	1925	1965	1914	1874
<i>Burkholderia cepacia</i> (ATCC 25416)	-0.002	0.002	-0.002	-0.002	-0.001
<i>Listeria ivanovii</i> (wild strain)	1663	1651	1691	1682	1680
<i>Listeria ivanovii</i> (wild strain)	-0.001	0.000	0.000	0.000	-0.001
<i>Moraxella nonliquefaciens</i> (ATCC 19975)	2057	2002	1956	1907	1969
<i>Moraxella nonliquefaciens</i> (ATCC 19975)	-0.002	0.000	-0.001	0.001	0.000
<i>Moraxella osloensis</i> (ATCC 19976)	2039	1938	1907	1945	1880
<i>Moraxella osloensis</i> (ATCC 19976)	0.001	0.000	0.000	0.000	0.000
<i>Pseudomonas fluorescens</i> (ATCC 13525)	1666	1691	1666	1624	1596
<i>Pseudomonas fluorescens</i> (ATCC 13525)	-0.004	-0.002	0.000	-0.002	0.000
<i>Pseudomonas putida</i> (ATCC 12633)	1660	1651	1660	1657	1648
<i>Pseudomonas putida</i> (ATCC 12633)	-0.002	0.001	0.001	0.001	0.001
<i>Serratia marcescens</i> (NCTC 10211)	1678	1641	1636	1621	1630
<i>Serratia marcescens</i> (NCTC 10211)	-0.002	-0.001	0.001	-0.001	-0.001
<i>Shewanella putrefaciens</i> (ATCC 8071)	1972	1917	1935	1990	1905
Dilution factor for suspension	10 ⁻¹⁰	10 ⁻¹¹	10 ⁻¹²	10 ⁻¹³	"blank"
<i>Shewanella putrefaciens</i> (ATCC 8071)	-0.002	0.001	-0.001	-0.002	0.000
<i>Shigella sonnei</i> (NCTC 8586)	1990	1960	1956	1911	1778
<i>Shigella sonnei</i> (NCTC 8586)	-0.003	0.003	-0.001	-0.004	0.000
<i>Staphylococcus aureus</i> (NCTC 6571)	1666	1620	1706	1669	1746
<i>Staphylococcus aureus</i> (NCTC 6571)	-0.001	0.001	0.003	0.000	0.000
<i>Streptococcus mitis</i> (NCTC 12261)	1691	1636	1644	1669	1682
<i>Streptococcus mitis</i> (NCTC 12261)	-0.002	0.001	-0.003	-0.003	-0.003
<i>Candida albicans</i> (ATCC 90028)	1751	1666	1702	1666	1672
<i>Candida albicans</i> (ATCC 90028)	-0.005	-0.002	0.005	0.000	0.000
Control with no microorganism	1730	1734	1700	1639	1734
Control with no microorganism	-0.001	-0.001	0.001	-0.001	-0.001

Table 8: After 24 hours in the presence of 7-nitrocoumarin-3-carboxylic acid: fluorescence readings (line 1) and optical density readings (line 2) for serial dilutions of suspensions of a variety of different microorganisms.

3º) Conclusions:

Derivatives of 7-nitrocoumarin, notably 7-nitrocoumarin-3-carboxylic acid, constitute a family of universal fluorescent indicators for the growth of microorganisms.

5

These novel indicators have numerous applications in microbiology and are relevant to all methods based on the detection of microbial growth. Among the possible applications, the following could be singled out:

- microorganism sensitivity to antibiotic and antifungal testing methods,
- 10 - identification methods based on assimilation tests (detection of growth in the presence of substrates which can be used as the sole carbon source),
- sterility testing on a sample (to confirm the absence of any microorganisms),
- any test to detect microorganisms in samples which may contain them, be they clinical, industrial (e.g. in the food processing, pharmaceutical and cosmetics industries) or environmental samples, and
- 15 - any kind of counting of microorganisms in a sample, in particular counts based on determining the most probable number, as are routinely practiced in the food processing industry.

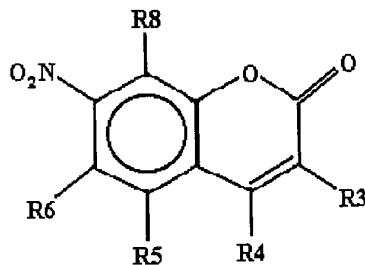
The discussion of the background to the invention herein is included to explain the context of the invention. This is not to be taken as an admission that any of the material referred to was published, known or part of the common general knowledge in Australia as at the priority date of any of the claims.

Throughout the description and claims of the specification the word "comprise" and variations of the word, such as "comprising" and "comprises", is not intended to exclude other additives, components, integers or steps.

CLAIMS

1. The use of a compound in a detection and/or diagnostic test to determine whether or not microorganisms are present, in which the compound is 7-nitrocoumarin or one of its derivatives.

2. The use, according to claim 1, wherein the compound is made up of a molecule having the following general formula:



in which R₃ is either H or CO_Z, where Z is conducive to the generation of a ketone, an acid or an ester group, or any other aliphatic group,

and in which R₄ is either H or a trifluoromethyl (CF₃) group or any aliphatic group.

3. The use, according to claim 2, wherein R₃ is one of the following groups: COOCH₃, COOC₂H₅, COOH, COC₃H₇, CONC₄H₄O or COCH₃, and R₄ is H or a CH₃ group.

4. The use, according to any of claims 1 through 3, wherein the compound is 7-nitrocoumarin-3-carboxylic acid.

5. The use, according to claim 4, wherein the concentration of the 7-nitrocoumarin-3-carboxylic acid is between 0.05 and 0.3 mmol/l.

6. The use of a compound, according to any of claims 1 through 5, in the detection of microbial growth with a view to checking sterility.

7. The use of a compound, according to any of claims 1 through 5, in the detection of microbial growth with a view to counting the number of microorganisms present in the sample.

8. The use of a compound, according to any of claims 1 through 5, in the detection of microbial growth with a view to determining the susceptibility of a microorganism to an antimicrobial agent.

9. The use of a compound, according to any of claims 1 through 5, in the detection of microbial growth with a view to detecting the presence of at least one microorganism.

10. A method for detecting single microorganisms or groups of microorganisms in samples which may contain them, including the following operations:

- i) adding a compound based on 7-nitrocoumarin or any of its derivatives to a culture medium which contains the sample, and
- ii) monitoring for the formation of a fluorescent product, the presence or absence of a fluorescent signal making it possible to conclude whether or not one or more of the suspected microorganisms are present.

11. A method for identifying at least one microorganism in a sample which may contain such a microorganism, involving the following operations:

- i) adding a compound based on 7-nitrocoumarin or any of its derivatives to an identification well containing a culture medium based on a single carbon source and an aliquot of the test sample, and
- ii) monitoring for the formation of a fluorescent product in the different wells, the presence or absence of fluorescent signals making it possible to identify the microorganisms.

12. A use according to claim 1 substantially as hereinbefore described with reference to any of the examples.

5 13. A method according to claim 10 or claim 11 substantially as hereinbefore described with reference to any of the examples.

DATED: 3 January, 2002

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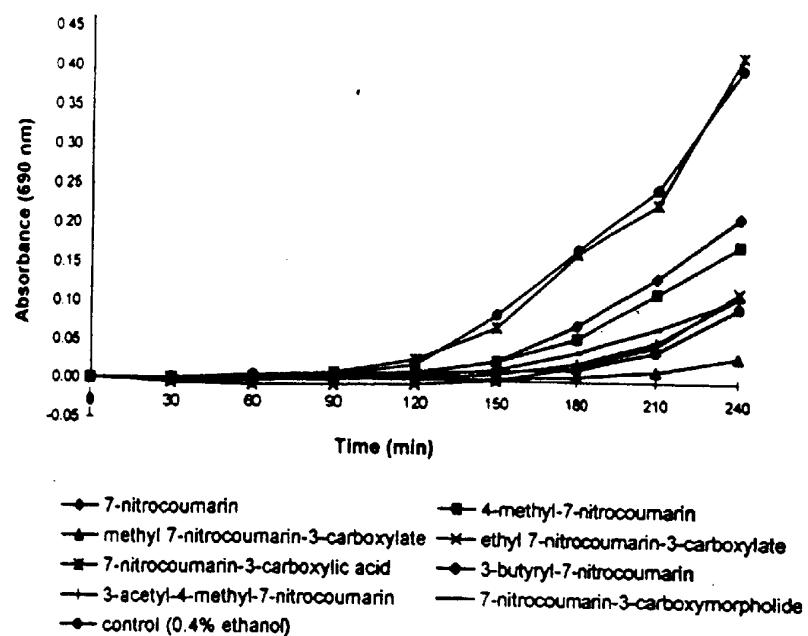


Fig. 1

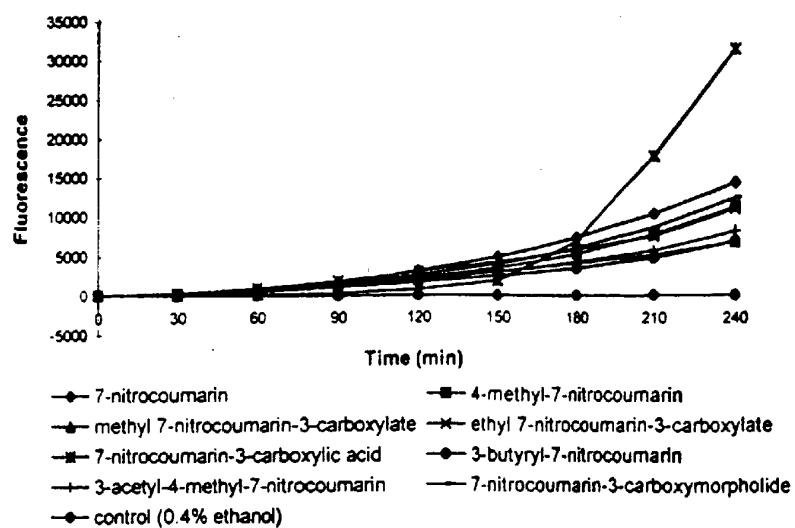


Fig. 2

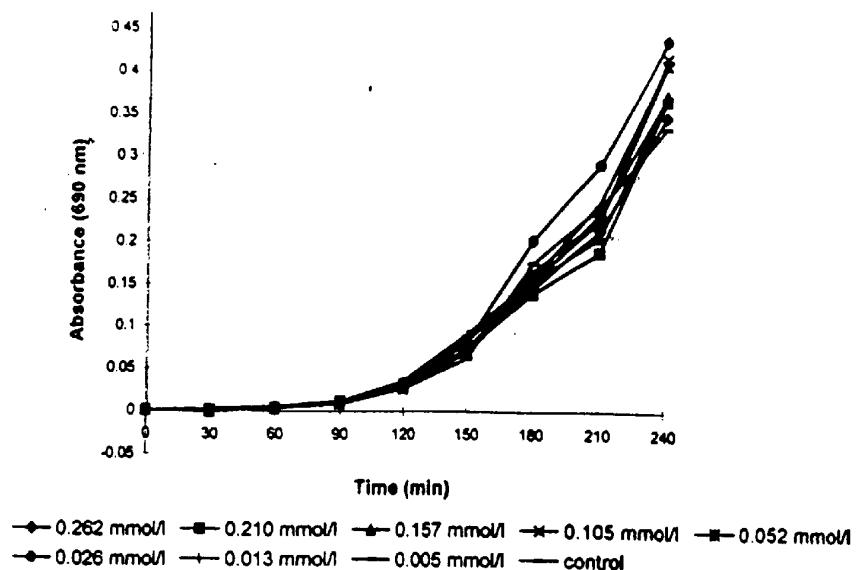


Fig. 3

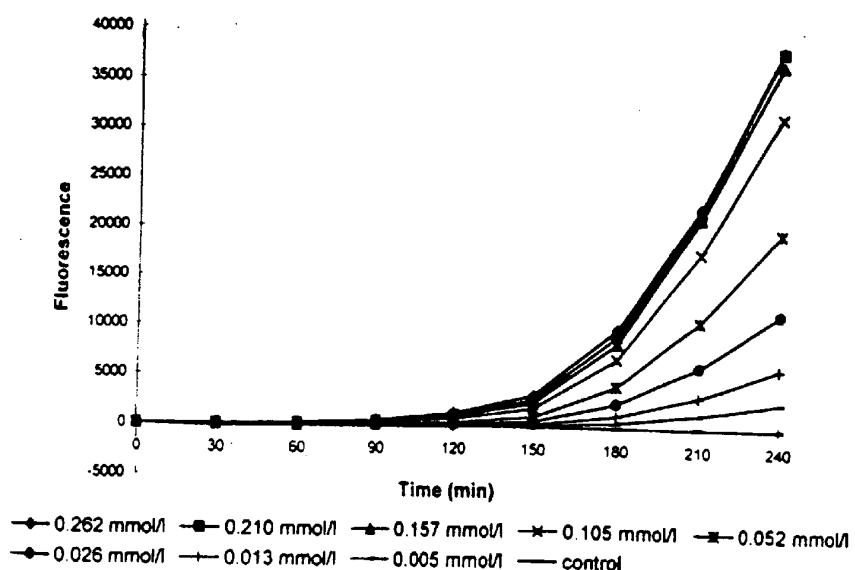


Fig. 4

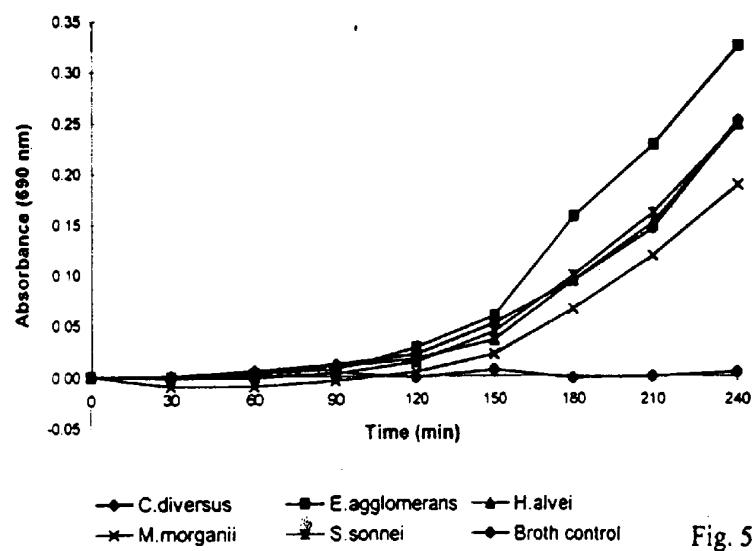


Fig. 5

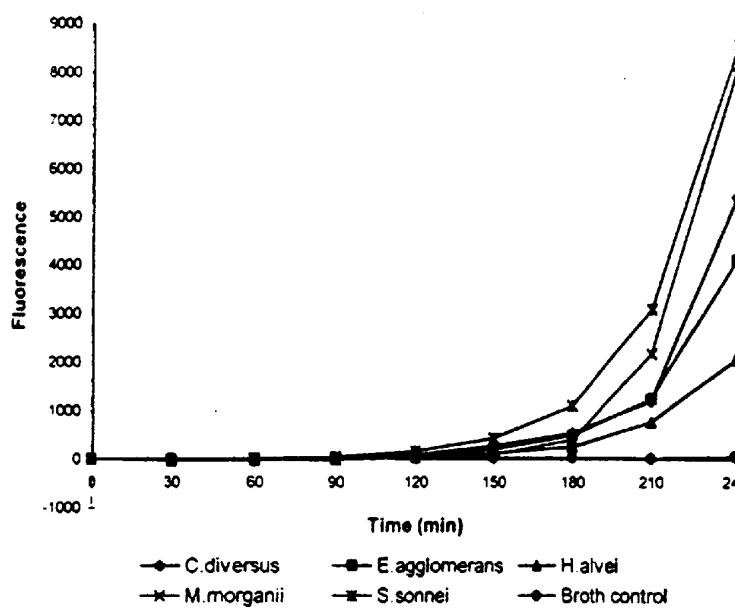


Fig. 6