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Shih et al.

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- [54] METHOD OF DEGRADING
KERATINACEOUS MATERIAL AND
BACTERIA USEFUL THEREFOR
- [75] Inventors: Jason C. H. Shih; C. Michael
Williams, both of Cary, N.C.
- [73] Assignee: North Carolina State University,
Raleigh, N.C.
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435/106, 267, 272, 836, 172.1, 68.1, 252.5;
426/20, 61-63

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- 4,959,311 9/1990 Shih et al. 435/68.1

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Primary Examiner—Robert A. Wax
Assistant Examiner—D. R. Preston
Attorney, Agent, or Firm—Bell, Seltzer, Park & Gibson

[57] ABSTRACT

A method of degrading keratinaceous material is disclosed. The method comprises the steps of combining the keratinaceous material with *Bacillus licheniformis* to form a fermentation media and then fermenting the media for a time sufficient to degrade the material. The method can be used to produce amino acids from keratinaceous material and to produce a hydrolyzed feather product useful as a feed additive from the keratinaceous material.

A preferred keratinaceous material for carrying out the present invention is feather, and a preferred bacteria for carrying out the invention is *Bacillus licheniformis* PWD-1.

2 Claims, No Drawings

METHOD OF DEGRADING KERATINACEOUS MATERIAL AND BACTERIA USEFUL THEREFOR

This application is a division of pending application Ser. No. 07/175,476, filed Mar. 31, 1988 now U.S. Pat. No. 4,959,311.

FIELD OF THE INVENTION

The present invention relates to fermentation processes generally, and particularly relates to a process for hydrolyzing keratinaceous material with *Bacillus licheniformis*.

BACKGROUND OF THE INVENTION

Feathers are produced in large quantities by the poultry industry. These feathers provide an inexpensive source of raw material for a variety of potential uses. Among other things, there has been considerable interest in developing methods of degrading feathers so they can be used as an inexpensive source of amino acids and digestible protein in animal feed.

Processes for converting feather into animal feed which have been developed to date include both steam hydrolysis processes and combined steam hydrolysis and enzymatic processes. See, e.g., Papadopoulos, M. C., *Animal Feed Science and Technology* 16, 151 (1986); Papadopoulos, M. C. et al., *Poultry Science* 64, 1729 (1985); Alderibigde, A. O. and D. Church, *J. Anim. Sci.*, 1198 (1983); Thomas and Beeson, *J. Anim. Sci.* 45, 819 (1977); Morris and Balloun, *Poultry Sci.* 52, 858 (1973); Moran et al., *Poultry Sci.* 46, 456 (1967); Davis et al., Processing of poultry by-products and their utilization in feeds. Part I. *USDA Util. Res. Rep.* no. 3, Washington, D.C. (1961). Disadvantages of these procedures, such as the degradation of heat sensitive amino acids by steam processes and the relatively low digestibility of the resulting products, have lead to continued interest in economical new feather degradation procedures which do not require a harsh steam treatment.

Accordingly, an object of the present invention is to provide a process for hydrolyzing keratinaceous material which does not depend upon steam hydrolysis.

An additional object is to provide a process for converting keratinaceous material into amino acids at high yields of the amino acids.

A further object of this invention is to provide a hydrolyzed feather product useful as a feed ingredient which is highly digestible and provides a good quality source of dietary protein and amino acids.

A still further object of the present invention is to provide an economical animal feed which employs a hydrolyzed feather product as a dietary amino acid source.

The foregoing and other objects and aspects of the present invention are explained in detail in the Summary, Detailed Description, and Examples sections below.

SUMMARY OF THE INVENTION

A first aspect of the present invention is a method of degrading keratinaceous material. The method comprises the steps of combining keratinaceous material with *Bacillus licheniformis* to form a fermentation media, and then fermenting the media for a time sufficient to degrade the material. In addition to degrading keratinaceous material, the method of the present invention can be used to produce amino acids. In this case, a

fermentation media produced as described above is fermented for a time sufficient to produce free amino acids therefrom, and the free amino acids are recovered from the media.

The method of the present invention can also be used to produce a hydrolyzed feather product. In this latter case, a fermentation media produced as described above, with feather as the keratinaceous material, is fermented for a time sufficient to increase the digestibility of the media (e.g., by enriching the concentration of digestible proteins and peptides therein). Preferably, the bacteria in the media are then killed to form a hydrolyzed feather product useful as a feed ingredient (i.e., the media with the bacteria are treated to kill the bacteria).

When the method of the present invention is used to produce free amino acids or a hydrolyzed feather product, the fermentation step is preferably an anaerobic fermentation step. Under anaerobic conditions, *B. licheniformis* does not actively grow. Hence, the utilization of amino acids by *B. licheniformis* is decreased and free amino acid production, or enrichment, is increased. In addition, prior to the step of combining the feathers with *B. licheniformis*, *B. licheniformis* is preferably first grown under aerobic conditions (preferably in a liquid culture) to obtain enriched quantities of active bacteria. These procedures, as explained in detail below, provide an efficient and cost-effective way to degrade keratinaceous material and to utilize feather.

A second aspect of the present invention is a pure culture of the keratinaceous material-degrading microorganism having the identifying characteristics of *Bacillus licheniformis* PWD-1, ATCC No. 53757. *B. licheniformis* PWD-1 is the preferred microorganism for carrying out the methods described above.

A third aspect of the present invention is a hydrolyzed feather product, which may be produced by the method described above. This product comprises partially hydrolyzed feather, proteins cleaved from the partially hydrolyzed feather, peptides cleaved from the partially hydrolyzed feather, and *B. licheniformis* cells (preferably killed *B. licheniformis* cells). This hydrolyzed feather product may be combined with a carbohydrate source and, preferably, minerals and vitamins, to form an animal feed. A second, supplementary protein source may optionally be included in the feed.

Additional aspects of the present invention are discussed below.

DETAILED DESCRIPTION OF THE INVENTION

The present invention can be carried out with all types of keratinaceous material, including hair, hooves, and feather. Feather is preferred. Any type of feather may be employed, including chicken, turkey, and duck feather. Chicken feather is preferred, and is the material recited in the text which follows. However, the teaching of this text is applicable to the degradation and utilization of all keratinaceous materials.

Prior to combining feather with *B. licheniformis* to form a fermentation medium, the feather should be sterilized to kill bacteria naturally present on the feather which might otherwise disrupt the fermentation process. This sterilization step may be carried out by any means, including fumigation by contacting feather to formalin or ethylene oxide gas, by contacting feather to steam under pressure, or by combinations of the same. We have found that, by contacting feather to steam

under pressure, even for a time insufficient to sterilize the feather, subsequent bacterial degradation of the feather is substantially improved. Accordingly, sterilization steps in the present invention preferably include a step of contacting the feather to steam for a time and at a temperature sufficient to facilitate the subsequent bacterial hydrolysis thereof, even if this steam treatment step does not accomplish a complete sterilization of the feather. We have found that contacting feather to steam under pressure, in an enclosed chamber, at 125 degrees Centigrade for a time as brief as 2 minutes is sufficient to substantially enhance the subsequent fermentation hydrolysis thereof. If sterilization of feather is carried out solely by steam, the feather should be contacted to steam under pressure at 125 degrees Centigrade for at least 15 minutes (a 15-20 minute treatment at this temperature being, by definition, an autoclaving step). The time and temperature of steam treatment should be less than those employed in commercial steam hydrolysis processes, which employ treatment times of 35 minutes or more at steam pressures of about 35 p.s.i. or more.

Prior to fermentation, *B. licheniformis* can be grown aerobically in any suitable liquid growth medium (preferably a feather-based liquid growth medium). The bacteria is preferably grown at a temperature of from about 45 to about 55 degrees centigrade. After a sufficient quantity of the bacteria is grown (preferably about 10^8 colony forming units per milliliter), the liquid growth medium is combined with feather in any suitable fermentation vessel. Preferably, the liquid growth medium and feather are combined at a high proportion of feather, so that the fermentation is a semi-solid fermentation. A preferred fermentation media comprises, by weight, at least about 1 part of dry feather per 4 parts of liquid growth medium, or more preferably about 1 part of dry feather per 2 parts of liquid growth medium.

Carbohydrate sources used to produce an animal feed according to the present invention include, for example, corn, oats, barley, sorghum, or combinations of the same. These grains are preferably ground into a meal for use in the animal feed. Supplementary protein sources include, for example, soy meal, fish meal, blood meal, poultry by-product (ground poultry offal), meat meal, and combinations of the same. An animal feed is comprised of from about 13% to about 25% by weight of protein from all protein sources (both hydrolyzed feather and supplemental). The hydrolyzed feather product may be the sole protein source, but is preferably from about 2% to about 15% by weight of the feed. Other nutrients in small amounts, such as vitamins, minerals, antibiotics, and other substances or compounds may be included in the feed as required.

Bacillus licheniformis strain PWD-1 was deposited with the American Type Culture Collection in accordance with the Budapest Treaty on Mar. 23, 1988, and has been assigned ATCC Accession No. 53757.

PWD-1 has been found to be a gram positive (but gram variable) bacteria. It is a straight rod-shaped bacteria, the rods being from about 2.1 to about 3.0 microns long and from about 0.5 to about 1.0 microns wide, with the ends of the rods being rounded. Bacterial cells are found both singly and in chains. One subterminal endospore is formed per cell, the endospore being centrally located and cylindrical or oval in shape.

PWD-1 forms opaque, entire (mucoid) colonies which are erose and irregular in shape. Low convex, high convex (mucoid) and flat colonies are seen. Colonies are seen to disassociate. The colonies are observed

as glistening (mucoid) dull, dry, smooth (mucoid) and rough, with an insoluble brown pigment present. Cells are motile (flagella being present) and peritrichous.

PWD-1 grows at temperatures of from about 20° C. to about 55° C., with trace growth being present at 60° C. In our hands, the bacteria is thermophilic, growing best at temperatures of from 45° C. to 50° C. Others have reported an optimum growth range of between 21 and 30 degrees Centigrade. Experiments are under way to examine the effects of different growth media on optimum growth temperature.

PWD-1 produces acid, but not gas, from L-arabinose, D-xylose (weakly), D-glucose, lactose (weakly), sucrose, and D-mannitol. It can utilize both citrate and propionate as a carbon source. PWD-1 hydrolyzes polysaccharide, starch and casein, but not hippurate. PWD-1 liquifies gelatin. It reduces, but does not reoxidize, methylene blue. It reduces nitrate to nitrite, but it does not reduce nitrite.

PWD-1 is Voges Proskauer (5198) positive, Voges Proskauer (5198 fil) positive, and Voges Proskauer (5331) positive. It decomposes hydrogen peroxide but not tyrosine, is negative for indole, and is positive for dihydroxyacetone. PWD-1 is negative in the Litmus milk acid test, negative in the Litmus milk coagulation test, and negative in the Litmus milk alkaline test, but is positive in both the litmus milk peptonization and litmus milk reduction tests.

PWD-1 grows at a pH of 5.7 and at a pH of 6.0. It shows a pH of 8.0 or more. The optimum pH in nutrient broth is 7.0 to 7.5. It is aerobic and facultative. It does not grow in 0.02% azide. It generates gas from sealed nitrate and grows in sealed glucose. It is negative for lecithinase.

A crude, cell-free extract comprised of a mixture of *Bacillus licheniformis* PWD-1 proteins capable of degrading keratinaceous material is also an aspect of the present invention. This crude extract is prepared, for example, by separating *B. licheniformis* PWD-1 cells from their liquid growth media, the liquid growth media so becoming the crude cell-free extract. Alternatively, *B. licheniformis* PWD-1 cells may be lysed (chemically or physically) in a liquid growth media to produce a crude, cell-free extract. Other means of preparing such an extract will be apparent to persons skilled in the art. The crude, cell-free extract may be provided in aqueous form. Alternatively, it may be provided in lyophilized form to increase the shelf life thereof.

A substantially pure, keratinaceous material-degrading, *Bacillus licheniformis* PWD-1 enzyme is a further aspect of the present invention. This substantially pure enzyme is produced by separating the proteins which comprise the crude, cell-free extract described above into its individual, constituent proteins. Any suitable separation procedure may be employed. Numerous such separation procedures, such as column chromatography, are known to and routinely employed by persons skilled in the art for this purpose. The individual constituent proteins are then screened for their ability to degrade keratinaceous material. That constituent protein which best degrades keratinaceous material comprises the substantially pure enzyme. Like the crude cell-free extract, the substantially pure enzyme may be provided in either aqueous or lyophilized form.

Both the crude cell-free extract and the substantially pure enzyme, when provided in aqueous form, may be used to degrade keratinaceous material (preferably

feather) by combining the same with the keratinaceous material to form a fermentation media, and then fermenting the fermentation media for a time sufficient to degrade the feathers.

A still further aspect of the present invention is a DNA sequence comprising a cloned gene or fragment thereof which codes for the production of a keratinaceous material-degrading *B. licheniformis* PWD-1 enzyme or active fragment thereof. This cloned gene is produced as follows. First, a multiplicity of *B. licheniformis* PWD-1 DNA sequences are generated (as either a genomic DNA or complementary DNA library). These sequences are then inserted into DNA expression vectors to form recombinant expression vectors. Next, the recombinant expression vectors are inserted into suitable hosts to form transformants which express the DNA sequences. Finally, these transformants are screened for the production of a keratinaceous material-degrading enzyme. Transformants which express such an enzyme carry, as an insertion in the vector contained therein, the desired DNA sequence.

A multiplicity of *B. licheniformis* PWD-1 DNA sequences may be generated by conventional techniques. One approach is to digest the genomic DNA of an *B. licheniformis* PWD-1, with the ultimate goal being the preparation of a genomic DNA library. See generally R. Old and S. Primrose, *Principles of Gene Manipulation*, 102-109 (3d ed. 1985). Another approach is to isolate mRNA from *B. licheniformis* PWD-1 and generate cDNA sequences therefrom, with the ultimate goal being the preparation of a cDNA library. See generally R. Old and S. Primrose, *supra* at 109-111; T. Maniatis, E. Fritsch and J. Sambrook, *Molecular Cloning: A Laboratory Manual*, 187-246 (1982).

A variety of vector-host combinations may be employed to produce the cloned gene. Host cells may be either prokaryotic or eukaryotic cells, and, when the host cells are bacterial cells, they may be either gram negative or gram positive bacteria. Useful hosts include, for example, *Escherichia coli* (including, for example, *E. coli*, X1776, *E. coli* X2282, *E. coli* HB101 and *E. coli* MRC1), species of *Salmonella* (including, for example, *S. typhimurium*, *S. enteritidis*, and *S. dublin*) species of *Pseudomonas* (including, for example, *P. aeruginosa* and *P. putida*), and *Bacillus subtilis*.

Vectors used in practicing the present invention are selected to be operable as cloning vectors or expression vectors in the selected host cell. The vectors may, for example, be bacteriophage, plasmids, viruses, or hybrids thereof. Vectors useful in *E. coli* include plasmids (for example, pSC101, ColE1, RSF2124, pBR322, pBR324, pBR325, pAT153, pUC-6 and pUC-8), bacteriophage lambda, cosmids, phasmids, and filamentous coliphages. *Salmonella* species may be transformed, for example, with plasmids such as pJC217, pBRD001, and pBRD026. Vectors useful in gram negative bacteria generally include plasmids of incompatibility groups P, Q or W, which have broad host ranges (for example, Sa, RP4, and RSF1010), and Transposons such as TnT. *Bacillus subtilis*, a gram positive bacteria, can be transformed with *S. aureus* plasmids (for example, pC194, pE194, pSA0501, pUB110, and pT127).

Within each specific vector various sites may be selected for insertion of the isolated DNA sequence. These sites are usually designated by the restriction enzyme or endonuclease that cuts them. For example, in pBR322 the Pst I site is located in the gene for penicilli-

nase between the nucleotide triplets that code for amino acids 181 and 182 of the penicillinase protein.

B. licheniformis PWD-1 DNA sequences may be inserted into the desired vector by known techniques. If, however, the vector is to serve as an expression vector, the vector should have a promoter, and the DNA sequence should be inserted in the vector downstream of the promoter and operationally associated therewith. The vector should be selected so as to have a promoter operable in the host cell into which the vector is to be inserted (that is, the promoter should be recognized by the RNA polymerase of the host cell). In addition, the vector should have a region which codes for a ribosome binding site positioned between the promoter and the site at which the DNA sequence is inserted so as to be operatively associated with the *B. licheniformis* PWD-1 DNA sequence once inserted (preferably, in correct translational reading frame therewith). The vector should be selected to provide a region which codes for a ribosomal binding site recognized by the ribosomes of the host cell into which the vector is to be inserted. For example, if the host cell is to be a prokaryotic cell such as *E. coli*, then the region which codes for a ribosomal binding site may code for a Shine-Dalgarno sequence.

Transformants may be screened for the production of keratinaceous material-degrading enzyme, or active fragment thereof, by any convenient procedure. Preferably, the transformants are grown on an agar medium containing powdered keratin substrate. Any powdered keratin may be used, but powdered feather is preferred, particularly powdered white feather, on which a clearing zone is easiest to observe. Colonies showing a clearing zone on the medium are producing the desired enzyme or enzyme fragment.

The present invention is explained further in the following examples. These examples are provided for illustrative purposes only, and are not to be taken as limiting.

EXAMPLE 1

Comparison of Amino Acid Production By Aerobic and Anaerobic Fermentations

Bacillus licheniformis PWD-1 was grown in two batches of a sterile aqueous medium containing feather as the sole source of carbon and energy. Each liter of medium contained 0.5 grams of NH₄Cl, 0.5 grams of NaCl, 0.3 grams of K₂HPO₄, 0.4 grams of KH₂PO₄, 0.24 grams of MgCl₂·6H₂O, 1.0 grams of hammer-milled feather (a coarsely chopped feather) and 0.1 grams of yeast extract. The media were adjusted to a pH of 7.5. Each culture was incubated at 50 degrees Centigrade, one being grown under aerobic conditions and the other being grown under anaerobic conditions. The quantity of amino acids found in the media at day zero (prior to inoculation) and after five days of incubation under both aerobic and anaerobic conditions, is shown in Table I below.

TABLE I

Free amino acid concentrations in the growth medium of feather degrading microorganisms under aerobic and anaerobic conditions.

Amino Acid (mg/l)	Day 0	Day 5	
		Aerobic	Anaerobic
ASP (N)	0.00	0.00	3.40
THR	0.78	0.90	9.00
SER	0.83	1.10	7.60
GLU (N)	0.00	1.70	11.80

TABLE 1-continued

Amino Acid (mg/l)	Day 0	Day 5	
		Aerobic	Anaerobic
GLY	1.61	0.50	6.60
ALA	1.35	1.10	14.50
CYS	0.11	3.00	10.20
VAL	0.36	2.10	17.10
MET	0.00	1.90	4.60
ILE	0.19	1.70	20.70
LEU	0.91	2.10	32.60
TYR	0.00	0.00	6.30
PHE	0.00	3.30	22.40
ORN	0.00	0.70	7.50
LYS	0.99	3.10	6.80
HIS	0.22	0.00	2.70
ARG	1.05	1.00	11.20
TOTAL	8.40	24.20	195.00

These data show that the total production of amino acids was approximately 800% greater under anaerobic conditions than under aerobic conditions.

EXAMPLE 2

Amino Acid Yields in Semi-Solid Fermentations

PWD-1 was grown in a liquid media like that described in Example 1 (except that 10.0 grams of hammer milled feather per liter was used instead of 1.0 gram/liter) for 5 days at 50 degrees Centigrade under aerobic conditions to reach 10^8 CFU per milliliter. An additional quantity of hammer milled feathers was autoclaved with steam at 125 degrees Centigrade (16 p.s.i.) for 15 minutes. The feathers were mixed with the growth medium at a proportion of 250 grams feather per liter of growth medium in a fermentation vessel to form a fermentation medium, and the fermentation medium was flushed with nitrogen. The fermentation medium was then incubated anaerobically for five days at 50 degrees Centigrade with periodic agitation. The same procedure was carried out on a separate occasion, except that the fermentation step was carried out aerobically. These procedures were duplicated for both conditions. The amino acid concentrations in the liquid phase of all the fermentation media were measured on day five of fermentation, these data being given in Table 2 below.

TABLE 2

Fermentation	Total free amino acid concentrations (g/l) in the liquid phase of the semi-solid phase fermentations	
	Anaerobic	Aerobic
1	14.7	1.7
2	12.4	1.9

Note that, under anaerobic conditions, free amino acids are produced in quantities in excess of 10 grams/liter by semi-solid phase fermentations.

EXAMPLE 3

Production of a Hydrolyzed Feather Meal Food Product

After five days of anaerobic fermentation, a semi-solid fermentation medium like that described in Example 2 above was autoclaved with steam at 125 degrees Centigrade for 15 minutes, then dried at 60 degrees Centigrade for 48 hours, and then milled through a one millimeter mesh. The resulting product was a brown powder comprised of partially hydrolyzed feather, short peptides, amino acids, and killed *Bacillus licheniformis* bacterial cells. This product is useful, among other things, as a dietary source of protein for growing chickens, as shown in Example 4 below.

EXAMPLE 4

Animal Feeds Incorporating *Bacillus licheniformis* Hydrolyzed Feather

One hundred and twenty-eight chicks were divided into four equal groups, 4x8 in each group. Each group was raised on a different diet: group (a) was raised on corn-soy feed/20% protein; group (b) was raised on corn-soy feed/15% protein; group (c) was raised on corn-soy feed/15% protein plus 5% unhydrolyzed hammer-milled feather; group (d) was raised on corn-soy feed/15% protein plus 5% protein from *Bacillus licheniformis* hydrolyzed feather produced in accordance with the procedure described in Example 3 above. All birds were weighed at three weeks of age and the weights for each group averaged. These averages are shown in Table 3 below.

TABLE 3

Diet	Ability of growing chickens to utilize feather-lysate as a dietary protein source.	
	Mean Body Weight (grams)	
	M	SEM
Standard corn-soy, 20% protein	554.7	± 8.5
Standard corn-soy, 15% protein	563.9	± 8.3
Corn-soy, 15% protein + 5% protein from untreated feathers	458.8	± 7.1
Corn-soy, 15% protein + 5% protein from feather-lysate	525.6	± 8.9

These data show that *Bacillus licheniformis* hydrolyzed feather can be used as an inexpensive source of dietary protein in animal feed.

The foregoing examples are provided to illustrate the present invention, and are not to be taken as restrictive thereof. The scope of the invention is defined by the following claims, with equivalents of the claims to be included therein.

That which is claimed is:

1. A biologically pure culture of a keratinaceous material degrading microorganism having the identifying characteristics of *Bacillus licheniformis* PWD-1, ATCC Accession No. 53757.

2. A crude, cell-free extract comprised of a mixture of *Bacillus licheniformis* PWD-1 proteins capable of degrading keratinaceous material.

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