Gram-negative bacteria associated with brewery yeasts: reclassification of *Obesumbacterium proteus* biogroup 2 as *Shimwellia pseudoproteus* gen. nov., sp. nov., and transfer of *Escherichia blattae* to *Shimwellia blattae* comb. nov.

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Phylogenetic analyses of type and reference strains of *Obesumbacterium proteus* biogroups 1 and 2 plus a novel isolate of biogroup 2 were carried out based on 16S rRNA gene sequences and partial sequences of four protein-coding genes (fusA, leuS, pyrG and rpoB). Both approaches revealed that *O. proteus* biogroup 1 strains were closely related to *Hafnia alvei*. Biogroup 2 strains, however, formed a distinct monophyletic clade of generic status that included *Escherichia blattae*. Phenotypic tests were consistent with the molecular classification and provided diagnostic features. It is proposed that biogroup 2 strains be placed in a new genus, *Shimwellia* gen. nov., as *Shimwellia pseudoproteus* sp. nov., with strain 521T (=DSM 3083T=LMG 24835=NCIMB 14534) as the type strain, and that *Escherichia blattae* be transferred to the genus *Shimwellia* as *Shimwellia blattae* comb. nov., with strain ATCC 29907T (=DSM 4481T) as the type strain.

These bacteria were first isolated in pure culture in 1936 and classified as *Flavobacterium proteus* (Shimwell, 1936; Shimwell & Grimes, 1936). Later, the genus *Obesumbacterium* was created for these bacteria, with *Obesumbacterium proteus* as the sole species (Shimwell, 1963, 1964). More detailed taxonomic investigation assigned *Obesumbacterium* to the *Enterobacteriaceae* and revealed two distinct taxa within *O. proteus*, referred to as biogroups 1 and 2 (Priest et al., 1973). These two biogroups have been substantiated by various phenotypic (Prest et al., 1994; van Vuuren et al., 1981) and molecular methods such as ribotyping (Koivula et al., 2006; Prest et al., 1994) and PCR procedures (Maugeret & Walker, 2002). DNA–DNA hybridization studies indicated that biogroup 1 strains share 75–78 % renaturation with *Hafnia alvei* and that biogroup 2 strains have an affinity with *Escherichia blattae*, a bacterium isolated from the hindgut of cockroaches (Burgess et al., 1973; Brenner, 1981). In this study, the almost complete sequences of the 16S rRNA genes and partial sequences of four protein-coding genes (fusA, leuS, pyrG and rpoB) of reference strains of *O. proteus*, a novel isolate of biogroup 2 from brewery yeast, and the type strain of *Escherichia blattae* have been determined. Phylogenetic analyses using these and reference sequences confirmed that *O. proteus* biogroup 1 is closely related to *Hafnia alvei*, but revealed that *O. proteus* biogroup 2 strains and *Escherichia blattae* are phylogeneti-

Traditional beer brewing practice involves using a portion of the yeast harvested from a current fermentation as inoculum for the next fermentation. However, this leads to the accumulation of Gram-negative bacteria with the yeast and, after about 10 fermentations, the extent of contamination is such that the yeast is generally discarded in favour of a new, pure-culture inoculum, or it is treated with acid to destroy the contaminating bacteria (Strandskov et al., 1953; Van Vuuren & Priest, 2003). These bacteria were first isolated in pure culture in 1936 and classified as *Flavobacterium proteus* (Shimwell, 1936; Shimwell & Grimes, 1936). Later, the genus *Obesumbacterium* was created for these bacteria, with *Obesumbacterium proteus* as the sole species (Shimwell, 1963, 1964). More detailed taxonomic investigation assigned *Obesumbacterium* to the *Enterobacteriaceae* and revealed two distinct taxa within *O. proteus*, referred to as biogroups 1 and 2 (Priest et al., 1973). These two biogroups have been substantiated by various phenotypic (Prest et al., 1994; van Vuuren et al., 1981) and molecular methods such as ribotyping (Koivula et al., 2006; Prest et al., 1994) and PCR procedures (Maugeret & Walker, 2002). DNA–DNA hybridization studies indicated that biogroup 1 strains share 75–78 % renaturation with *Hafnia alvei* and that biogroup 2 strains have an affinity with *Escherichia blattae*, a bacterium isolated from the hindgut of cockroaches (Burgess et al., 1973; Brenner, 1981). In this study, the almost complete sequences of the 16S rRNA genes and partial sequences of four protein-coding genes (fusA, leuS, pyrG and rpoB) of reference strains of *O. proteus*, a novel isolate of biogroup 2 from brewery yeast, and the type strain of *Escherichia blattae* have been determined. Phylogenetic analyses using these and reference sequences confirmed that *O. proteus* biogroup 1 is closely related to *Hafnia alvei*, but revealed that *O. proteus* biogroup 2 strains and *Escherichia blattae* are phylogeneti-
Bacteria were grown routinely on nutrient agar at 30 °C. They included *O. proteus* biotype 1 strain NCIMB 8771<sup>T</sup> and two biotype 1 isolates from ale brewery yeasts from the UK, strains 511 and 540 (=LMG 3048) (Priest et al., 1973). *O. proteus* biotype 2 strain 521 (=DSM 3038=LMG 24835) has been described previously (Pриest et al., 1973). *Escherichia blattae* DSM 4481<sup>T</sup> was obtained from the DSMZ, Braunschweig, Germany. *O. proteus* Am-4 (available as LMG 24836) was isolated from ale brewery yeast from Edinburgh; the yeast sample was plated directly on MacConkey agar supplemented with 25 μg cycloheximide ml<sup>−1</sup> and incubated at 30 °C for 2 days. Small, lactose-negative colonies were purified by plating on the same medium. DNA was prepared from strains grown in nutrient broth for 18 h at 30 °C. The culture (2 ml) was centrifuged and DNA was isolated using a PureGene isolation kit as described by the manufacturer. 16S rRNA genes were amplified and sequenced using standard primers at an annealing temperature of 56 °C: 27F, 5'-AGAGTTTGATCMTGGCTCAG-3'; 926F, 5'-AAACCTCA-AGGAATTGACGG-3'; 685R3, 5'-TCTACGAGTTTACGACTT-CCGTAC-3'; 1100R, 5'-GGGTGCGCTCGTGTG-3' and 1492R, 5'-TACGGYTACTGTTAGACTT-3'. Genes for *fusA*, *leuS*, *pyrG* and *rpoB* were amplified and sequenced using the primers described by Salerno et al. (2007) (annealing temperatures in parentheses): *fusA*3-*fusA*4 (58 °C), *leuS*3-*leuS*4 (58 °C), *pyrG*3-*pyrG*4 (55 °C) and *vic*4-*vic*6 (55 °C). PCR mixtures (50 μl) contained 0.2 mM of each nucleotide in 10 × NH<sub>4</sub> buffer (Bioline), 0.25 μM primers, 2.5 mM MgCl<sub>2</sub> for protein-coding genes (2.0 mM MgCl<sub>2</sub> for 16S rRNA genes), and ~100 ng DNA template, made up to 49.7 μl with sterile deionized water. The PCR comprised denaturation at 95 °C for 5 min, followed by the addition of 0.3 μl Biotaq enzyme (5 U μl<sup>−1</sup>; Bioline). There were 30 cycles of denaturation at 95 °C for 1 min, annealing for 2 min and elongation at 72 °C for 2 min. Final elongation was at 72 °C for 10 min and samples were stored at 4 °C. Amplification products were checked using agarose gel electrophoresis, purified by polyethylene glycol precipitation (Embley, 1991) and sequenced by MWG Biotech. Forward and reverse sequences were assembled using STADEN software.

16S rRNA gene sequences (1349–1352 bases) for representative *Enterobacteriaceae* species were obtained from GenBank. Wherever possible, sequence data from the type strains were chosen and strains were selected to match the multilocus sequence typing (MLST) data of Salerno et al. (2007). Details of the strains used and accession numbers of the gene sequences are given in Supplementary Table S1 (available in IJSEM Online). Sequences were aligned using CLUSTAL_X and neighbour-joining trees were constructed. The trees were visualized using TREEVIEW 1.6.6 (Page, 1996). Bootstrap values (%) were determined for 1000 replications using CLUSTAL_X. Maximum-parsimony trees were constructed using MEGA version 4 (Tamura et al., 2007).

The four protein-coding alleles were concatenated to provide sequences of 2082 bases (*fusA*, 633; *leuS*, 642; *pyrG*, 306; and *rpoB*, 501), with the exception of *Haemophilus influenzae* Rd KW20, which was 2085 bases due to a 3 bp insertion in *rpoB*. Nucleotide sequences for MLST were obtained from GenBank (EU010012–EU010119). Sequences were aligned and neighbour-joining trees were constructed as described above.

Yeast from three breweries in the south of Scotland was examined for the presence of Gram-negative bacteria by culturing on MacConkey agar containing cycloheximide to inhibit yeast growth. Only one sample contained lactose-negative bacteria typical of *O. proteus*, which were recovered in pure culture as strain Am-4. The bacterium was isolated from the only brewery that did not practice acid-washing of its yeast to remove contaminating organisms. Almost complete 16S rRNA gene sequences (1412–1496 bases) were prepared from: *O. proteus* biogroup 1 strains NCIMB 8771<sup>T</sup>, 511 and 540; *O. proteus* biogroup 2 strains 521 and Am-4; and *Escherichia blattae* DSM 4481<sup>T</sup>. The sequences were aligned with 16S rRNA gene sequences of representatives of the *Enterobacteriaceae* and a phylogenetic tree was constructed (Fig. 1). This revealed that the two biogroups of *O. proteus* were distantly related. The three biogroup 1 strains had identical 16S rRNA genes that showed 99% similarity with that of *Hafnia alvei* ATCC 13337<sup>T</sup>. In the *O. proteus* NCIMB 8771<sup>T</sup> sequence of 1436 bases, there were seven ambiguous bases at positions 434 (A or G), 971 (A or G), 972 (G or C), 973 (C or T), 980 (A or G), 981 (G or C) and 982 (C or T). These probably represent intragenomic variation in the rRNA genes since they lie in regions (H17 and H33) noted for such heterogeneity (Case et al., 2007). The two 16S rRNA gene sequences from *O. proteus* biogroup 2 strains 521 and Am-4 were identical and shared 99% similarity with that of *Escherichia blattae* DSM 4481<sup>T</sup>. Moreover, the *Escherichia blattae* 16S rRNA gene sequence shared little similarity with those of the type strains of *Escherichia coli* and *Escherichia fergusonii* (95 and 96%, respectively) showing that the bacterium is incorrectly placed in the genus *Escherichia*. Trees constructed using maximum-parsimony were similar topologically to the neighbour-joining tree and, in particular, confirmed that *O. proteus* biogroup 1 strains were closely related to *Hafnia alvei* with *Serratia liquefaciens* as a close relative, whereas the biogroup 2 strains included *Escherichia blattae* and formed a cluster with *Erwinia amylovora* and representatives of the genus *Pantoeca* (data not shown).

To understand the phylogenetic positions of the *O. proteus* biogroups in more detail, the four protein-coding genes as used for the MLST of *Plesiomonas shigelloides* (Salerno et al., 2007) were analysed. The fifth gene from the MLST study, *recG*, was not amplified in our strains using the recommended primers. Trees derived from the individual gene sequences, together with reference sequences from GenBank, showed limited topological variation suggesting limited horizontal gene transfer (data not shown). A
consensus tree derived from the concatenated gene sequences is shown in Fig. 2. The three *O. proteus* biogroup 1 strains had identical sequences for all alleles, as did the two biogroup 2 strains. The MLST tree supported the 16S rRNA gene tree and again showed that the two biogroups of *O. proteus* are phylogenetically distinct: biogroup 1 strains were closely related to *Hafnia alvei*, whereas the biogroup 2 strains formed a monophyletic group with *Escherichia blattae*. As with the rRNA tree, *Escherichia blattae* was distinct phylogenetically from other species of the genus *Escherichia*.

Protein-coding genes tend to accumulate more mutations than rRNA genes and can provide insight into species relationships at a higher resolution than rRNA genes. Alignments of the MLST fragments (2082 bases) were compared for all cases in which there was more than one species representing a genus. The two most closely related species within a genus were *Escherichia coli* and *Escherichia fergusonii* (98 %) and the two most distant species within a genus were *Pantoea agglomerans* and *Pantoea stewartii* subsp. *stewartii* (86 %). For the 12 comparisons covering *Citrobacter*, *Escherichia*, *Enterobacter*, *Pantoea* and

**Fig. 1.** Neighbour-joining tree of representative strains from the *Enterobacteriaceae* using almost complete 16S rRNA gene sequences. Numbers at nodes are bootstrap values (%; 1000 replicates). Bar, 0.01 nt substitutions per site.
Salmonella species, the mean similarity over the 2082 bases was 92.2% (3.25 standard deviation). In this context, O. proteus biogroup 2 strains and Escherichia blattae shared 93% similarity, providing convincing evidence that they represent distinct species.

The molecular classification of these bacteria is generally supported by phenotype. The original numerical classification adequately separated O. proteus biotypes 1 and 2 and key diagnostic tests are shown in Table 1. Phenotypic descriptions of these bacteria based on larger numbers of strains have been published by Priest et al. (1973), van Vuuren et al. (1981) and Farmer & Brenner (2005).

The genus Obesumbacterium has been associated with brewery yeasts for more than 40 years and we have shown that biogroup 2 strains, at least, still occupy this environmental niche. Biogroup 1 strains are less common in breweries than those of biogroup 2 (Priest et al., 1973) and have also been associated with the intestines of fish (Skrodenyte-Arbaciauskiene et al., 2006) and edible snails (Charrier et al., 2006), whereas biogroup 2 strains have not

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**Fig. 2.** Neighbour-joining tree of representative strains from the Enterobacteriaceae using the concatenated sequences of four loci (fusA, leuS, pyrG and rpoB). With the exception of Morganella morganii subsp. morganii, strains used are the same as those for Fig. 1, but in some cases type strains were from different culture collections (see Supplementary Table S1 available in IJSEM Online). Numbers at nodes are bootstrap values (%; 1000 replicates). Bar, 0.05 nt substitutions per site.
Escherichia blattae is transferred to the genus Shimwellia as Shimwellia blattae comb. nov. Phenotypic features that distinguish these taxa are shown in Table 1.

### Description of Shimwellia gen. nov.


Cells are non-motile, straight Gram-stain-negative rods that occur singly. Members conform to the general description of the family Enterobacteriaceae. Aerobic and facultatively anaerobic. Oxidase-negative and catalase-positive, although this reaction is delayed and weak in the type species. Cells reduce nitrate to nitrite, do not grow in KCN and do not produce H₂S. The type species is Shimwellia pseudoproteus.

### Description of Shimwellia pseudoproteus sp. nov.

Shimwellia pseudoproteus (pseudo.pro’tæ.us. Gr. adj. pædes false; L. n. proteus the ancient sea-god, noted for being able to change his form at will, and also a bacterial epithet; N.L. masc. n. pseudoproteus, the false [Obesumbacterium] proteus).

This description is taken from Priest et al. (1973), Brenner (1981) and Farmer & Brenner (2005). Displays the following properties in addition to those given in the genus description. There is a tendency for shapes to be pleomorphic on initial isolation. Mesophilic with optimum growth near 30 °C and between pH 4.5 and 8.0. After growth on nutrient agar for 48 h, cells form small, circular, entire colonies, 1.0–1.5 mm in diameter with a convex elevation and smooth glassy surface. Acid, but no gas, is produced from glucose, rhamnose and trehalose. No acid is produced from lactose, mannitol, salicin or numerous other sugars. Does not utilize malonate. Arginine dihydrolase-negative, lysine decarboxylase-positive. Voges–Proskauer-negative. The DNA G+C content is 48 ± 1 mol%.

The type strain is 521T (=DSM 3038T =LMG 24835T =NCIMB 14534T), isolated from ale brewery yeast in Birmingham, UK. Strain Am-4 is an additional strain of the species.

### Emended description of Shimwellia blattae comb. nov.

Shimwellia blattae (blat’æe. L. fem. n. blatta cockroach; L. gen. n. blattae of the cockroach).


The description is the same as that given by Burgess et al. (1973) and Scheutz & Stockbine (2005) with the following additional properties, including those given in the genus description. After growth on nutrient agar for 48 h, colonies are 1–5 mm diameter, circular, smooth, glossy, creamy in colour with a convex elevation and an entire margin. Acid and gas are produced from glucose; acid is

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**Table 1. Differential phenotypic characteristics of Obesumbacterium proteus biogroup 1, Shimwellia pseudoproteus sp. nov., Shimwellia blattae comb. nov. and Hafnia alvei**

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<td>Motility (24 h)</td>
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<td>Voges–Proskauer test</td>
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*The catalase reaction is weak and delayed by about 30 s.*

been isolated outside the brewery. The original *O. proteus* isolate of Shimwell has been lost (Farmer & Brenner, 2005) and the current type strain was provided by F. B. Strandskov and J. B. Bockelmann, who isolated the bacterium from yeast in their North American brewery, although its similarity to the original isolate was substantiated by J. L. Shimwell. However, the descriptions at that time were limited and, as discussed by Farmer and Brenner, were not definitive (Farmer & Brenner, 2005). So we do not know whether Shimwell’s original isolates were of biogroup 1 or 2. Farmer & Brenner (2005) refer to *O. proteus* biogroup 1 strains as *Hafnia alvei* biogroup 1 because of their close relationship with *Hafnia alvei*.

The type strain is 521T ( =DSM 3038T =LMG 24835T =NCIMB 14534T), isolated from ale brewery yeast in Birmingham, UK. Strain Am-4 is an additional strain of the species.
produced from L-arabinose, glycerol, D-mannose, L-rhamnose and D-xylose. Methyl-red-positive, indole-negative. Arginine dihydrolase-negative; positive for lysine and ornithine decarboxylases. Voges–Proskauer-negative. The DNA G+C content has not been determined.

The type strain is ATCC 29907T (= CDC 9005-74T = CIP 103175T = CIP 104942T = DSM 4481T = HAMBI 1692T = JCMI 1650T = LMG 3030T = NCTC 12127T).

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References


