BACTERIAL HOST STRAIN

The invention relates to a recombinant bacterial host strain, particularly *E. coli*. The invention also relates to a method for producing a protein of interest in such a cell.

Background of the invention

Bacterial cells, such as *E. coli*, are commonly used for producing recombinant proteins. There are many advantages to using bacterial cells, such as *E. coli*, for producing recombinant proteins particularly due to the versatile nature of bacterial cells as host cells allowing the gene insertion via plasmids. *E. coli* have been used to produce many recombinant proteins including human insulin.

Despite the many advantages to using bacterial cells to produce recombinant proteins, there are still significant limitations including the difficulty of producing protease sensitive proteins. Proteases play an important role in turning over old and miss-folded proteins in the *E. coli* periplasm and cytoplasm. Bacterial proteases act to degrade the recombinant protein of interest, thereby often significantly reducing the yield of active protein.

A number of bacterial proteases have been identified. In *E. coli* proteases including Protease III (ptr), DegP, OmpT, Tsp, prlC, ptrA, ptrB, pepA-T, tsh, espc, eatA, clpP and lon have been identified.

The Protease III (ptr) protein is a 110kDa periplasmic protease which degrades high molecular weight proteins.

Tsp (also known as Prc) is a 60kDa periplasmic protease. The first known substrate of Tsp was Penicillin-binding protein-3 (PBP3) (Determination of the cleavage site involved in C-terminal processing of penicillin-binding protein 3 of Escherichia coli; Nagasawa H, Sakagami Y, Suzuki A, Suzuki H, Hara H, Hirota Y. J Bacteriol. 1989 Nov;171(11):5890-3 and Cloning, mapping and characterization of the Escherichia coli Tsp gene which is involved in C-terminal processing of penicillin-binding protein 3; Hara H, Yamamoto Y, Higashitani A, Suzuki H, Nishimura Y. J Bacteriol. 1991

Aug;173 (15):4799-813) but it was later discovered that the Tsp was also able to cleave phage tail proteins and, therefore, it was renamed as Tail Specific Protease (Tsp) (Silber et al., Proc. Natl. Acad. Sci. USA, 89: 295-299 (1992)). Silber et al. (Deletion of the prc(tsp) gene provides evidence for additional tail-specific proteolytic activity in *Escherichia coli* K-12; Silber, K.R., Sauer, R.T.; Mol Gen Genet 1994 242:237-240) describes a prc deletion strain (KS1000) wherein the mutation was created by replacing a segment of the prc gene with a fragment comprising a Kan^r marker.

DegP (also known as HtrA) is a 46kDa protein having dual function as a chaperone and a protease (Families of serine peptidases; Rawlings ND, Barrett AJ. Methods Enzymol. 1994;244:19-61).

It is known to knockout bacterial proteases in order to affect the yield of recombinant protein.

Georgiou et al. (Construction and characterization of Escherichia coli strains deficient in multiple secreted proteases: protease III degrades high-molecular-weight substrates in vivo. Baneyx F, Georgiou G.J Bacteriol. 1991 Apr; 173(8):2696-703) studied the effects on growth properties and protein stability of *E. coli* strains deficient in protease III constructed by insertional inactivation of the ptr gene and observed an increase in the expression of a protease-sensitive secreted polypeptide. A strain comprising the ptr mutation and also deficient in the secreted protease DegP was also produced and found to have a decreased growth rate and an increase in protein expression. In Georgiou et al., the *E. coli* strains deficient in protease III and/or DegP were constructed from the KS272 parental strain which already comprises a number of genomic mutations.

US 5264365 (Georgiou et al.) discloses the construction of protease-deficient *Escherichia coli* hosts which when combined with an expression system are useful for the production of proteolytically sensitive polypeptides.

Meerman et al. (Construction and characterization of *Escherichia coli* strains deficient in All Known Loci Affecting the Proteolytic Stability of Secreted Recombinant Proteins. Meerman H. J., Georgeou G., Nature Biotechnology, 1994 Nov; 12;1107-1110) disclose *E. coli* strains comprising mutations in the rpoH, the RNA polymerase sigma factor responsible for heat shock protein synthesis, and different combinations of mutations in protease genes including DegP, Protease III, Tsp(Prc) and OmpT, where null mutations of the protease genes were caused by insertional mutations. In Meerman et al , the *E. coli* strains deficient in one or more of Tsp, protease III and DegP were constructed from the KS272 parental strain which already comprises a number of genomic mutations.

US 5508192 (Georgiou et al.) discloses a method of producing recombinant polypeptides in protease-deficient bacterial hosts and constructs of single, double, triple and quadruple protease deficient bacteria which also carry a mutation in the rpoH gene.

Chen et al describes the construction of *E. coli* strains carrying different combinations of mutations in prc (Tsp) and DegP created by amplifying the upstream and downstream regions of the gene and ligating these together on a vector comprising selection markers and a sprW148R mutation (High-level accumulation of a recombinant antibody fragment in the periplasm of Escherichia coli requires a triple-mutant (ΔDegP Δprc spr W148R) host strain. Chen C, Snedecor B, Nishihara JC, Joly JC, McFarland N, Andersen DC, Battersby JE, Champion KM. Biotechnol Bioeng. 2004 Mar 5;85(5):463-74). The combination of the ΔDegP, Δprc and W148Rspr mutations were found to provide the highest levels of antibody light chain, antibody heavy chain and F(ab')2-LZ. EP1341899 discloses an E. coli strain that is deficient in chromosomal DegP and prc encoding proteases DegP and Prc, respectively, and harbors a mutant spr gene that encodes a protein that suppresses growth phenotypes exhibited by strains harboring prc mutants.

Kandilogiannaki et al (Expression of a recombinant human anti-MUC1 scFv fragment in protease-deficient Escherichia coli mutants. Kandilogiannaki M, Koutsoudakis G,

Zafiropoulos A, Krambovitis E. Int J Mol Med. 2001 Jun;7(6):659-64) describes the utilization of a protease deficient strain for the expression of a scFv protein.

The protease deficient bacterial strains used previously to express recombinant proteins comprise further mutations of genes involved in cell metabolism and DNA replication such as, for example *phoA, fhuA, lac, rec, gal,ara, arg, thi* and *pro* in *E. coli* strains. These mutations may have many deleterious effects on the host cell including effects on cell growth, stability, recombinant protein expression yield and toxicity. Strains having one or more of these genomic mutations, particularly strains having a high number of these mutations, may exhibit a loss of fitness which reduces bacterial growth rate to a level which is not suitable for industrial protein production. Further, any of the above genomic mutations may affect other genes in *cis* and/or in *trans* in unpredictable harmful ways thereby altering the strain's phenotype, fitness and protein profile. Further, the use of heavily mutated cells is not generally suitable for producing recombinant proteins for commercial use, particularly therapeutics, because such strains generally have defective metabolic pathways and hence may grow poorly or not at all in minimal or chemically defined media.

Protease deficient bacterial strains also typically comprise knockout mutations to one or more protease encoding genes which have been created by insertion of a DNA sequence into the gene coding sequence. The inserted DNA sequence typically codes for a selection marker such as an antibiotic resistance gene. Whilst this mutation method may be effective at knocking out the target protease, there are many disadvantages associated with this method. One disadvantage is the insertion of the foreign DNA, such as an antibiotic resistance gene, causes disruption in the host's genome which may result in any number of unwanted effects including the over-expression of detrimental proteins and/or down-regulation or knockout of other essential proteins. This effect is particularly evident for those genes positioned immediately upstream or downstream of the target protease gene. A further disadvantage to the insertion of foreign DNA, particularly antibiotic resistance genes, is the unknown phenotypic modifications to the host cell which may affect expression of the target protein and/or growth of the host cell and may also make the host cell unsuitable for production of proteins intended for use as therapeutics. Antibiotic

resistance proteins are particularly disadvantageous for biosafety requirements large scale manufacturing particularly for the production of therapeutics for human administration. A further disadvantage to the insertion of antibiotic resistance markers is the metabolic burden on the cell created by the expression of the protein encoded by the antibiotic resistance gene. The use of antibiotic resistance markers for use as markers for genetic manipulations such as knockout mutations, are also limited by the number of different antibiotic resistance markers available.

Accordingly, there is still a need to provide new bacterial strains which provide advantageous means for producing recombinant proteins.

Summary of the Invention

It is an aim of the present invention to solve one or more of the problems described above.

In a first aspect the present invention provides a recombinant gram-negative bacterial cell comprising one or more of the following mutated protease genes:

a. a mutated Tsp gene, wherein the mutated Tsp gene encodes a Tsp protein having reduced protease activity or is a knockout mutated Tsp gene;

b. a mutated ptr gene, wherein the mutated ptr gene encodes a Protease III protein having reduced protease activity or is a knockout mutated ptr gene; and

c. a mutated DegP gene encoding a DegP protein having chaperone activity and reduced protease activity ;

wherein the cell is isogenic to a wild-type bacterial cell except for the mutated Tsp gene and/or mutated ptr gene and/or mutated Deg P gene and optionally a polynucleotide sequence encoding a protein of interest.

In one embodiment the present invention provides a cell comprising a mutated Tsp gene, wherein the mutated Tsp gene encodes a Tsp protein having reduced protease activity or is a knockout mutated Tsp gene and no further mutated protease genes. Accordingly, the present invention provides a cell which is isogenic to a wild-type bacterial cell except for the mutated Tsp gene and optionally a polynucleotide sequence encoding a protein of interest.

In one embodiment the present invention provides a cell comprising a mutated ptr gene, wherein the mutated ptr gene encodes a Protease III protein having reduced protease activity or is a knockout mutated ptr gene and no further mutated protease genes. Accordingly, the present invention provides a cell which is isogenic to a wild-type bacterial cell except for the mutated ptr gene and optionally a polynucleotide sequence encoding a protein of interest.

In one embodiment the present invention provides a cell comprising a mutated DegP gene encoding a DegP protein having chaperone activity and reduced protease activity and no further mutated protease genes. Accordingly, the present invention provides a cell which is isogenic to a wild-type bacterial cell except for the mutated DegP gene and optionally a polynucleotide sequence encoding a protein of interest.

In one embodiment the present invention provides a cell comprising a mutated DegP gene encoding a DegP protein having chaperone activity and reduced protease activity, a mutated Tsp gene, wherein the mutated Tsp gene encodes a Tsp protein having reduced protease activity or is a knockout mutated Tsp gene and no further mutated protease genes. Accordingly, the present invention provides a cell which is isogenic to a wild-type bacterial cell except for the mutated DegP gene and the mutated Tsp gene and optionally a polynucleotide sequence encoding a protein of interest.

In one embodiment the present invention provides a cell comprising a mutated ptr gene, wherein the mutated ptr gene encodes a Protease III protein having reduced protease activity or is a knockout mutated ptr gene, a mutated Tsp gene wherein the mutated Tsp gene encodes a Tsp protein having reduced protease activity or is a

knockout mutated Tsp gene and no further mutated protease genes. Accordingly, the present invention provides a cell which is isogenic to a wild-type bacterial cell except for the mutated ptr gene and the mutated Tsp gene and optionally a polynucleotide sequence encoding a protein of interest.

In one embodiment the present invention provides a cell comprising a mutated DegP gene encoding a DegP protein having chaperone activity and reduced protease activity, a mutated ptr gene, wherein the mutated ptr gene encodes a Protease III protein having reduced protease activity or is a knockout mutated ptr gene and no further mutated protease genes. Accordingly, the present invention provides a cell which is isogenic to a wild-type bacterial cell except for the mutated DegP gene and mutated ptr gene and optionally a polynucleotide sequence encoding a protein of interest.

In one embodiment the present invention provides a cell comprising a mutated DegP gene encoding a DegP protein having chaperone activity and reduced protease activity, a mutated ptr gene, wherein the mutated ptr gene encodes a Protease III protein having reduced protease activity or is a knockout mutated ptr gene, a mutated Tsp gene, wherein the mutated Tsp gene encodes a Tsp protein having reduced protease activity or is a knockout mutated Tsp gene and no further mutated protease genes. Accordingly, the present invention provides a cell which is isogenic to a wild-type bacterial cell except for the mutated DegP gene, the mutated ptr gene and the mutated Tsp gene and optionally a polynucleotide sequence encoding a protein of interest.

In a preferred embodiment the mutated ptr gene and/or the mutated Tsp gene referred to above are knockout mutations.

The present inventors have found that a bacterial host strain isogenic to a wild-type bacterial cell except for one or more of the above mutated protease provides an advantageous host for producing a recombinant protein of interest. The cells provided by the present invention have reduced protease activity compared to a non-mutated cell, which may reduce proteolysis of a recombinant protein of interest, particularly

proteins of interest which are proteolytically sensitive. In addition, the cell according to the present invention carries only minimal mutations to the genomic sequence in order to introduce one or more of the above protease mutations and does not carry any other mutations which may have deleterious effects on the cell's growth and/or ability to express a protein of interest.

One or more of the gram-negative cells provided by the present invention may provide a high yield of the recombinant protein of interest. One or more of the gram-negative cells provided by the present invention may provide a fast rate of production of a protein of interest. One or more of the cells may provide fast initial yield of the recombinant protein of interest. Further, one or more of the cells may show good growth characteristics.

In a second aspect, the present invention provides a recombinant gram-negative bacterial cell comprising:

a. a knockout mutated Tsp gene comprising a mutation to the gene start codon and/or one or more stop codons positioned downstream of the gene start codon and upstream of the gene stop codon; and/or
b. a knockout mutated ptr gene comprising a mutation to the gene start codon and/or one or more stop codons positioned downstream of the gene start codon and upstream of the gene stop codon; and
c. optionally a mutated DegP gene encoding a DegP protein having chaperone activity and reduced protease activity.

In one embodiment the present invention provides a cell comprising a knockout mutated Tsp gene comprising a mutation to the gene start codon and/or one or more stop codons positioned downstream of the gene start codon and upstream of the gene stop codon.

In one embodiment the present invention provides a cell comprising a knockout mutated ptr gene comprising a mutation to the gene start codon and/or one or more stop codons positioned downstream of the gene start codon and upstream of the gene stop codon.

In one embodiment the present invention provides a cell comprising a mutated DegP gene encoding a DegP protein having chaperone activity and reduced protease activity and a knockout mutated Tsp gene comprising a mutation to the gene start codon and/or one or more stop codons positioned downstream of the gene start codon and upstream of the gene stop codon.

In one embodiment the present invention provides a cell comprising a knockout mutated ptr gene comprising a mutation to the gene start codon and/or one or more stop codons positioned downstream of the gene start codon and upstream of the gene stop codon and a knockout mutated Tsp gene comprising a mutation to the gene start codon and/or one or more stop codons positioned downstream of the gene start codon and upstream of the gene stop codon.

In one embodiment the present invention provides a cell comprising a mutated DegP gene encoding a DegP protein having chaperone activity and reduced protease activity and a knockout mutated ptr gene comprising a mutation to the gene start codon and/or one or more stop codons positioned downstream of the gene start codon and upstream of the gene stop codon.

In one embodiment the present invention provides a cell comprising a mutated DegP gene encoding a DegP protein having chaperone activity and reduced protease activity, a knockout mutated ptr gene comprising a mutation to the gene start codon and/or one or more stop codons positioned downstream of the gene start codon and upstream of the gene stop codon and a knockout mutated Tsp gene comprising a mutation to the gene start codon and/or one or more stop codons positioned downstream of the gene start codon and upstream of the gene stop codon.

The cell provided by the second aspect of the present invention overcomes the above described disadvantages of knockout mutation methods employing DNA insertion typically used in the art to provide protease deficient strains. In the present invention the knockout mutations to the ptr gene and/or the Tsp gene are provided by a mutation to the gene start codon and/or one or more stop codons positioned downstream of the

gene start codon and upstream of the gene stop codon. A mutation, such as a missense point mutation, to the target knockout gene start codon ensures that the target gene does not comprise a suitable start codon at the start of the coding sequence. The insertion of one or more stop codons positioned between the gene start codon and stop codon ensures that even if transcription of the gene is initiated, the full coding sequence will not be transcribed. The host genome required minimal disruption to mutate the start codon and/or insert one or more stop codons, thereby minimizing the deleterious effects of genome disruption on the expression of the target protein and/or growth of the host cell. The cell of the present invention may also be more suitable for production of proteins intended for use as therapeutics due to the minimal disruption to the cell genome.

In a third aspect, the present invention provides a method for producing a recombinant protein of interest comprising expressing the recombinant protein of interest in a recombinant gram-negative bacterial cell as defined above in the first aspect or second aspect of the present invention.

Brief Description of the Drawings

Figure 1a shows the 5' end of the wild type ptr (protease III) and knockout mutated ptr (protease III) protein and gene sequences.

Figure 1b shows the 5' end of the wild type Tsp and knockout mutated Tsp protein and gene sequences.

Figure 1c shows a region of the wild type DegP and mutated DegP protein and gene sequences.

Figure 2 shows the growth of *E. coli* strain MXE001 carrying a knockout mutated Tsp gene and *E. coli* strain MXE005 carrying a knockout mutated Tsp gene and mutated DegP gene compared to *E. coli* wild type W3110.

Figure 3 shows the expression of a Fab' in MXE005 and MXE001 compared to wild type W3110.

Figure 4 shows the growth of *E. coli* strain MXE004 carrying a knockout mutated Tsp gene and a knockout mutated protease III compared to wild type W3110.

Figure 5 shows the expression of a Fab' in MXE004 and W3110.

Figure 6 shows the expression of a Fab in MXE001, MXE004, MXE005 and W3110.

Figure 7 shows the light chain (L chain), heavy chain (H chain) and Fab' expression during a fermentation experiment for MXE001, MXE005 and wild type W3110.

Figure 8 shows the results of a western blot analysis for wild type W3110, MXE001 and MXE005 showing relative fragmentation of a Fab'.

Figure 9 shows the growth profile of MXE001 compared to control W3110.

Figure 10 shows Fab' yield from the supernatant (dotted lines) and periplasm (solid lines) from *E. coli* strain MXE001 compared to control *E. coli* W3110.

Figure 11 shows the total Fab' yield from the supernatant and periplasm of the *E. coli* strain MXE001 compared to control W3110.

Figure 12 shows the Fab' specific production rate of *E. coli* strain MXE001 compared to the control W3110.

Figure 13 shows the growth profile of MXE004 and MXE005 compared to control W3110.

Figure 14 shows Fab' yields from the supernatant (dotted lines) and periplasm (solid lines) of *E. coli* strains MXE004, MXE005 and the W3110 control.

Figure 15 shows the total Fab' yield from the supernatant and periplasm of the *E. coli* strains MXE004 and MXE005.

Figure 16 shows the Fab' specific production rate of *E. coli* strains MXE004 and MXE005 and the W3110 control.

Figure 17 shows the growth profile of *E. coli* strains W3110, MXE001, MXE004 and MXE005 compared to *E. coli* strains XL1 Blue, TOP10, Stbl 3 and Sure.

Brief Description of the Sequences

SEQ ID NO:1 is the DNA sequence of the non-mutated Tsp gene including the 6 nucleotides ATGAAC upstream of the start codon.

SEQ ID NO:2 is the amino acid sequence of the non-mutated Tsp protein.

SEQ ID NO:3 is the DNA sequence of a mutated knockout Tsp gene including the 6 nucleotides ATGAAT upstream of the start codon.

SEQ ID NO:4 is the DNA sequence of the non-mutated Protease III gene.

SEQ ID NO:5 is the amino acid sequence of the non-mutated Protease III protein.

SEQ ID NO:6 is the DNA sequence of a mutated knockout Protease III gene.

SEQ ID NO:7 is the DNA sequence of the non-mutated DegP gene.

SEQ ID NO:8 is the amino acid sequence of the non-mutated DegP protein.

SEQ ID NO:9 is the DNA sequence of a mutated DegP gene.

SEQ ID NO:10 is the amino acid sequence of a mutated DegP protein.

SEQ ID NO: 11 is the amino acid sequence of the light chain variable region of an anti-TNF antibody.

SEQ ID NO:12 is the amino acid sequence of the heavy chain variable region of an anti-TNF antibody.

SEQ ID NO:13 is the amino acid sequence of the light chain of an anti-TNF antibody.

SEQ ID NO:14 is the amino acid sequence of the heavy chain of an anti-TNF antibody.

SEQ ID NO: 15 is the sequence of the 3' oligonucleotide primer for the region of the mutated Tsp gene comprising the Ase I restriction site.

SEQ ID NO: 16 is the sequence of the 5' oligonucleotide primer for the region of the mutated Tsp gene comprising the Ase I restriction site.

SEQ ID NO: 17 is the sequence of the 3' oligonucleotide primer for the region of the mutated Protease III gene comprising the Ase I restriction site.

SEQ ID NO: 18 is the sequence of the 5' oligonucleotide primer for the region of the mutated Protease III gene comprising the Ase I restriction site.

SEQ ID NO: 19 is the sequence of the 5' oligonucleotide primer for the region of the mutated DegP gene comprising the Ase I restriction site.

SEQ ID NO: 20 is the sequence of the 3' oligonucleotide primer for the region of the mutated DegP gene comprising the Ase I restriction site.

Detailed Description of the Preferred Embodiments of the Invention

In the first aspect and second aspect of the present invention the present inventors have provided a recombinant gram-negative bacterial cell suitable for expressing a protein of interest which comprises only the minimal mutations to the genome required to introduce one or more protease mutations. In the first aspect of the invention, the bacterial cell only differs from a wild-type bacterial cell by the one or more mutated protease genes selected from a mutated DegP gene encoding a DegP protein having chaperone activity and reduced protease activity; a mutated ptr; and a mutated Tsp gene and optionally a polynucleotide sequence encoding a protein of interest. In the second aspect of the present invention the bacterial cell comprises

knockout mutations of Tsp and/or Protease III, wherein the Tsp and/or Protease III gene comprises a mutation to the gene start codon and/or one or more stop codons positioned downstream of the gene start codon and upstream of the gene stop codon.

The cells provided by the first and second aspects of the present invention have reduced protease activity compared to non-mutated cell, which may reduce proteolysis of a recombinant protein of interest, particularly proteins of interest which are proteolytically sensitive. Therefore, one or more of the gram-negative cells provided by the first and second aspects of the present invention may provide higher yield of the intact recombinant protein of interest and a lower yield, or preferably no yield, of proteolytic fragments of the protein of interest compared to a non-mutated bacterial cell.

The skilled person would easily be able to test a candidate cell clone to see if it has the desired yield of a protein of interest using methods well known in the art including a fermentation method, ELISA and protein G hplc. Suitable fermentation methods are described in Humphreys D P, *et al.* (1997). Formation of dimeric Fabs in *E. coli*: effect of hinge size and isotype, presence of interchain disulphide bond, Fab' expression levels, tail piece sequences and growth conditions. *J. IMMUNOL. METH.* 209: 193-202; Backlund E. Reeks D. Markland K. Weir N. Bowering L. Larsson G. Fedbatch design for periplasmic product retention in Escherichia coli, Journal Article. Research Support, Non-U.S. Gov't Journal of Biotechnology. 135(4):358-65, 2008 Jul 31; Champion KM. Nishihara JC. Joly JC. Arnott D. Similarity of the Escherichia coli proteome upon completion of different biopharmaceutical fermentation processes. [Journal Article] Proteomics. 1(9):1133-48, 2001 Sep; and Horn U. Strittmatter W. Krebber A. Knupfer U. Kujau M. Wenderoth R. Muller K. Matzku S. Pluckthun A. Riesenberg D. High volumetric yields of functional dimeric miniantibodies in Escherichia coli, using an optimized expression vector and high-cell-density fermentation under non-limited growth conditions, Journal Article. Research Support, Non-U.S. Gov't Applied Microbiology & Biotechnology. 46(5-6):524-32, 1996 Dec. The skilled person would also easily be able to test secreted protein to see if the protein is correctly folded using methods well known in the art, such as protein G

HPLC, circular dichroism, NMR, X-Ray crystallography and epitope affinity measurement methods.

One or more of the recombinant bacterial cells of the first and second aspects of the present invention may exhibit significantly improved protein yield compared to a non-mutated bacterial cell. The improved protein yield may be the periplasmic protein yield and/or the supernatant protein yield. One or more of the recombinant bacterial cells of the first and second aspects of the present invention may be capable of faster rate of production of a protein of interest and, therefore, the same quantity of a protein of interest may be produced in a shorter time compared to a non-mutated bacterial cell. The faster rate of production of a protein of interest may be especially significant over the initial period of growth of the cell, for example over the first 5, 10, 20 or 30 hours post induction of protein expression

The cells according to the present invention comprising the Tsp mutation, which is preferably the knockout mutation, either alone or in combination with the DegP mutation or the Protease III mutation, are particularly preferred. These cells exhibit a higher yield and a faster initial yield of a protein of interest compared to a non-mutated cell. Example of such cell lines comprising the mutated Tsp gene either alone or in combination with mutated DegP gene or the mutated ptr gene are mutant *E. coli* cell strains MXE001 having genotype ΔTsp and deposited on 21st May 2009 at the National Collection of Type Cultures, HPA, United Kingdom, under Accession number NCTC13444, MXE004 having genotype ΔTsp Δptr, and deposited on 21st May 2009 at the National Collection of Type Cultures, HPA, United Kingdom, under Accession number NCTC13447, and MXE005 having genotype ΔTsp, DegP S210A and deposited on 21st May 2009 at the National Collection of Type Cultures, HPA, United Kingdom, under Accession number NCTC13448.

Further, one or more of the cells may show good growth characteristics including cell growth and/or reproduction which may be substantially the same as a non-mutated bacterial cell or improved compared to a non-mutated bacterial cell.

The genome of the cell according to the first aspect of the present invention has had minimal disruption to the genome compared to a wild-type cell thereby reducing deleterious effects of other mutations typically found in host cells on the expression of other cellular proteins. Accordingly, one or more of the recombinant host cells according to the first aspect of the present invention may exhibit improved protein expression and/or improved growth characteristics compared to cells comprising further genetically engineered mutations to the genomic sequence.

The genome of the cell according to the second aspect of the present invention has had minimal disruption to the genome to introduce the knockout mutations thereby reducing deleterious effects of creating protease gene knockouts by inserting DNA, such as antibiotic resistance markers. Accordingly, one or more of the recombinant host cells according to the second aspect of the present invention may exhibit improved protein expression and/or improved growth characteristics compared to cells comprising protease knockout mutations created by the insertion of DNA, such as antibiotic resistance markers.

The cells provided by the first and second aspects of the present invention are also more suitable for use to produce therapeutic proteins compared to cells comprising further disruptions to the cell genome.

The present invention will now be described in more detail. All embodiments herein described refer to the first, second and third aspects of the present invention unless specifically stated otherwise.

The terms "protein" and "polypeptide" are used interchangeably herein, unless the context indicates otherwise. "Peptide" is intended to refer to 10 or less amino acids.

The terms "polynucleotide" includes a gene, DNA, cDNA, RNA, mRNA etc unless the context indicates otherwise.

As used herein, the term "comprising" in context of the present specification should be interpreted as "including".

The non-mutated cell or control cell in the context of the present invention means a cell of the same type as the recombinant gram-negative cell of the invention wherein the cell has not been modified to carry the above protease mutations. For example, a non-mutated cell may be a wild-type cell and may be derived from the same population of host cells as the cells of the invention before modification to introduce the one or more mutations.

The expressions "cell", "cell line", "cell culture" and "strain" are used interchangeably.

The term "isogenic" in the context of the present invention means that the genome of the cell of the present invention has substantially the same or the same genomic sequence compared to wild-type cell except for one or more of the above mutated protease genes and optionally a polynucleotide encoding a protein of interest. In this embodiment the cell according to the present invention comprises no further non-naturally occurring or genetically engineered mutations compared to the wild-type cell. In one embodiment the cell according to the present invention may have substantially the same genomic sequence compared to the wild-type cell except for the above protease mutations and optionally a polynucleotide encoding a protein of interest taking into account any naturally occurring mutations which may occur. It should also be noted that during the introduction of the protease mutations into the strain, for example by a gene replacement vector, and during the introduction of the polynucleotide encoding the protein of interest into the strain one or more further genomic mutations may be introduced into the strain. Accordingly, in one embodiment the cell according to the present invention may have substantially the same genomic sequence compared to the wild-type cell except for the above protease mutations and optionally a polynucleotide encoding a protein of interest taking into account any naturally occurring mutations which may occur and any further genomic mutations which may result from the introduction of the protease mutations and/or the polynucleotide encoding the protein of interest.

Examples of gene mutations involved in cell metabolism and DNA replication, which are commonly used in *E. coli* strains in the art but are not used in the cell according to the present invention include *phoA, fhuA, lac, rec, gal, ara, arg, thi* and *pro*.

In one embodiment, the cell according to the present invention may have exactly the same genomic sequence compared to the wild-type cell except for the above protease mutations and optionally a polynucleotide encoding a protein of interest.

The term "wild-type" in the context of the present invention means a strain of a gram-negative bacterial cell as it may occur in nature or may be isolated from the environment, which does not carry any genetically engineered mutations. An example of a wild-type strain of *E. coli* is W3110, such as W3110 K-12 strain. Examples of wild-type strains include strains of the K-12 strain family which includes W3110 (F^- λ^- rph-1 INV(rrnD, rrnE) ilvG) (ATCC27325), MG1655 (F^- λ^- ilvG- rfb-50 rph-1) (ATCC700926), W1485 (F+ λ^- rph-1 rpoS396) (ATCC12435), W3101 (F^- λ^- ilvG- IN(rrnD-rrnE)1 rph-1 galT22) and BW30270 (F^- λ^- fnr+). Further examples of wild-type *E. coli* strains include the W strain (ATCC9637) and the B strain (ATCC23226).

Any suitable gram-negative bacterium may be used as the parental cell for producing the recombinant cell of the present invention. Suitable gram-negative bacterium include *Salmonella typhimurium, Pseudomonas fluorescens, Erwinia carotovora, Shigella, Klebsiella pneumoniae, Legionella pneumophila, Pseudomonas aeruginosa, Acinetobacter baumannii and E. coli*. Preferably the parental cell is *E. coli*. Any suitable strain of *E. coli* may be used in the present invention as the parental cell. Examples of suitable *E. coli* strains include the K-12 strain family which comprises W3110 (F^- λ^- rph-1 INV(rrnD, rrnE) ilvG) (ATCC27325), MG1655 (F^- λ^- ilvG- rfb-50 rph-1) (ATCC700926), W1485 (F+ λ^- rph-1 rpoS396) (ATCC12435), W3101 (F^- λ^- ilvG- IN(rrnD-rrnE)1 rph-1 galT22) and BW30270 (F^- λ^- fnr+). Further suitable *E. coli* strains include the W strain (ATCC9637) and the B strain (ATCC23226). Preferably a wild-type W3110 strain, such as K-12 W3110, is used.

The cell according to the first aspect of the present is isogenic to a wild-type bacterial cell except for the one or more mutated protease genes and optionally a polynucleotide sequence encoding a protein of interest. The cell according to the second aspect of the present invention is preferably also isogenic to a wild-type bacterial cell except for the one or more mutated protease genes and optionally a polynucleotide sequence encoding a protein of interest.

In a preferred embodiment, the cell is isogenic to a wild-type *E. coli* cell except for the above protease mutations and optionally a polynucleotide encoding a protein of interest. More preferably the cell according to the present invention is isogenic to an *E. coli* strain W3110 except for the above protease mutations and optionally a polynucleotide encoding a protein of interest. Examples of other suitable wild-type *E. coli* cells which the cell according to the present invention may be isogenic to except for the above protease mutations and optionally the polynucleotide encoding a protein of interest are strains of the K-12 strain family which includes W3110 (F^- λ^- rph-1 INV(rrnD, rrnE) ilvG) (ATCC27325), MG1655 (F^- λ^- ilvG- rfb-50 rph-1) (ATCC700926), W1485 (F+ λ^- rph-1 rpoS396) (ATCC12435), W3101 (F^- λ^- ilvG-IN(rrnD-rrnE)1 rph-1 galT22) and BW30270 (F^- λ^- fnr+). Further suitable wild-type *E. coli* strains which the cell according to the present invention may be isogenic to except for the above protease mutations and optionally the polynucleotide encoding a protein of interest are include the W strain (ATCC9637) and the B strain (ATCC23226).

The cell of the present invention may further differ from a wild-type cell by comprising a polynucleotide encoding the protein of interest. In this embodiment, the polynucleotide encoding the protein of interest may be contained within a suitable expression vector transformed into the cell and/or integrated into the host cell's genome. In the embodiment where the polynucleotide encoding the protein of interest is inserted into the host's genome, the cell of the present invention will also differ from a wild-type cell due to the inserted polynucleotide sequence encoding the protein of interest. Preferably the polynucleotide is in an expression vector in the cell thereby causing minimal disruption to the host cell's genome.

In certain embodiments of the present invention the recombinant gram-negative bacterial cell comprises a mutated DegP gene encoding a DegP protein having chaperone activity and reduced protease activity. As used herein, "DegP" means a gene encoding DegP protein (also known as HtrA), which has dual function as a chaperone and a protease (Families of serine peptidases; Rawlings ND, Barrett AJ. Methods Enzymol. 1994;244:19-61). The sequence of the non-mutated DegP gene is shown in SEQ ID NO: 7 and the sequence of the non-mutated DegP protein is shown in SEQ ID NO: 8.

At low temperatures DegP functions as a chaperone and at high temperatures DegP has a preference to function as a protease (A Temperature-Dependent Switch from Chaperone to Protease in a Widely Conserved Heat Shock Protein. Cell, Volume 97 , Issue 3 , Pages 339 – 347. Spiess C, Beil A, Ehrmann M) and The proteolytic activity of the HtrA (DegP) protein from *Escherichia coli* at low temperatures, Skorko-Glonek J *et al* Microbiology 2008, 154, 3649-3658).

In the embodiments where the cell comprises the DegP mutation the DegP mutation in the cell provides a mutated DegP gene encoding a DegP protein having chaperone activity but not full protease activity.

The expression "having chaperone activity" in the context of the present invention means that the mutated DegP protein has the same or substantially the same chaperone activity compared to the wild-type non-mutated DegP protein. Preferably, the mutated DegP gene encodes a DegP protein having 50% or more, 60% or more, 70% or more, 80% or more, 90% or more or 95% or more of the chaperone activity of a wild-type non-mutated DegP protein. More preferably, the mutated DegP gene encodes a DegP protein having the same chaperone activity compared to wild-type DegP.

The expression "having reduced protease activity" in the context of the present invention means that the mutated DegP protein does not have the full protease activity compared to the wild-type non-mutated DegP protein. Preferably, the mutated DegP gene encodes a DegP protein having 50% or less, 40% or less, 30% or less, 20% or

less, 10% or less or 5% or less of the protease activity of a wild-type non-mutated DegP protein. More preferably, the mutated DegP gene encodes a DegP protein having no protease activity. The cell is not deficient in chromosomal DegP i.e. the DegP gene sequences has not been deleted or mutated to prevent expression of any form of DegP protein.

Any suitable mutation may be introduced into the DegP gene in order to produce a protein having chaperone activity and reduced protease activity. The protease and chaperone activity of a DegP protein expressed from a gram-negative bacterium may be easily tested by a person skilled in the art by any suitable method such as the method described in Spiess et al wherein the protease and chaperone activities of DegP were tested on MalS, a natural substrate of DegP (A Temperature-Dependent Switch from Chaperone to Protease in a Widely Conserved Heat Shock Protein. Cell, Volume 97 , Issue 3 , Pages 339 – 347. Spiess C, Beil A, Ehrmann M) and also the method described in The proteolytic activity of the HtrA (DegP) protein from *Escherichia coli* at low temperatures, Skorko-Glonek J *et al* Microbiology 2008, 154, 3649-3658.

DegP is a serine protease and has an active center consisting of a catalytic triad of amino acid residues of His105, Asp135 and Ser210 (Families of serine peptidases, Methods Enzymol., 1994, 244:19-61 Rawlings N and Barrett A). The DegP mutation to produce a protein having chaperone activity and reduced protease activity may comprise a mutation, such as a missense mutation to one, two or three of His105, Asp135 and Ser210. Accordingly, the mutated DegP gene may comprise:

- a mutation to His105; or
- a mutation to Asp135; or
- a mutation to Ser210; or
- a mutation to His105 and Asp135; or
- a mutation to His105 and Ser210; or
- a mutation to Asp135 and Ser210; or
- a mutation to His105, Asp135 and Ser210.

One, two or three of His105, Asp135 and Ser210 may be mutated to any suitable amino acid which results in a protein having chaperone activity and reduced protease activity. For example, one, two or three of His105, Asp135 and Ser210 may be mutated to a small amino acid such as Gly or Ala. A further suitable mutation is to change one, two or three of His105, Asp135 and Ser210 to an amino acid having opposite properties such as Asp135 being mutated to Lys or Arg, polar His105 being mutated to a non-polar amino acid such as Gly, Ala, Val or Leu and small hydrophilic Ser210 being mutated to a large or hydrophobic residue such as Val, Leu, Phe or Tyr. Preferably, the DegP gene comprises the point mutation S210A, as shown in Figure 1c, which has been found to produce a protein having chaperone activity but not protease activity (A Temperature-Dependent Switch from Chaperone to Protease in a Widely Conserved Heat Shock Protein. Cell, Volume 97 , Issue 3 , Pages 339 – 347. Spiess C, Beil A, Ehrmann M).

The present invention also provides a recombinant gram-negative bacterial cell comprising a mutated DegP gene encoding a DegP protein having chaperone activity and reduced protease activity, wherein the DegP gene comprises a mutation to His105; or a mutation to Asp135; or a mutation to His105 and Asp135; or a mutation to His105 and Ser210; or a mutation to Asp135 and Ser210; or a mutation to His105, Asp135 and Ser210, as discussed above.

DegP has two PDZ domains, PDZ1 (residues 260-358) and PDZ2 (residues 359-448), which mediate protein-protein interaction (A Temperature-Dependent Switch from Chaperone to Protease in a Widely Conserved Heat Shock Protein. Cell, Volume 97 , Issue 3 , Pages 339 – 347. Spiess C, Beil A, Ehrmann M). In one embodiment of the present invention the degP gene is mutated to delete PDZ1 domain and/or PDZ2 domain. The deletion of PDZ1 and PDZ2 results in complete loss of protease activity of the DegP protein and lowered chaperone activity compared to wild-type DegP protein whilst deletion of either PDZ1 or PDZ2 results in 5% protease activity and similar chaperone activity compared to wild-type DegP protein (A Temperature-Dependent Switch from Chaperone to Protease in a Widely Conserved Heat Shock Protein. Cell, Volume 97 , Issue 3 , Pages 339 – 347. Spiess C, Beil A, Ehrmann M).

The present invention also provides a recombinant gram-negative bacterial cell comprising a mutated DegP gene encoding a DegP protein having chaperone activity and reduced protease activity, wherein the degP gene is mutated to delete PDZ1 domain and/or PDZ2 domain, as discussed above.

The mutated DegP gene may also comprise a silent non-naturally occurring restriction site, such as Ase I in order to aid in identification and screening methods, for example as shown in Figure 1c.

The preferred sequence of the mutated DegP gene comprising the point mutation S210A and an Ase I restriction marker site is provided in SEQ ID NO: 9 and the encoded protein sequence is shown in SEQ ID NO: 10. The mutations which have been made in the mutated DegP sequence of SEQ ID NO: 9 are shown in Figure 1c.

In the embodiments of the present invention wherein the cell comprises a mutated DegP gene encoding a DegP protein having chaperone activity and reduced protease activity, one or more of the cells provided by the present invention may provide improved yield of correctly folded proteins from the cell relative to mutated cells wherein the DegP gene has been mutated to knockout DegP preventing DegP expression, such as chromosomal deficient DegP. In a cell comprising a knockout mutated DegP gene preventing DegP expression, the chaperone activity of DegP is lost completely whereas in the cell according to the present invention the chaperone activity of DegP is retained whilst the full protease activity is lost. In these embodiments, one or more cells according to the present invention have a lower protease activity to prevent proteolysis of the protein whilst maintaining the chaperone activity to allow correct folding and transportation of the protein in the host cell.

The skilled person would easily be able to test secreted protein to see if the protein is correctly folded using methods well known in the art, such as protein G HPLC, circular dichroism, NMR, X-Ray crystallography and epitope affinity measurement methods.

In these embodiments, one or more cells according to the present invention may have improved cell growth compared to cells carrying a mutated knockout DegP gene preventing DegP expression. Without wishing to be bound by theory improved cell growth maybe exhibited due to the DegP protease retaining chaperone activity which may increase capacity of the cell to process all proteins which require chaperone activity. Accordingly, the production of correctly folded proteins necessary for the cell's growth and reproduction may be increased in one or more of the cells of the present invention compared to cells carrying a DegP knockout mutation thereby improving the cellular pathways regulating growth. Further, known DegP protease deficient strains are generally temperature-sensitive and do not typically grow at temperatures higher than about 28°C. However, the cells according to the present invention are not temperature-sensitive and may be grown at temperatures of 28°C or higher, including temperatures of approximately 30°C to approximately 37°C, which are typically used for industrial scale production of proteins from bacteria.

In certain embodiments of the present invention the recombinant gram-negative bacterial cell comprises a knockout mutated ptr gene. As used herein, "ptr gene" means a gene encoding Protease III, a protease which degrades high molecular weight proteins. The sequence of the non-mutated ptr gene is shown in SEQ ID NO: 4 and the sequence of the non-mutated Protease III protein is shown in SEQ ID NO: 5.

In certain embodiments of the present invention the recombinant gram-negative bacterial cell comprises a knockout mutated Tsp gene. As used herein, "Tsp gene" means a gene encoding protease Tsp (also known as Prc) which is a periplasmic protease capable of acting on Penicillin-binding protein-3 (PBP3) and phage tail proteins. The sequence of the non-mutated Tsp gene is show in SEQ ID NO: 1 and the sequence of the non-mutated Tsp protein is shown in SEQ ID NO: 2.

In the first aspect of the present invention, reference to the mutated ptr gene or mutated ptr gene encoding Protease III, refers to either a mutated ptr gene encoding a Protease III protein having reduced protease activity or a knockout mutated ptr gene, unless otherwise indicated.

In the first aspect of the present invention, reference to the mutated Tsp gene or mutated Tsp gene encoding Tsp, refers to either a mutated Tsp gene encoding a Tsp protein having reduced protease activity or a knockout mutated Tsp gene, unless otherwise indicated.

In the first aspect of the present invention the expressions "mutated ptr gene encoding a Protease III protein having reduced protease activity" and "mutated Tsp gene encoding a Tsp protein having reduced protease activity" in the context of the present invention means that the mutated ptr gene or the mutated Tsp gene does not have the full protease activity compared to the wild-type non-mutated ptr gene or Tsp gene.

In the first aspect of the present invention, preferably, the mutated ptr gene encodes a Protease III having 50% or less, 40% or less, 30% or less, 20% or less, 10% or less or 5% or less of the protease activity of a wild-type non-mutated Protease III protein. More preferably, the mutated ptr gene encodes a Protease III protein having no protease activity. In this embodiment the cell is not deficient in chromosomal ptr i.e. the ptr gene sequence has not been deleted or mutated to prevent expression of any form of Protease III protein.

Any suitable mutation may be introduced into the ptr gene in order to produce a Protease III protein having reduced protease activity. The protease activity of a Protease III protein expressed from a gram-negative bacterium may be easily tested by a person skilled in the art by any suitable method in the art.

In the first aspect of the present invention, preferably, the mutated Tsp gene encodes a Tsp protein having 50% or less, 40% or less, 30% or less, 20% or less, 10% or less or 5% or less of the protease activity of a wild-type non-mutated Tsp protein. More preferably, the mutated Tsp gene encodes a Tsp protein having no protease activity. In this embodiment the cell is not deficient in chromosomal Tsp i.e. the Tsp gene sequence has not been deleted or mutated to prevent expression of any form of Tsp protein.

Any suitable mutation may be introduced into the Tsp gene in order to produce a protein having reduced protease activity. The protease activity of a Tsp protein expressed from a gram-negative bacterium may be easily tested by a person skilled in the art by any suitable method in the art, such as the method described in Keiler et al (Identification of Active Site Residues of the Tsp Protease* THE JOURNAL OF BIOLOGICAL CHEMISTRY Vol. 270, No. 48, Issue of December 1, pp. 28864–28868, 1995 Kenneth C. Keiler and Robert T. Sauer) wherein the protease activities of Tsp was tested.

Tsp has been repored in Keiler et al (*supra*) as having an active site comprising residues S430, D441 and K455 and residues G375, G376, E433 and T452 are important for maintaining the structure of Tsp. Keiler et al (*supra*) reports findings that the mutated Tsp genes S430A, D441A, K455A, K455H, K455R, G375A, G376A, E433A and T452A had no detectable protease activity. It is further reported that the mutated Tsp gene S430C displayed about 5-10% wild-type activity. Accordingly, the Tsp mutation to produce a protein having reduced protease activity may comprise a mutation, such as a missense mutation to one or more of residues S430, D441, K455, G375, G376, E433 and T452. Preferably the Tsp mutation to produce a protein having reduced protease activity may comprise a mutation, such as a missense mutation to one, two or all three of the active site residues S430, D441 and K455.

According the mutated Tsp gene may comprise:

- a mutation to S430; or
- a mutation to D441; or
- a mutation to K455; or
- a mutation to S430 and D441; or
- a mutation to S430 and K455; or
- a mutation to D441 and K455; or
- a mutation to S430, D441 and K455.

One or more of S430, D441, K455, G375, G376, E433 and T452 may be mutated to any suitable amino acid which results in a protein having reduced protease activity. Examples of suitable mutations are S430A, S430C, D441A, K455A, K455H, K455R,

G375A, G376A, E433A and T452A. The mutated Tsp gene may comprise one, two or three mutations to the active site residues, for example the gene may comprise:

- S430A or S430C; and/or
- D441A; and/or
- K455A or K455H or K455R.

Preferably, the Tsp gene comprises the point mutation S430A or S430C.

The present invention also provides a recombinant gram-negative bacterial cell comprising a mutated Tsp gene, wherein the mutated Tsp gene encodes a Tsp protein having reduced protease activity, wherein the Tsp gene comprise a mutation, such as a missense mutation to one or more of residues S430, D441, K455, G375, G376, E433 and T452, as discussed above.

In the first aspect of the present invention the expression "knockout mutated ptr gene" and "knockout mutated Tsp gene" in the context of the present invention means that the gene comprises one or more mutations thereby causing no expression of the protein encoded by the gene to provide a cell deficient in the protein encoded by the knockout mutated gene. The knockout gene may be partially or completely transcribed but not translated into the encoded protein.

In the first aspect of the present invention, the knockout mutated ptr gene and/or knockout mutated Tsp gene may be mutated in any suitable way, for example by one or more deletion, insertion, point, missense, nonsense and frameshift mutations, to cause no expression of the protein. For example, the gene may be knocked out by insertion of a foreign DNA sequence, such as an antibiotic resistance marker, into the gene coding sequence.

In a preferred embodiment of the first aspect of the present invention the gene is not mutated by insertion of a foreign DNA sequence, such as an antibiotic resistance marker, into the gene coding sequence. Preferably the Tsp gene and/or Protease III gene comprise a mutation to the gene start codon and/or one or more stop codons

positioned downstream of the gene start codon and upstream of the gene stop codon thereby preventing expression of the Tsp protein and/or Protease III protein.

The cell according to the second aspect of the present invention comprises Tsp and/or Protease III knockout mutations where the Tsp gene and/or Protease III gene comprise a mutation to the gene start codon and/or one or more stop codons positioned downstream of the gene start codon and upstream of the gene stop codon thereby preventing expression of the Tsp protein and/or Protease III protein.

A mutation to the target knockout gene start codon causes loss of function of the start codon and thereby ensures that the target gene does not comprise a suitable start codon at the start of the coding sequence. The mutation to the start codon may be a missense mutation of one, two or all three of the nucleotides of the start codon. Alternatively or additionally the start codon may be mutated by an insertion or deletion frameshift mutation.

The ptr gene and Tsp gene each comprise an ATG start codon. If the gene comprises more than one suitably positioned start codon, as found in the Tsp gene where two ATG codons are present at the 5' end of the coding sequence, one or both of the ATG codons may be mutated by a missense mutation.

In a preferred embodiment the ptr gene is mutated to change the ATG start codon to ATT, as shown in Figure 1a. In a preferred embodiment the Tsp gene is mutated at the second ATG codon (codon 3) to TCG, as shown in Figure 1b.

The knockout mutated ptr gene and/or the knockout mutated Tsp gene may alternatively or additionally comprise one or more stop codons positioned downstream of the gene start codon and upstream of the gene stop codon. Preferably the knockout mutated ptr gene and/or the knockout mutated Tsp gene comprise both a missense mutation to the start codon and one or more inserted stop codons.

The one or more inserted stop codons are preferably in-frame stop codons. However the one or more inserted stop codons may alternatively or additionally be out-of-frame

stop codons. One or more out-of-frame stop codons may be required to stop translation where an out-of-frame start codon is changed to an in-frame start codon by an insertion or deletion frameshift mutation.The one or more stop codons may be introduced by any suitable mutation including a nonsense point mutation and a frameshift mutation. The one or more stop codons are preferably introduced by a frameshift mutation and/or an insertion mutation, preferably by replacement of a segment of the gene sequence with a sequence comprising a stop codon. For example an *Ase I* restriction site may be inserted, which comprises the stop codon TAA.

In a preferred embodiment the ptr gene is mutated to insert an in-frame stop codon by insertion of an Ase I restriction site, as shown in Figure 1a.

In a preferred embodiment the Tsp gene is mutated to delete "T" from the fifth codon thereby causing a frameshift resulting in stop codons at codons 11 and 16, as shown in Figure 1b. In a preferred embodiment the Tsp gene is mutated to insert an Ase I restriction site to create a third in-frame stop codon at codon 21, as shown in Figure 1b.

In a preferred embodiment the knockout mutated ptr gene has the DNA sequence of SEQ ID NO: 6. The mutations which have been made in the knockout mutated ptr gene sequence of SEQ ID NO: 6 are shown in Figure 1a.

In a preferred embodiment the knockout mutated Tsp gene has the DNA sequence of SEQ ID NO: 3, which includes the 6 nucleotides ATGAAT upstream of the start codon. The mutations which have been made in the knockout mutated Tsp sequence of SEQ ID NO: 3 are shown in Figure 1b. In one embodiment the mutated Tsp gene has the DNA sequence of nucleotides 7 to 2048 of SEQ ID NO:3.

The above described knockout mutations are advantageous because they cause minimal or no disruption to the chromosomal DNA upstream or downstream of the target knockout gene site and do not require the insertion and retention of foreign DNA, such as antibiotic resistance markers, which may affect the cell's suitability for expressing a protein of interest, particularly therapeutic proteins. Accordingly, one or

more of the cells according to the present invention may exhibit improved growth characteristics and/or protein expression compared to cells wherein the protease gene has been knocked out by insertion of foreign DNA into the gene coding sequence.

Many genetically engineered mutations including knockout mutations involve the use of antibiotic resistance markers which allow the selection and identification of successfully mutated cells. However, as discussed above, there are a number of disadvantages to using antibiotic resistance markers.

A further embodiment of the present invention overcomes the above disadvantages of using antibiotic resistance markers wherein the mutated protease genes selected from one or more of a mutated DegP gene encoding a DegP protein having chaperone activity but not protease activity; a mutated ptr gene encoding Protease III; and a mutated Tsp gene encoding protease Tsp, are mutated to comprise one or more restriction marker sites. The restriction sites are genetically engineered into the gene and are non-naturally occurring. The restriction marker sites are advantageous because they allow screening and identification of correctly modified cells which comprise the required chromosomal mutations. Cells which have been modified to carry one or more of the mutated protease genes may be analyzed by PCR of genomic DNA from cell lysates using oligonucleotide pairs designed to amplify a region of the genomic DNA comprising a non-naturally occurring restriction marker site. The amplified DNA may then be analyzed by agarose gel electrophoresis before and after incubation with a suitable restriction enzyme capable of digesting the DNA at the non-naturally occurring restriction marker site. The presence of DNA fragments after incubation with the restriction enzyme confirms that the cells have been successfully modified to carry the one or more mutated protease genes.

In the embodiment wherein the knockout mutated ptr gene has the DNA sequence of SEQ ID NO: 6, the oligonucleotide primer sequences shown in SEQ ID NO: 17 and SEQ ID NO:18 may be used to amplify the region of the DNA comprising the non-naturally occurring Ase I restriction site from the genomic DNA of transformed cells. The amplified genomic DNA may then be incubated with Ase I restriction enzyme

and analyzed by gel electrophoresis to confirm the presence of the mutated ptr gene in the genomic DNA.

In the embodiment wherein the knockout mutated Tsp gene has the DNA sequence of SEQ ID NO: 3 or nucleotides 7 to 2048 of SEQ ID NO:3, the oligonucleotide primer sequences shown in SEQ ID NO: 15 and SEQ ID NO:16 may be used to amplify the region of the DNA comprising the non-naturally occurring Ase I restriction site from the genomic DNA of transformed cells. The amplified genomic DNA may then be incubated with Ase I restriction enzyme and analyzed by gel electrophoresis to confirm the presence of the mutated Tsp gene in the genomic DNA.

In the embodiment wherein the mutated DegP gene has the DNA sequence of SEQ ID NO: 9, the oligonucleotide primer sequences shown in SEQ ID NO: 19 and SEQ ID NO:20 may be used to amplify the region of the DNA comprising the non-naturally occurring Ase I restriction site from the genomic DNA of transformed cells. The amplified genomic DNA may then be incubated with Ase I restriction enzyme and analyzed by gel electrophoresis to confirm the presence of the mutated DegP gene in the genomic DNA.

The one or more restriction sites may be introduced by any suitable mutation including by one or more deletion, insertion, point, missense, nonsense and frameshift mutations. A restriction site may be introduced by the mutation of the start codon and/or mutation to introduce the one or more stop codons, as described above. This embodiment is advantageous because the restriction marker site is a direct and unique marker of the knockout mutations introduced.

A restriction maker site may be inserted which comprises an in-frame stop codon, such as an *Ase I* restriction site. This is particularly advantageous because the inserted restriction site serves as both a restriction marker site and a stop codon to prevent full transcription of the gene coding sequence. For example, in the embodiment wherein a stop codon is introduced to the ptr gene by introduction of an *Ase I* site, this also creates a restriction site, as shown in Figure 1a. For example, in the embodiment

wherein a stop codon is introduced to the Tsp gene at codon 21 by introduction of an *Ase I* site, this also creates a restriction site, as shown in Figure 1b.

A restriction marker site may be inserted by the mutation to the start codon and optionally one or more further point mutations. In this embodiment the restriction marker site is preferably an *EcoR I* restriction site. This is particularly advantageous because the mutation to the start codon also creates a restriction marker site. For example, in the embodiment wherein the start codon of the ptr gene is changed to ATT, this creates an *EcoR I* marker site, as shown in Figure 1a. For example, in the embodiment wherein the start codon (codon 3) of the Tsp gene is changed from ATG to TCG, as shown in Figure 1b, a further point mutation of codon 2 from AAC to AAT and mutation of codon 3 ATG to TCG creates an *EcoR I* restriction marker site, as shown in Figure 1b.

In the DegP gene, a marker restriction site may be introduced using silent codon changes. For example, an *Ase I* site may be used as a silent restriction marker site, wherein the TAA stop codon is out-of-frame, as shown in Figure 1c.

In the embodiments of the present invention, wherein the ptr gene and/or the Tsp gene are mutated to encode a Protease III or Tsp having reduced protease activity, one or more marker restriction site may be introduced using silent codon changes.

The recombinant gram-negative bacterial cell according to the present invention may be produced by any suitable means. The skilled person knows of suitable techniques which may be used to replace a chromosomal gene sequence with a mutated gene sequence. Suitable vectors may be employed which allow integration into the host chromosome by homologous recombination.

Suitable gene replacement methods are described, for example, in Hamilton *et al* (New Method for Generating Deletions and Gene Replacements in *Escherichia coli*, Hamilton C. M. *et al.*, Journal of Bacteriology Sept. 1989, Vol. 171, No. 9 p 4617-4622), Skorupski *et al* (Positive selection vectors for allelic exchange, Skorupski K and Taylor R. K., Gene, 1996, 169, 47-52), Kiel *et al* (A general method for the

construction of *Escherichia coli* mutants by homologous recombination and plasmid segregation, Kiel J.A.K.W. *et al*, Mol Gen Genet 1987, 207:294-301), Blomfield *et al* (Allelic exchange in *Escherichia coli* using the *Bacillus subtilis sacB* gene and a temperature sensitive pSC101 replicon, Blomfield I. C. *et al.*, Molecular Microbiology 1991, 5(6), 1447-1457) and Ried *et al.* (An *nptI-sacB-sacR* cartridge for constructing directed, unmarked mutations in Gram-negative bacteria by marker exchange-eviction mutagenesis, Ried J. L. and Collmer A., Gene 57 (1987) 239-246). A suitable plasmid which enables homologous recombination/replacement is the pKO3 plasmid (Link *et al.*, 1997, *Journal of Bacteriology*, 179, 6228-6237).

Successfully mutated strains may be identified using methods well known in the art including colony PCR DNA sequencing and colony PCR restriction enzyme mapping.

In the embodiment wherein the cell comprises two or three of the mutated protease genes, the mutated protease may be introduced into the gram-negative bacterium on the same or different vectors.

In one embodiment the present invention provides a mutant *E. coli* cell strain MXE001 having genotype ΔTsp and deposited on 21st May 2009 at the National Collection of Type Cultures, Health Protection Agency (HPA), Centre for Infections, 61 Colindale Avenue, London, NW9 5EQ, United Kingdom, under Accession number NCTC13444. In a further embodiment the present invention provides a mutant *E. coli* cell strain MXE002 having genotype Δptr and deposited on 21st May 2009 at the National Collection of Type Cultures, Health Protection Agency (HPA), Centre for Infections, 61 Colindale Avenue, London, NW9 5EQ, United Kingdom, under Accession number NCTC13445. In one embodiment the present invention provides a mutant *E. coli* cell strain MXE003 having genotype DegP S210A and deposited on 21st May 2009 at the National Collection of Type Cultures, Health Protection Agency (HPA), Centre for Infections, 61 Colindale Avenue, London, NW9 5EQ, United Kingdom, under Accession number NCTC13446.

In a further embodiment the present invention provides a mutant *E. coli* cell strain MXE004 having genotype ΔTsp Δptr, and deposited on 21st May 2009 at the National

Collection of Type Cultures, Health Protection Agency (HPA), Centre for Infections, 61 Colindale Avenue, London, NW9 5EQ, United Kingdom, under Accession number NCTC13447.

In one embodiment the present invention provides a mutant *E. coli* cell strain MXE005 having genotype ΔTsp, DegP S210A and deposited on 21st May 2009 at the National Collection of Type Cultures, Health Protection Agency (HPA), Centre for Infections, 61 Colindale Avenue, London, NW9 5EQ, United Kingdom, under Accession number NCTC13448.

In a further embodiment the present invention provides a mutant *E. coli* cell strain MXE006 having genotype Δptr, DegP S210A and deposited on 21st May 2009 at the National Collection of Type Cultures, Health Protection Agency (HPA), Centre for Infections, 61 Colindale Avenue, London, NW9 5EQ, United Kingdom, under Accession number NCTC13449.

In one embodiment the gram-negative bacterial cell according to the present invention does not carry a knockout mutated ompT gene, such as being deficient in chromosomal ompT. In one embodiment the cell according to the present invention does not carry any further knockout mutated protease genes apart from the knockout mutated ptr gene and/or the knockout mutated Tsp gene.

The cell according to the present invention may further comprise a polynucleotide sequence encoding a protein of interest. The polynucleotide sequence encoding the protein of interest may be exogenous or endogenous. The polynucleotide sequence encoding the protein of interest may be integrated into the host's chromosome or may be non-integrated in a vector, typically a plasmid.

In one embodiment the cell according to the present invention expresses a protein of interest. "Protein of interest" in the context of the present specification is intended to refer to polypeptide for expression, usually a recombinant polypeptide. However, the protein of interest may be an endogenous protein expressed from an endogenous gene in the host cell.

As used herein, a "recombinant polypeptide" refers to a protein that is constructed or produced using recombinant DNA technology. The protein of interest may be an exogenous sequence identical to the endogenous protein or a mutated version thereof, for example with attenuated biological activity, or fragment thereof, expressed from an exogenous vector. Alternatively, the protein of interest may be a heterologous protein, not normally expressed by the host cell.

The protein of interest may be any suitable protein including a therapeutic, prophylactic or diagnostic protein.

In one embodiment the protein of interest is useful in the treatment of diseases or disorders including inflammatory diseases and disorders, immune disease and disorders, fibrotic disorders and cancers.

The term "inflammatory disease" or "disorder" and "immune disease or disorder" includes rheumatoid arthritis, psoriatic arthritis, still's disease, Muckle Wells disease, psoriasis, Crohn's disease, ulcerative colitis, SLE (Systemic Lupus Erythematosus), asthma, allergic rhinitis, atopic dermatitis, multiple sclerosis, vasculitis, Type I diabetes mellitus, transplantation and graft-versus-host disease.

The term "fibrotic disorder" includes idiopathic pulmonary fibrosis (IPF), systemic sclerosis (or scleroderma), kidney fibrosis, diabetic nephropathy, IgA nephropathy, hypertension, end-stage renal disease, peritoneal fibrosis (continuous ambulatory peritoneal dialysis), liver cirrhosis, age-related macular degeneration (ARMD), retinopathy, cardiac reactive fibrosis, scarring, keloids, burns, skin ulcers, angioplasty, coronary bypass surgery, arthroplasty and cataract surgery.

The term "cancer" includes a malignant new growth that arises from epithelium, found in skin or, more commonly, the lining of body organs, for example: breast, ovary, prostate, lung, kidney, pancreas, stomach, bladder or bowel. Cancers tend to infiltrate into adjacent tissue and spread (metastasise) to distant organs, for example: to bone, liver, lung or the brain.

The protein may be a proteolytically-sensitive polypeptide, i.e. proteins that are prone to be cleaved, susceptible to cleavage, or cleaved by one or more gram-negative bacterial, such as *E. coli*, proteases, either in the native state or during secretion. In one embodiment the protein of interest is proteolytically-sensitive to a protease selected from DegP, Protease III and Tsp. In one embodiment the protein of interest is proteolytically-sensitive to the proteases DegP and Protease III. In one embodiment the protein of interest is proteolytically sensitive to the proteases DegP and Tsp. In one embodiment the protein of interest is proteolytically-sensitive to the proteases Tsp and Protease III. In one embodiment the protein of interest is proteolytically sensitive to the proteases DegP, Protease III and Tsp.

Preferably the protein is a eukaryotic polypeptide.

The protein of interest expressed by the cells according to the invention may, for example be an immunogen, a fusion protein comprising two heterologous proteins or an antibody. Antibodies for use as the protein of interest include monoclonal, multi-valent, multi-specific, humanized, fully human or chimeric antibodies. The antibody can be from any species but is preferably derived from a monoclonal antibody, a human antibody, or a humanized fragment. The antibody can be derived from any class (e.g. IgG, IgE, IgM, IgD or IgA) or subclass of immunoglobulin molecule and may be obtained from any species including for example mouse, rat, shark, rabbit, pig, hamster, camel, llama, goat or human. Parts of the antibody fragment may be obtained from more than one species for example the antibody fragments may be chimeric. In one example the constant regions are from one species and the variable regions from another.

The antibody may be a complete antibody molecule having full length heavy and light chains or a fragment thereof, e.g. VH, VL, VHH, Fab, modified Fab, Fab', $F(ab')_2$, Fv, scFv fragment, Fab-Fv, or a dual specificity antibody, such as a Fab-dAb, as described in PCT/GB2008/003331. .

The antibody may be specific for any target antigen. The antigen may be a cell-associated protein, for example a cell surface protein on cells such as bacterial cells,

yeast cells, T-cells, endothelial cells or tumour cells, or it may be a soluble protein. Antigens of interest may also be any medically relevant protein such as those proteins upregulated during disease or infection, for example receptors and/or their corresponding ligands. Particular examples of cell surface proteins include adhesion molecules, for example integrins such as β1 integrins e.g. VLA-4, E-selectin, P selectin or L-selectin, CD2, CD3, CD4, CD5, CD7, CD8, CD11a, CD11b, CD18, CD19, CD20, CD23, CD25, CD33, CD38, CD40, CD40L, CD45, CDW52, CD69, CD134 (OX40), ICOS, BCMP7, CD137, CD27L, CDCP1, CSF1 or CSF1-Receptor, DPCR1, DPCR1, dudulin2, FLJ20584, FLJ40787, HEK2, KIAA0634, KIAA0659, KIAA1246, KIAA1455, LTBP2, LTK, MAL2, MRP2, nectin-like2, NKCC1, PTK7, RAIG1, TCAM1, SC6, BCMP101, BCMP84, BCMP11, DTD, carcinoembryonic antigen (CEA), human milk fat globulin (HMFG1 and 2), MHC Class I and MHC Class II antigens, KDR and VEGF, and where appropriate, receptors thereof.

Soluble antigens include interleukins such as IL-1, IL-2, IL-3, IL-4, IL-5, IL-6, IL-8, IL-12, IL-13, IL-14, IL-16 or IL-17, such as IL17A and/or IL17F, viral antigens for example respiratory syncytial virus or cytomegalovirus antigens, immunoglobulins, such as IgE, interferons such as interferon α, interferon β or interferon γ, tumour necrosis factor TNF (formerly known as tumour necrosis factor-α), tumor necrosis factor-β, colony stimulating factors such as G-CSF or GM-CSF, and platelet derived growth factors such as PDGF-α, and PDGF-β and where appropriate receptors thereof. Other antigens include bacterial cell surface antigens, bacterial toxins, viruses such as influenza, EBV, HepA, B and C, bioterrorism agents, radionuclides and heavy metals, and snake and spider venoms and toxins.

In one embodiment, the antibody may be used to functionally alter the activity of the antigen of interest. For example, the antibody may neutralize, antagonize or agonise the activity of said antigen, directly or indirectly.

In a preferred embodiment the protein of interest expressed by the cells according to the present invention is an anti-TNF antibody, more preferably an anti-TNF Fab', as described in WO01/094585 (the contents of which are incorporated herein by reference).

Preferably the antibody molecule has specificity for human TNF (formerly known as TNFα), wherein the light chain comprises the light chain variable region of SEQ ID NO: 11 and the heavy chain comprises the heavy chain variable region of SEQ ID NO: 12.

Preferably the antibody molecule having specificity for human TNF is a Fab' and has a light chain sequence comprising or consisting of SEQ ID NO: 13 and a heavy chain sequence comprising or consisting of SEQ ID NO: 14.

The inventors of the present invention have surprisingly discovered that Fab yield may be improved by expression in one or more cells according to the present invention. Without wishing to be bound by theory, the mutated DegP gene used in the strains of the present invention having chaperone activity and reduced protease activity improves Fab yield because the chaperone activity of DegP facilitates the correct folding of Fab.

After expression, antibody fragments may be further processed, for example by conjugation to another entity such as an effector molecule.

The term effector molecule as used herein includes, for example, antineoplastic agents, drugs, toxins (such as enzymatically active toxins of bacterial or plant origin and fragments thereof e.g. ricin and fragments thereof) biologically active proteins, for example enzymes, other antibody or antibody fragments, synthetic or naturally occurring polymers, nucleic acids and fragments thereof e.g. DNA, RNA and fragments thereof, radionuclides, particularly radioiodide, radioisotopes, chelated metals, nanoparticles and reporter groups such as fluorescent compounds or compounds which may be detected by NMR or ESR spectroscopy. Effector molecular may be attached to the antibody or fragment thereof by any suitable method, for example an antibody fragment may be modified to attach at least one effector molecule as described in WO05/003171 or WO05/003170 (the contents of which are incorporated herein by reference). WO05/003171 or WO05/003170 also describe suitable effector molecules.

In one embodiment the antibody or fragment thereof, such as a Fab, is PEGylated to generate a product with the required properties, for example similar to the whole antibodies, if required. For example, the antibody may be a PEGylated anti-TNF- α Fab', as described in WO01/094585, preferably having attached to one of the cysteine residues at the C-terminal end of the heavy chain a lysyl-maleimide-derived group wherein each of the two amino groups of the lysyl residue has covalently linked to it a methoxypoly(ethyleneglycol) residue having a molecular weight of about 20,000 Da, such that the total average molecular weight of the methoxypoly(ethyleneglycol) residues is about 40,000Da, more preferably the lysyl-maleimide-derived group is [1-[[[2-[[3-(2,5-dioxo-1-pyrrolidinyl)-1-oxopropyl]amino]ethyl]amino]-carbonyl]-1,5-pentanediyl]bis(iminocarbonyl).

The cell may also comprise further polynucleotide sequences encoding one or more further proteins of interest.

The polynucleotide encoding the protein of interest may be expressed as a fusion with another polypeptide, preferably a signal sequence or other polypeptide having a specific cleavage site at the N-terminus of the mature polypeptide. The heterologous signal sequence selected should be one that is recognized and processed by the host cell. For prokaryotic host cells that do not recognize and process the native or a eukaryotic polypeptide signal sequence, the signal sequence is substituted by a prokaryotic signal sequence. Suitable signal sequences include OmpA, PhoA, LamB, PelB, DsbA and DsbC.

In one embodiment an expression cassette is employed in the present invention to carry the polynucleotide encoding the protein of interest which typically comprises one or more protein coding sequences encoding one or more proteins of interest and one or more regulatory expression sequences. The one or more regulatory expression sequences may include a promoter. The one or more regulatory expression sequences may also include a 3' untranslated region such as a termination sequence. Suitable promoters are discussed in more detail below.

In one embodiment, the cell according to the present invention comprises a vector, such as plasmid. The vector preferably comprises one or more of the expression cassettes as defined above.

The vector for use in the present invention may be produced by inserting an expression cassette as defined above into a suitable vector. Alternatively, the regulatory expression sequences for directing expression of the polynucleotide sequence encoding a protein of interest may be contained in the vector and thus only the encoding region of the polynucleotide may be required to complete the vector.

Examples of vectors which may be employed to transform the host cell with a polynucleotide according to the invention include:

- a plasmid, such as pBR322 or PACYC184, and/or
- a viral vector such as bacterial phage
- a transposable genetic element such as a transposon

Many forms of expression vector are available. Such vectors usually comprise a plasmid origin of DNA replication, an antibiotic selectable marker a promoter and transcriptional terminator separated by a multi-cloning site (expression cassette) and a DNA sequence encoding a ribosome binding site.

The promoters employed in the present invention can be linked to the relevant polynucleotide directly or alternatively be located in an appropriate position, for example in a vector such that when the relevant polypeptide is inserted the relevant promoter can act on the same. In one embodiment the promoter is located before the encoding portion of the polynucleotide on which it acts, for example a relevant promoter before each encoding portion of polynucleotide. "Before" as used herein is intended to imply that the promoter is located at the 5 prime end in relation to the encoding polynucleotide portion.

The promoters may be endogenous or exogenous to the host cells. Suitable promoters include Lac, tac, trp, PhoA, Ipp, Arab, Tet and T7.

One or more promoters employed may be inducible promoters.

Expression units for use in bacterial systems also generally contain a Shine-Dalgarno (S. D.) ribosome sequence operably linked to the DNA encoding the polypeptide of interest.

In the embodiments of the present invention wherein a polynucleotide sequence comprises two or more encoding sequences for two or more proteins of interest, for example an antibody light chain and antibody heavy chain, the polynucleotide sequence may comprise one or more internal ribosome entry site (IRES) sequences which allows translation initiation in the middle of an mRNA. An IRES sequence may be positioned between encoding polynucleotide sequences to enhance separate translation of the mRNA to produce the encoded polypeptide sequences.

The terminators may be endogenous or exogenous to the host cells. A suitable terminator is rrnB.

Further suitable transcriptional regulators including promoters and terminators and protein targeting methods may be found in "Strategies for Achieving High-Level Expression of Genes in *Escherichia coli*" Savvas C. Makrides, Microbiological Reviews, Sept 1996, p 512-538.

Embodiments of the invention described herein with reference to the polynucleotide apply equally to alternative embodiments of the invention, for example vectors, expression cassettes and/or host cells comprising the components employed therein, as far as the relevant aspect can be applied to same.

According to a third aspect of the present invention there is provided a method for producing a recombinant protein of interest comprising expressing the recombinant protein of interest in a recombinant gram-negative bacterial cell as described above in the first or second aspect of the present invention.

The gram negative bacterial cell and protein of interest preferably employed in the method of the present invention are described in detail above.

When the polynucleotide encoding the protein of interest is exogenous the polynucleotide may be incorporated into the host cell using any suitable means known in the art. Typically, the polynucleotide is incorporated as part of an expression vector which is transformed into the cell. Accordingly, in one aspect the cell according to the present invention comprises an expression cassette comprising the polynucleotide encoding the protein of interest.

The polynucleotide sequence can be transformed into a cell using standard techniques, for example employing rubidium chloride, PEG or electroporation.

The method according to the present invention may also employ a selection system to facilitate selection of stable cells which have been successfully transformed with the polynucleotide encoding the protein of interest. The selection system typically employs co-transformation of a polynucleotide sequence encoding a selection marker. In one embodiment, each polynucleotide transformed into the cell further comprises a polynucleotide sequence encoding one or more selection markers. Accordingly, the transformation of the polynucleotide encoding the protein of interest and the one or more polynucleotides encoding the marker occurs together and the selection system can be employed to select those cells which produce the desired proteins.

Cells able to express the one or more markers are able to survive/grow/multiply under certain artificially imposed conditions, for example the addition of a toxin or antibiotic, because of the properties endowed by the polypeptide/gene or polypeptide component of the selection system incorporated therein (e.g. antibiotic resistance). Those cells that cannot express the one or more markers are not able to survive/grow/multiply in the artificially imposed conditions. The artificially imposed conditions can be chosen to be more or less vigorous, as required.

Any suitable selection system may be employed in the present invention. Typically the selection system may be based on including in the vector one or more genes that

provides resistance to a known antibiotic, for example a tetracycline, chloramphenicol, kanamycin or ampicillin resistance gene. Cells that grow in the presence of a relevant antibiotic can be selected as they express both the gene that gives resistance to the antibiotic and the desired protein.

In one embodiment, the method according to the present invention further comprises the step of culturing the transformed cell in a medium to thereby express the protein of interest.

An inducible expression system or a constitutive promoter may be used in the present invention to express the protein of interest. Suitable inducible expression systems and constitutive promoters are well known in the art.

Any suitable medium may be used to culture the transformed cell. The medium may be adapted for a specific selection system, for example the medium may comprise an antibiotic, to allow only those cells which have been successfully transformed to grow in the medium.

The cells obtained from the medium may be subjected to further screening and/or purification as required. The method may further comprise one or more steps to extract and purify the protein of interest as required.

The polypeptide may be recovered from the strain, including from the cytoplasm, periplasm, or culture medium.

The specific method (s) used to purify a protein depends on the type of protein. Suitable methods include fractionation on immunoaffnity or ion-exchange columns; ethanol precipitation; reversed-phase HPLC; hydrophobic-interaction chromatography; chromatography on silica; chromatography on an ion-exchange resin such as S-SEPHAROSE and DEAE; chromatofocusing; ammonium-sulfate precipitation; and gel filtration.

Antibodies may be suitably separated from the culture medium and/or cytoplasm

extract and/or periplasm extract by conventional antibody purification procedures such as, for example, protein A-Sepharose, protein G chromatography, protein L chromatograpy, thiophilic, mixed mode resins, Histag, FLAGTag, hydroxylapatite chromatography, gel electrophoresis, dialysis, affinity chromatography, Ammonium Sulphate, ethanol or PEG fractionation/precipitation, ion exchange membranes, expanded bed adsorption chromatography (EBA) or simulated moving bed chromatography..

The method may also include a further step of measuring the quantity of expression of the protein of interest and selecting cells having high expression levels of the protein of interest.

One or more method steps described herein may be performed in combination in a suitable container such as a bioreactor.

Examples

Example 1 – Generation of Mutant *E. coli* cell strains

The host cell strain used was W3110 genotype: F- LAM- IN (rrnD-rrnE)1 rph1 (ATCC no. 27325).

W3110A, as shown in the figures, is a different batch of W3110.

The following mutant *E. coli* cell strains were generated using a gene replacement vector system using the pKO3 homologous recombination/replacement plasmid (Link *et al.*, 1997, *Journal of Bacteriology*, 179, 6228-6237).

Mutant *E. coli* Cell Strain	**Genotype**
MXE001	ΔTsp
MXE004	ΔTsp, Δprotease III
MXE005	ΔTsp, DegP S210A

Strain MXE001 was deposited on 21st May 2009 at the National Collection of Type Cultures, HPA, United Kingdom, under Accession number NCTC13444.

Strain MXE004 was deposited on 21st May 2009 at the National Collection of Type Cultures, HPA, United Kingdom, under Accession number NCTC13447.
Strain MXE005 was deposited on 21st May 2009 at the National Collection of Type Cultures, HPA, United Kingdom, under Accession number NCTC13448.

The Tsp, protease III and DegP integration cassettes were moved as Sal I, Not I restriction fragments into similarly restricted pKO3 plasmids.

The plasmid uses the temperature sensitive mutant of the pSC101 origin of replication (*RepA*) along with a chloramphenicol marker to force and select for chromosomal integration events. The *sacB* gene which encodes for levansucrase is lethal to *E . coli* grown on sucrose and hence (along with the chloramphenicol marker and pSC101 origin) is used to force and select for de-integration and plasmid curing events. This methodology had been described previously (Hamilton *et al.*, 1989, *Journal of Bacteriology*, 171, 4617-4622 and Blomfield *et al.*, 1991, *Molecular Microbiology*, 5, 1447-1457). The pKO3 system removes all selective markers from the host genome except for the inserted gene.

The following plasmids were constructed.

pMXE191 comprising the knockout mutated Tsp gene as shown in the SEQ ID NO: 3 comprising *EcoR I* and *Ase I* restriction markers.

pMXE192 comprising the knockout mutated Protease III gene as shown in the SEQ ID NO: 6 comprising *EcoR I* and *Ase I* restriction markers.

pMXE192 comprising the mutated DegP gene as shown in the SEQ ID NO: 9 comprising an *Ase I*.

These plasmids were then transformed into chemically competent *E. coli* W3110 cells prepared using the method found in Chung CT *et al* Transformation and storage of bacterial cells in the same solution. PNAS 86:2172-2175 (1989).

Day 1 **40**µl of *E.coli* cells were mixed with (10pg) **1**µl of pKO3 DNA in a chilled BioRad **0.2cm** electroporation cuvette before electroporation at 2500V, 25µF and 200Ω. **1000**µl of 2xPY was added immediately, the cells recovered by shaking at 250rpm in an incubator at 30°C for 1 hour. Cells were serially 1/10 diluted in 2xPY before 100µl aliquots were plated out onto 2xPY agar plates containing chloramphenicol at 20µg/ml prewarmed at 30°C and 43°C. Plates were incubated overnight at 30°C and 43°C.

Day 2 The number of colonies grown at 30°C gave an estimate of the efficiency of electroporation whilst colonies that survive growth at 43°C represent potential integration events. Single colonies from the 43°C plate were picked and resuspended in 10ml of 2xPY. 100µl of this was plated out onto 2xPY agar plates containing 5% (w/v) sucrose pre-warmed to 30°C to generate single colonies. Plates were incubated overnight at 30°C.

Day 3 Colonies here represent potential simultaneous de-integration and plasmid curing events. If the de-integration and curing events happened early on in the growth, then the bulk of the colony mass will be clonal. Single colonies were picked and replica plated onto 2xPY agar that contained either chloramphenicol at 20µg/ml or 5% (w/v) sucrose. Plates were incubated overnight at 30°C.

Day 4 Colonies that both grow on sucrose and die on chloramphenicol represent potential chromosomal replacement and plasmid curing events. These were picked and screened by PCR with a mutation specific oligonucleotide. Colonies that generated a positive PCR band of the correct size were struck out to produce single colonies on 2xPY agar containing 5% (w/v) sucrose and the plates were incubated overnight at 30°C.

Day 5 Single colonies of PCR positive, chloramphenicol sensitive and sucrose resistant *E . coli* were used to make glycerol stocks, chemically competent cells and act as PCR templates for a PCR reaction with 5' and 3' flanking oligos to generate PCR product for direct DNA sequencing using **Taq** polymerase.

Cell strains MXE001, MXE004 and MXE005 were tested to confirm successful modification of genomic DNA carrying one or more the mutated protease genes by PCR amplification of the region of each mutated protease gene comprising a non-

naturally occurring Ase I restriction site, as shown in Figures 1a, 1b and 1c, using oligonucleotides primers. The amplified regions of the DNA were then analyzed by gel electrophoresis before and after incubation with Ase I restriction enzyme to confirm the presence of the non-naturally occurring Ase I restriction site in the mutated genes. This method was carried out as follows:

The following oligos were used to amplify, using PCR, genomic DNA from prepared *E. coli* cell lysates from MXE001, MXE004, MXE005, and W3110:

6284 Tsp 3'	5'-GCATCATAATTTTCTTTTTACCTC-3' (SEQ ID NO: 15)
6283 Tsp 5'	5'-GGGAAATGAACCTGAGCAAAACGC-3' (SEQ ID NO: 16)
6362 Protease III 3'	5'-GTGCCAGGAGATGCAGCAGCTTGC-3' (SEQ ID NO: 17)
6361 Protease III 5'	5'-TTTGCAGCCAGTCAGAAAGTG-3' (SEQ ID NO: 18)
6282 DegP 5'	5'-CTGCCTGCGATTTTCGCCGGAACG-3' (SEQ ID NO: 19)
6281 DegP 3'	5'-CGCATGGTACGTGCCACGATATCC-3' (SEQ ID NO: 20)

The lysates were prepared by heating a single colony of cells for 10 minutes at 95 ^{O}C in 20ul of 1x PCR buffer. The mixture was allowed to cool to room temperature then centrifugation at 13,200rpm for 10 minutes. The supernatant was removed and labeled as 'cell lysate'.

Each strain was amplified using every pair of oligos' Tsp pair, Protease III pair and DegP pair .

The DNA was amplified using a standard PCR procedure.

5ul	Buffer x10 (Roche)

1ul	dNTP mix (Roche, 10mM mix)
1.5ul	5' oligo (5 pmol)
1.5ul	3' oligo (5 pmol)
2ul	Cell lysate
0.5ul	Taq DNA polymerase (Roche 5U/ul)
38.5ul	H2O

PCR cycle.

94 ^{O}C	1 minute
94 ^{O}C	1 minute)
55 ^{O}C	1 minute) repeated for 30 cycles
72 ^{O}C	1 minute)
72 ^{O}C	10 minutes

Once the reactions were complete 25ul was removed to a new microfuge tube for digestion with Ase I. To the 25ul of PCR reaction 19ul of H2O, 5ul of buffer 3 (NEB), 1ul of Ase I (NEB) was added, mixed and incubated at 37 ^{O}C for 2 hours.

To the remaining PCR reaction 5ul of loading buffer (x6) was added and 20ul was loaded onto a 0.8% TAE 200ml agarose gel (Invitrogen) plus Ethidium Bromide (5ul of 10mg/ml stock) and run at 100 volts for 1 hour. 10ul of size marker (Perfect DNA marker 0.1-12Kb, Novagen) was loaded in the final lane.

Once the Ase I digestions were complete 10ul of of loading buffer (x6) was added and 20ul was loaded onto a 0.8% TAE agarose gel (Invitrogen) plus Ethidium Bromide (5ul of 10mg/ml stock) and run at 100 volts for 1 hour. 10ul of size marker (Perfect DNA marker 0.1-12Kb, Novagen) was loaded in the final lane.

Both gels were visualized using UV transluminator.

All genomic fragments amplified showed the correct sized band of 2.8Kb for Tsp, 1.8Kb for protease III and 2.2K.b for DegP.

Following digestion with Ase I this confirmed the presence of the introduced Ase I sites in the protease deficient strains but not in the W3110 control.

MXE001: genomic DNA amplified using the Tsp primer set and the resulting DNA was digested with Ase I to produce 2.2 and 0.6 Kbps bands.

MXE004: genomic DNA amplified using the Tsp primer set and the protease III primer set and the resulting DNA was digested with Ase I to produce 2.2 and 0.6 Kbps bands (Tsp fragments) and 1.0 and 0.8 Kbps bands (Protease III fragments).

MXE005 genomic DNA amplified using the Tsp primer set and the DegP primer set and the resulting DNA was digested with Ase I to produce 2.2 and 0.6 Kbps bands (Tsp fragments) and 1.25 and 0.95 Kbps bands (DegP fragments).

W3110 PCR amplified DNA was not digested by Ase I restriction enzyme.

Plasmid pMXE117 (pTTO CDP870 or 40.4), an expression vector for the CDP870 Fab' (an anti-TNF Fab'), was constructed using conventional restriction cloning methodologies which can be found in Sambrook *et al* 1989, Molecular cloning: a laboratory manual. CSHL press, N.Y. The plasmid pMXE117 (pTTO CDP870 or 40.4) contained the following features; a strong *tac* promoter and *lac* operator sequence. The Fab light and heavy chain genes were transcribed as a single dicistronic message. DNA encoding the signal peptide from the *E. coli* OmpA protein was fused to the 5' end of both light and heavy chain gene sequences, which directed the translocation of the polypeptides to the *E. coli* periplasm. Transcription was terminated using a dual transcription terminator *rrnB t1t2*. The *lacIq* gene encoded the constitutively expressed Lac I repressor protein. This repressed transcription from the tac promoter until de-repression was induced by the presence of allolactose or IPTG. The origin of replication used was p15A, which maintained a low copy number. The plasmid contained a tetracycline resistance gene for antibiotic selection.

pMXE117 was then transformed into chemically competent proteases deficient cells (strains MXE001, MXE004 and MXE005) and W3110 cells prepared using the method found in Chung C.T *et al* Transformation and storage of bacterial cells in the same solution. PNAS 86:2172-2175 (1989).

Example 2 – Expression of an anti-TNFα Fab' in mutated *E. coli* strains using shake flask cultures

Strains MXE001, MXE004 and MXE005 were tested in a shake flask experiment comparing growth and expression of an anti-TNFα Fab' against W3110.

The shake flask experimental protocol used was performed as follows:

Preparation of defined medium adapted cells.

A single colony was picked into 5ml 2xPY (1% phytone, Difco, 0.5% yeast extract, Difco, 0.5% NaCl) broth plus tetracycline (Sigma) at 10ug/ml and grown overnight at 37^{O}C with shaking at 250rpm. 100ul of this overnight culture was used to inoculate 200ml of chemically defined SM6E medium (described in Humphreys *et al.*, 2002, Protein Expression and Purification, 26, 309-320) plus tetracycline at 10ug/ml, grown overnight at 30^{O}C with shaking at 250rpm. 100ul of this second overnight culture was used to inoculate a 2nd 200ml SM6E media flask plus tetracycline at 10ug/ml. This was grown until the culture reached an OD600 of about 2. The cultures were centrifuged briefly to collect cells before being re-suspended in 100ml of SM6E. Glycerol was added to a final concentration of 12.5% before storing aliquots of 'adapted cells' at -80oC

200ml Shake flask experiment

Shake flask cultures were initiated by addition of a 2ml aliquot of thawed defined medium 'adapted cells' to 200ml of SM6E media plus tetracycline 10ug/ml. These where grown overnight at 30^{O}C with agitation at 250rpm. Each strain being tested was grown in triplicate.

Cultures grown to 2.0 OD600 were induced for production of heterologous protein by the addition of IPTG to 200uM. 1ml culture samples where taken at 1hr, 2hr, 4hr, 6hr,

12hr and 24hrs and after centrifugation at 13,200rpm for 5 minutes the cell pellet was res-uspended in 200ul of periplasmic extraction buffer (100mM Tris.Cl/10mM EDTA pH 7.4). Periplasmic extracts were agitated at 250rpm over night at 30oC. The next day, the extracts were centrifuged for 10 minutes at 13,200 rpm, the supernatant decanted off and stored at -20oC as 'periplasmic extract'. The spent cell pellet was discarded.

ELISA quantification.

96 well ELISA plates were coated overnight at 4°C with AB141 (rabbit anti-human CH1, UCB) at 2 $\mu g ml^{-1}$ in PBS. After washing 3x with 300ul of sample/conjugate buffer (PBS, BSA 0.2% (w/v), Tween 20 0.1% (v/v)), serial ½ dilutions of samples and standards were performed on the plate in 100 µl of sample/conjugate buffer, and the plate agitated at 250 r.p.m at room temperature for 1 hour. After washing 3x with 300ul of wash buffer (PBS, Tween 20 0.1% (v/v)), 100 µl of the revealing antibody 6062 (rabbit anti-human kappa HRP conjugated, The Binding Site, Birmingham, U.K.) was added, after dilution at 1/1000 in sample/conjugate buffer. The plate was then agitated at 250 r.p.m at room temperature for 1 hour. After washing with 3x 300ul of wash buffer, 100µl of TMB substrate was added (50:50 mix of TMB solution (Calbiochem): dH_2O) and the A_{630} recorded using an automated plate reader. The concentration of Fab' in the periplasmic extracts were calculated by comparison with purified Fab' standards of the appropriate isotype.

Figure 2 shows growth of MXE005 and MXE001 compared to the wild type W3110. Figure 3 shows improved expression of the Fab' from MXE005 and MXE001 strains compared to the wild type W3110.

Figure 4 shows the growth of MXE004 and W3110 and Figure 5 shows expression of the Fab' in MXE004 and W3110 where it can be seen that the expression from MXE004 was higher than W3110.

Example 3 – Expression of an anti-mIL13 mouse Fab in mutated *E. coli* strains using shake flask cultures

Strains MXE001, MXE004, MXE005 and wild type W3110 cells were transformed with plasmid pMKC006 expressing a murinised anti-mIL13 Fab' and tested using the same shake flask method described in Example 2 except the experiment was stopped after 6 hours instead of 24 hours.

Figure 6 shows the expression of an anti-mIL-13 mouse Fab in MXE001, MXE004, MXE005 and W3110, where it can be seen that MXE001, MXE004 and MXE005 show higher Fab expression compared to W3110.

Example 4 – Analysis of Light and Heavy Chain Expression from mutated *E. coli* strains

Periplasmic extracts from strain MXE005 and wild type W3110 cells transformed with plasmid pMXE117, from the shake flask experiment described in Example 2 and were tested using a surface Plasmon resonance binding assay performed using a BIAcore™ 2000 instrument (Pharmacia Biosensor AB, Uppsala, Sweden). The anti-TNFα Fab' was immobilised onto CM5 sensor chips using standard NHS/EDC chemistry. Residual NHS esters were inactivated with ethanolamine hydrochloride (1 M).

Fab' fragments were captured by either an immobilised monoclonal antiheavy chain or by an immobilised monoclonal anti-light chain antibody in separate flow cells. The presence of bound Fab' was revealed by binding of the complementary monoclonal antibody (anti-light chain or anti-heavy chain) in a second step. High levels of immobilised antibody ensure that measurements are performed under mass transport-limited conditions, where the contribution of the association rate constant to binding is low in comparison to the contribution made by the concentration of the Fab' in the sample. The solution phase monoclonal antibody used in the second step is passed over the surface at a high concentration so that binding is not limited by the association rate constant of this interaction.

Assembled Fab' fragments and correctly folded unassembled chains are both detected during the first capture step. Binding of the second antibody is only to an intact Fab' fragment. Therefore, analysis of the relative binding at the first and second stages

reveals the presence of either excess unassembled light chain, or excess unassembled heavy chain in the Fab' sample and provides information on the stoichiometry of assembly.

Assays were performed in both configurations for each sample, and each sample was run in duplicate and in a randomised order.

(i) Where the concentration of assembled Fab' was to be determined by light chain capture, samples and standards zu at 10gl/min) were injected over immobilised HP6053, followed by a second step in which HP6045 at 300Rg/ml was passed over the surface in the solution phase.

(ii) Where the concentration of assembled Fab' was to be determined by heavy chain capture, samples and standards (10t at tOjuVmin) were injected over immobilised HP6045, followed by a second step in which HP6053 at 5001lg/ml was passed over the surface in the solution phase. In both cases, the surface was regenerated with 10gi of 30mM HCI at 30 l/min.

The number of resonance units determined using the BlAevaluation 3.1 (Pharmacia Biosensor AB), was read against a standard curve.

Figure 7 shows the light chain (L chain), heavy chain (H chain) and Fab expression during the course of a fermentation run where a higher light chain, heavy chain and Fab' expression from MXE001 after 2 hours, 4 hours and 6 hours compared to W3110 is shown. Figure 7 shows higher light chain after 6 hours from MXE005 compared to W3110 and higher Fab' expression from MXE005 after 2 hours, 4 hours and 6 hours compared to W3100.

Example 5 – Analysis of proteolysis activity of mutated *E. coli* strains for Fab'

Periplasmic extracts from strains MXE001, MXE005 and wild type W3110 cells, transformed with plasmid pMXE117 from the Shake flask experiment in Example 2

were tested in a polyclonal western blot analysis comparing proteolysis of an anti-TNFα Fab' as follows:

12ul of each periplasmic extract plus 4ul of SDS-PAGE loading buffer (Invitrogen) was heated to 85°C for 5 minutes, allowed to cool to 25^{0}C then centrifuged briefly before loading on to a pre prepared NuPAGE 4-12% Bis-Tris gel (Invitrogen). SeeBlue 2 size markers (Invitrogen) were used for molecular weight estimation.. The gel was electrophoresed for 1 hour at 150V before transfer of proteins onto pre-wetted PVDF membrane (Invitrogen) using immunoblotting at 150mA for 2 hours. The membrane was blocked for 1hr in 'blocking buffer' (PBS, 3% (w/v) milk powder, 0.1% (v/v) Tween20 (Sigma)) with gentle agitation. A polyclonal rabbit anti-human Fab' sera (UCB) was applied at a dilution of 1 in 1000 in 5mls of blocking buffer and incubated at room temperature for 1 hour with gentle agitation. The membrane was washed three times for 5mins each with gentle agitation with blocking buffer. A secondary antibody (donkey anti-rabbit IgG HRP conjugated antibody (Jackson)) applied at a dilution of 1 in 5000 in blocking buffer and incubation at room temperature for 1 hour with gentle agitation. The membrane was washed four times for 5 minutes each with agitation firstly with blocking buffer followed by PBS, 0.1% Tween for two washes then PBS for the final wash. The blot was visualized using Metal Enhanced Dab substrate (Thermo Scientific).

Figure 8 shows the results of the western blot analysis where W = W3110, 1 = MXE001 (ΔTsp) and 5 = MXE005 (ΔTsp, DegP S210A). Fragmentation around the 14KDa is thought to represent proteolytic fragments of the light chain of the expressed Fab'. It can be seen that MXE001 and MXE005 have less proteolysed products compared to the wild type W3110 around the 14KDa mark. Without being bound by theory, this data suggests that the anti-TNFα Fab' is susceptible to proteolysis by Tsp and DegP.

Example 6 – Growth of mutated *E. coli* strains and expression of Fab' in mutated *E. coli* strains using high density fermentations

Strain MXE005 and wild type W3110 cells were transformed with plasmid pMXE117 tested in fermentation experiments comparing growth and expression of an anti-TNFα Fab'.

Growth medium.

The fermentation growth medium was based on SM6E medium (described in Humphreys *et al.*, 2002, Protein Expression and Purification, 26, 309-320) with 3.86 g/l $NaH_2PO_4.H_2O$ and 112 g/l glycerol.

Inoculum. Inoculum cultures were grown in the same medium supplemented with 10 μg/ml tetracycline. Cultures were incubated at 30°C with agitation for approximately 22 hours.

Fermentation. Fermenters (2.5 litres total volume) were seeded with inoculum culture to 0.3-0.5 OD_{600}. Temperature was maintained at 30°C during the growth phase and was reduced to 25°C prior to induction. The dissolved oxygen concentration was maintained above 30% air saturation by variable agitation and airflow. Culture pH was controlled at 7.0 by automatic titration with 15% (v/v) NH_4OH and 10% (v/v) conc. H_2SO_4. Foaming was controlled by the addition of 10% (v/v) Struktol J673 solution (Schill and Seilacher).

A number of additions were made at different stages of the fermentation. When biomass concentration reached approximately 40 OD_{600}, magnesium salts and $NaH_2PO_4.H_2O$ were added. Further additions of $NaH_2PO_4.H_2O$ were made prior to and during the induction phase to ensure phosphate was maintained in excess. When the glycerol present at the beginning of fermentation had depleted (approximately 75 OD_{600}) a continuous feed of 80% (w/w) glycerol was applied. At the same point in the fermentation an IPTG feed at 170μM was applied. The start of IPTG feeding was taken as the start of induction. Fermentations were typically run for 70-73 hours at the lower glycerol feed rates (0.5-2.5 ml/h) and 50-60 h at the higher glycerol feed rates (5.4-10.9 ml/h).

Measurement of biomass concentration and growth rate. Biomass concentration was determined by measuring the optical density of cultures at 600 nm.

Periplasmic Extraction. Cells were collected from culture samples by centrifugation. The supernatant fraction was retained (at -20°C) for further analysis. The cell pellet fraction was resuspended to the original culture volume in extraction buffer (100 mM

Tris-HCl, 10 mM EDTA; pH 7.4). Following incubation at 60°C for approximately 16 hours the extract was clarified by centrifugation and the supernatant fraction retained (at -20°C) for analysis.

Fab' quantification. Fab' concentrations in periplasmic extracts and culture supernatants were determined by Fab' assembly ELISA as described in Humphreys *et al.*, 2002, Protein Expression and Purification, 26, 309-320.

Figure 9 shows the growth profile of MXE001 compared to control W3110 which shows that the growth profiles are substantially the same for approximately 35 hours.

Figure 10 shows Fab yield from the supernatant (dotted lines) and periplasm (solid lines) from *E. coli* strain MXE001 compared to control W3110. The MXE001 strain shows higher periplasmic Fab' expression up to approximately 30 hours and significantly higher supernatant Fab' expression over the whole fermentation period.

Figure 11 shows the total Fab' yield from the supernatant and periplasm of the *E. coli* strain MXE001 compared to control W3110 where it can be seen that the MXE005 strain produced higher Fab' yield compared to the control W3110.

Figure 12 shows the Fab' specific production rate of *E. coli* strain MXE001 compared to the control W3110 where it can be seen that MXE001 has significantly higher specific production rate compared to W3110.

Figure 13 shows the growth profile of MXE004 and MXE005 compared to control W3110. The growth profiles of MXE004 and MXE005 are faster over the initial period of approximately 35 hours compared to the control W3110.

Figure 14 shows Fab' yields from the supernatant (dotted lines) and periplasm (solid lines) of *E. coli* strains MXE004, MXE005 and the W3110 control. The MXE005 strain shows higher Fab' yield from the periplasm for approximately 28 hours compared to the control and significantly higher supernatant Fab' yield compared to the control over the whole fermentation period. The MXE004 strain shows higher Fab' yield from the periplasm for approximately 20 hours compared to the control and

significantly higher supernatant Fab' yield compared to the control over the whole fermentation period.

Figure 15 shows the total Fab' yield from the supernatant and periplasm of the *E. coli* strains MXE004 and MXE005 where it can be clearly seen that the MXE004 and MXE005 strains produced significantly higher yield compared to the control.

Figure 16 shows the Fab' specific production rate of *E. coli* strains MXE004 and MXE005 and the W3110 control where it can be seen that MXE004 and MXE005 have a significantly higher specific production rate compared to W3110.

Example 7 – Growth of mutated *E. coli* strains MXE001, MXE004 and MXE005 compared to W3110 and highly mutated *E. coli* strains in shake flask experiment

The following strains were analyzed in a shake flask experiment to assess growth rate:
Mutated *E. coli* strains MXE001, MXE004 and MXE005 derived from W3110 (Example 1)
Wild-type *E. coli* strain W3110
SURE (Stratagene) having genotype: endA1 glnV44 thi-1 gyrA96 relA1 lac recB recJ sbcC umuC::Tn5 uvrC e14- Δ(mcrCB-hsdSMR-mrr)171 F'[$proAB^+$ $lacI^q$ lacZΔM15 Tn10]
STBL3 (Invitrogen) having genotype: F- glnV44 recA13 mcrB mrr hsdS20(rB-, mB-) ara-14 galK2 lacY1 proA2 rpsL20 xyl-5 leu mtl-1
TOP10 (Invitrogen) having genotype: F- mcrA Δ(mrr-hsdRMS-mcrBC) φ80lacZΔM15 ΔlacX74 nupG recA1 araD139 Δ(ara-leu)7697 galE15 galK16 rpsL(Str^R) endA1 λ^-
and
XL1-Blue (Stratagene) having genotype endA1 gyrA96(nal^R) thi-1 recA1 relA1 lac glnV44 F'[::Tn10 $proAB^+$ $lacI^q$ Δ(lacZ)M15] hsdR17(r_K^- m_K^+)

A single colony was picked into 5ml of LB broth (10 g Tryptone, 5 g yeast extract, 10 g Na Cl per litre) and grown overnight at 37°C with shaking at 250rpm. The overnight culture was used to inoculate 75ml of LB broth to an OD_{660} of 0.1 (n=2). The cultures were grown at 37°C with shaking at 250rpm, 0.2ml samples were

removed every hour and the OD_{600} recorded. The OD600 was then plotted against time in hours and the results are shown in Figure 17. It can be seen from Figure 17 that the heavily mutated *E. coli* strains have a lower growth rate compared to MXE001, MXE004, MXE005 and W3110.

While this invention has been particularly shown and described with reference to preferred embodiments, it will be understood to those skilled in the art that various changes in form and detail may be made without departing from the scope of the invention as defined by the appendant claims.

Claims:

1. A recombinant gram-negative bacterial cell comprising:

    a. a knockout mutated Tsp gene comprising a mutation to the gene start codon and/or one or more stop codons positioned downstream of the gene start codon and upstream of the gene stop codon; and

    b. optionally a mutated DegP gene encoding a DegP protein having chaperone activity and 50% or less protease activity of the protease activity of a wild-type non-mutated DegP protein;

wherein the cell is isogenic to *E. coli* cell W3110 except for the one or more mutated protease genes and optionally a polynucleotide sequence encoding a protein of interest.

2. A recombinant gram-negative bacterial cell according to claim 1 further comprising a knockout mutated ptr gene comprising a mutation to the gene start codon and/or one or more stop codons positioned downstream of the gene start codon and upstream of the gene stop codon.

3. A cell according to claim 1, wherein the cell is strain MXE001 (Accession Number NCTC13444).

4. A cell according to any of claim 1 or 2, wherein the cell comprises a mutated DegP gene encoding a DegP protein having chaperone activity but not protease activity and a knockout mutated Tsp gene.

5. A cell according to claim 4, wherein the cell is strain MXE005 (Accession Number NCTC13448).

6. A cell according to any of claim 1 or 2, wherein the cell comprises a knockout mutated ptr gene and a knockout mutated Tsp gene.

7. A cell according to claim 6, wherein the cell is strain MXE004 (Accession Number NCTC13447).

8. A cell according to any preceding claim, wherein the mutated DegP gene, the mutated ptr gene and/or the mutated Tsp gene are mutated to comprise one or more restriction marker sites.

9. A cell according to claim 8, wherein the knockout mutated ptr gene and/or the knockout mutated Tsp gene are mutated to comprise a restriction marker site comprising an in-frame stop codon.

10. A cell according to claim 8, wherein the restriction marker site is an *Ase I* restriction site.

11. A cell according to any of claims 8 to 10, wherein the knockout mutated ptr gene and/or the knockout mutated Tsp gene comprise a restriction marker site created by a missense mutation to the gene start codon and optionally one or more further point mutations.

12. A cell according to claim 11, wherein the restriction marker site is an *EcoR I* marker site.

13. A cell according to any of claims 2, 4, 6 or 7 to 12, wherein the knockout mutated ptr gene comprises SEQ ID NO:6.

14. A cell according to any of claims 1 to 12, wherein the knockout mutated Tsp gene comprises SEQ ID NO:3.

15. A cell according to any of claims 1, 2, 4, 5, 8, or 10, wherein the mutated DegP gene comprises the mutation S210A.

16. A cell according to claim 15, wherein the mutated DegP gene comprises SEQ ID NO:9.

17. A cell according to any preceding claim, wherein the cell further comprises a polynucleotide sequence encoding a protein of interest.

18. A cell according to claim 17, wherein the polynucleotide sequence encoding the protein of interest is exogenous.

19. A cell according to claim 18, wherein the cell comprises an expression cassette or a vector comprising the polynucleotide sequence encoding the protein of interest.

20. A cell according to any of claims 17 to 19, wherein the protein of interest is an antibody or an antigen binding fragment thereof.

21. A cell according to claim 20, wherein the antibody or antigen binding fragment thereof is specific for TNF.

22. A method for producing a recombinant protein of interest comprising expressing the recombinant protein of interest in a recombinant gram-negative bacterial cell as defined in any of claims 1 to 21.