UNIVERSITY OF KWAZULU-NATAL

CYTOCHROME P450 MONOOXYGENASE CYP139 FAMILY INVOLVED IN THE SYNTHESIS OF SECONDARY METABOLITES IN MYCOBACTERIAL SPECIES

By

PULENG ROSINAH SYED

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A thesis submitted to the School of Health Science, Discipline of Pharmaceutical science, Department of Pharmaceutical Chemistry, University of KwaZulu-Natal, Westville, for the Master's degree.

This thesis has been prepared according to Format 4 (Thesis by publications) as outlined in the guidelines of College of Health Sciences, University of KwaZulu-Natal. The chapters consist of an overall of 5 chapters which includes: Thesis overall, introduction; literature review; experimental; result and discussion and conclusion.

As the candidate's supervisor, I have approved this thesis for examination/submission.

Supervisor: Prof Rajshekhar Karpoormath Signed: [redacted] 19/August/2019

ABSTRACT

Tuberculosis (TB) is one of the top infectious diseases causing numerous human deaths in the world. Despite enormous efforts, the physiology of the causative agent, *Mycobacterium tuberculosis*, is still poorly understood. To contribute to better understanding the physiological capacity of these microbes, we have carried out extensive *in silico* analyses of the 1111 mycobacterial species genomes focusing on revealing the role of the orphan cytochrome P450 monooxygenase (CYP) CYP139 family. We have found that CYP139 members are present in 894 species belonging to three mycobacterial groups: *M. tuberculosis* complex (850-species), *Mycobacterium avium* complex (34-species), and non-tuberculosis mycobacteria (10-species), with all CYP139 members belonging to the subfamily "A". CYP139 members have unique amino acid patterns at the CXG motif. Amino acid conservation analysis placed this family in the 8th among CYP families belonging to different biological domains and kingdoms. Biosynthetic gene cluster analyses have revealed that 92% of CYP139As might be associated with producing different secondary metabolites. Such enhanced secondary metabolic potentials with the involvement of CYP139A members might have provided mycobacterial species with advantageous traits in diverse niches competing with other microbial or viral agents, and might help these microbes infect hosts by interfering with the hosts' metabolism and immune system.

Keywords: Biosynthetic gene clusters; Cytochrome P450 monooxygenase; CYP139A1; Genome data mining; Host metabolism; *Mycobacterium tuberculosis*; Polyketides; Secondary metabolites; Tuberculosis

DECLARATION – PLAGIARISM

I, **PULENG ROSINAH SYED**, declare that

i. The research reported in this dissertation, except where otherwise indicated, is my original work.

ii. This dissertation has not been submitted for any degree or examination at any other university.

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Date: 17 August 2019

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"Education is the most powerful weapon which you can use to change the world."

Nelson Mandela

RESEARCH OUTPUTS

1. **Syed PR,** Wanping C, Nelson DR, Kappo AP, Yu JH, Karpoormath R, Syed K. **2019.** Cytochrome P450 monooxygenase CYP139 family involved in the synthesis of secondary metabolites in 824 mycobacterial species. International Journal of Molecular Sciences, 20(11). pii: E2690. doi: 10.3390/ijms20112690.

2. Senate LM, Tjatji MP, Pillay K, Chen W, Zondo NM, **Syed PR,** Mnguni FC, Chiliza ZE, Bamal HD, Karpoormath R, Khoza T, Mashele SS, Blackburn JM, Yu JH, Nelson DR, Syed K. **2019**. Similarities, variations, and evolution of cytochrome P450s in *Streptomyces versus Mycobacterium*. Scientific reports, 9(1):3962; doi: 10.1038/s41598-019-40646-y.

3. Mthethwa B, Chen W, Ngwenya M, Kappo A, **Syed PR,** Karpoormath R, Yu JH, Nelson DR, Syed, K., **2018.** Comparative analyses of cytochrome P450s and those associated with secondary metabolism in *Bacillus* species. International journal of molecular sciences, 19(11). pii: E3623. doi: 10.3390/ijms19113623.

LIST OF ABBREVIATIONS

anti-SMASH	Antibiotics and secondary metabolite analysis shell
BGCs	Biosynthetic gene clusters
BLAST	Basic local alignment search tool
CYP/P450	Cytochrome P450 monooxygenase
HIV	Human immunodeficiency virus
IMG/M	Integrated Microbial Genomes and Microbiomes
JGI/DOE	Joint Genome Institute, Department of Energy, USA
M. tuberculosis	*Mycobacterium tuberculosis*
MAFFT	Multiple alignment using fast Fourier transform
MAV	*Mycobacterium avium* complex
MCAC	*Mycobacterium chelonae-abscessus* complex
MCL	*Mycobacterium* causing leprosy
MTBC	*Mycobacterium tuberculosis* complex
nm	Nanometer
NTM	Non-tuberculosis mycobacteria
PROMALS3D	PROfile multiple alignment with local structures and 3D constraints
SAP	Saprophytes
SSA	Statistics South Africa
TB	Tuberculosis
WHO	World Health Organization

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CHAPTER 1: THESIS OVERVIEW

1.1. Background

The actinomycete *Mycobacterium tuberculosis* that causes tuberculosis (TB), a chronic lung disease in humans, remains one of the greatest threats to mankind (Quan et al., 2017, WHO, 2018). The latest data from Statistics South Africa showed that TB is one of the top killers in South Africa (SSA, 2018), suggesting an urgent need to understand *M. tuberculosis* physiology to be able to come up with novel drugs and drug targets. However, after 19 years of *M. tuberculosis* genome sequencing (Cole et al., 1998), its physiology is still poorly understood and most of the proteins remain orphans. World-wide researchers, including South African researchers, are making serious efforts to understand the function of orphan proteins in *M. tuberculosis* physiology in the hope of finding novel drug targets, enabling them to develop novel drugs.

M. tuberculosis genome sequencing analysis revealed the presence of 20 cytochrome P450 monooxygenases (CYPs/P450s) in its genome (Cole et al., 1998). P450s are heme-thiolate proteins that are ubiquitously present in organisms belonging to all domains, including non-living entities such as viruses (Lamb et al., 2009, Nelson, 2018). It is now well established that P450s serve as drug target against pathogens, including *M. tuberculosis* (Ortiz de Montellano, 2018). Apart from six P450s, to date all *M. tuberculosis* P450s remain orphans (Ortiz de Montellano, 2018). This study is aimed at understanding the role of the orphan P450 family CYP139 in mycobacterial species physiology.

In this study, the functional role of CYP139 P450s in mycobacterial species was identified using *in silico* genome data mining and biosynthetic gene cluster analysis. Based on the study results, it is assumed that CYP139A P450s play a role in the synthesis of different secondary metabolites that help in mycobacterial species pathogenesis.

1.2. Rationale for the study

The advancement of genome sequencing and bioinformatics tools helps significantly in understanding the role of orphan proteins in organisms. This study is an attempt to utilize the availability of quite a large number of mycobacterial species' genome sequences and different bioinformatics tools to understand the role of the orphan CYP139 family in mycobacterial species. The availability of a large number of mycobacterial species' genomes for public use at different databases (Kanehisa et al., 2016, Chen et al., 2019) will give researchers an opportunity to predict the role of orphan P450s such as CYP139 P450 in mycobacterial species physiology.

1.3. Problem statement

Apart from six P450s, to date all *M. tuberculosis* P450s remain orphans (Ortiz de Montellano, 2018). This study is aimed at understanding the role of the orphan P450 CYP139A1 in *M. tuberculosis* physiology. The *CYP139A1* gene was found downstream of polyketide synthase genes (*pks10*, *pks7*, *pks8*, *pks17*, *pks9* and *pks11*) and situated next to macrolide transport protein (Ouellet et al., 2010). Two of the polyketide synthases *pks7* and *pks8* were found to be essential for survival of *M. tuberculosis* (Sassetti et al., 2003, Griffin et al., 2011). Based on its location, CYP139A1 is assumed to be involved in oxidative tailoring of macrolide antibody. However, to date, functional analysis of CYP139 P450s has not been reported.

1.4 Aims and objectives

1.4.1. Aim of the study

The aim of this study is to predict the functional role of CYP139 P450s in mycobacterial species physiology.

1.4.2. Objectives

- To perform genome data-mining for identification of CYP139 P450s in mycobacterial species.
- To perform annotation (assigning P450 family and subfamilies) to the identified CYP139 P450s.
- To perform phylogenetic analysis of CYP139 P450s.

- To identify secondary metabolite biosynthetic gene clusters that has *CYP139* P450 genes.
- To predict the functional role of CYP139 P450s in mycobacterial species physiology.

1.5. Overview of the thesis

This thesis has five chapters, outlined as follows:

Chapter 1: This chapter addresses the background, aim, objectives and structure of the thesis.

Chapter 2: **(Published work – most of the information is presented in the required format of the journal and is the final version of the published manuscript, except for bibliography and figures that have been included in the chapter)**

The chapter provides an overview of cytochrome P450s, their catalytic diversity, their applications and their use as drug targets in dealing with *Mycobacterium tuberculosis*, its impact in the world and the role of P450s in its physiology, as well as justification for the research presented in this thesis.

Chapter 3: **(Published work - this chapter is presented in the required format of the journal and is the final version of the published manuscript, except for bibliography and tables that have been included in the chapter)**

This chapter describes the methodology used in the study. The chapter includes information on species used in the study, the procedure for data mining and annotation of CYP139 P450s, phylogenetic analysis, analysis of homology and amino acid conservation, generation of EXXR and CXG P450 logos and identification of CYP139 P450s that are part of different secondary metabolite clusters.

Chapter 4: **(Published work - this chapter is presented in the required format of the journal and is the final version of the published manuscript except for bibliography and supplementary tables that have been included in the chapter)**

This chapter highlights the results obtained during the course of the research and a discussion of these. The distribution of CYP139 in different mycobacterial categories, CYP139 P450s annotation and phylogenetic analysis, CYP139 P450s characteristic P450 motif EXXR and CXG consensus sequences, the place of the CYP139 family in P450 families found in species from

different biological kingdoms and the role of CYP139 P450 in mycobacterial physiology with an example of its possible role in pathogenesis are described.

Chapter 5: (Published work - this chapter is presented in the required format of the journal and is the final version of the published manuscript except conclusion and future studies were separated in the chapter)

This chapter focuses on general concluding remarks and the future scope of the research work, which includes validation of results identified in this study using wet laboratory experiments and structural and functional analysis of CYP139 P450 from *M. tuberculosis H37Rv*.

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CHAPTER 2: INTRODUCTION

2.1. Cytochrome P450 monooxygenases

Cytochrome P450 monooxygenases (CYPs/P450s) are heme-thiolate proteins found in all forms of life on earth (Nelson, 2018) and in non-living entities such as viruses (Lamb et al., 2009). These proteins belong to the superfamily of oxidoreductases and contain heme as a prosthetic group (Klingenberg, 1958, Omura and Sato, 1962, Omura, 2011). The presence of heme moiety as a prosthetic group relates these proteins to a characteristic spectrum known as the P450 carbon monoxide-differential spectrum, where these proteins absorb wavelength at 450 nanometer (nm), thus the name implies "P" for "protein" and 450 for wavelength absorption at 450 nm (Klingenberg, 1958, Omura and Sato, 1962, Omura, 2011) (Figure 2.1). Initially these proteins were found to be involved in a monooxygenase reaction, i.e. insertion of one atom of oxygen into the aliphatic position of an organic substrate [RH], while the other oxygen atom is reduced to water, as in the following reaction (Sono et al., 1996, Bernhardt, 2006):

$$NADPH + H^+ + O_2 + RH \rightarrow NADP^+ + H_2O + ROH.$$

In the reaction, RH represents an oxidisable drug substrate and ROH is the hydroxylated metabolite, the overall reaction being catalysed by the enzyme P450. Because of this type of reaction, "monooxygenase" has also been ascribed to the name. Thus the full name of the proteins is cytochrome P450 monooxygenases (Klingenberg, 1958, Omura and Sato, 1962, Omura, 2011).

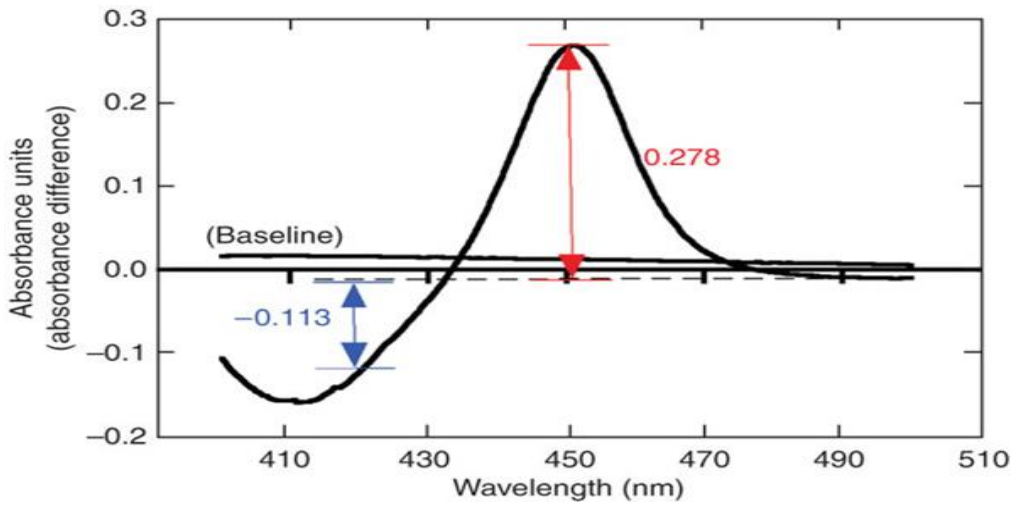

Figure 2. 1 Typical cytochrome P450 monooxygenase ferrous-CO versus ferrous-difference spectrum (Guengerich et al., 2009).

Apart from the monooxygenase reaction, P450s were found to perform a large number of different types of enzymatic reactions with stereo- and regio-specific activity (Sono et al., 1996, Bernhardt, 2006, McLean et al., 2015) (Figure 2.2). Because of this property these enzymes have been in the limelight for more than five decades (Yamazaki, 2014) and researchers across the world are still exploring the applications of these enzymes.

Hydrocarbon hydroxylation
Alkene epoxidation
Alkyne oxygenation
Arene epoxidation
Aromatic hydroxylation
N-Dealkylation
S- Dealkylation
O- Dealkylation
N-Hydroxylation
N-Oxidation
S-Oxidation
Oxidative deamination
Oxidative dehalogenation
Alcohol and aldehyde oxidations
Dehydrogenation
Dehydratations
Reductive dehalogenation
N-Oxide reduction
Epoxide reduction
Reductive β-scission of alkyl peroxides
NO reduction
Isomerizations
Oxidative C-C bond cleavage

Figure 2. 2 Different types of enzymatic reactions catalyzed by P450s (Sono et al., 1996, Bernhardt, 2006).

2.2. Applications of P450s

Because of the catalytic diversity and regio- and stereo-selective manner of enzymatic reactions, P450s' properties have been investigated for various biotechnological, environmental and pharmaceutical applications, as listed in Table 2.1.

Table 2. 1 Applications of P450s.

Application	Information	References
Drug discovery and development	P450s have been applied in drug toxicity testing to predict the *in vivo* human metabolism, effects of prodrugs and other xenobiotics.	Miners, 2002, Ingelman-Sundberg, 2004, Guengerich, 2006
Production of fine chemicals, fragrances and pharmaceutical compounds	• Biotransformation of steroids to drugs • Antibiotics production • Production of anti-cancer drugs	Andersen et al., 1993, Guengerich, 2002, van Beilen et al., 2003, van Beilen et al., 2005, Jennewein et al., 2005, Urlacher and Eiben, 2006
Biofuels	Production of 1-alkenes (terminal olefins) from fatty acids; butane to 1-butanol	Koch et al., 2009, Rude et al., 2011, Zhang et al., 2011
Biosensing	• P450s have been applied to detect drugs, xenobiotic compounds and fatty acids	Paternolli et al., 2004
Bioremediation	P450s have been engineered for removing toxic compounds from the environment	Harford-Cross et al., 2000, Jones et al., 2001, Sulistyaningdyah et al., 2004

2.3. P450s as drug target against pathogenic organisms

One of the applications of P450s is their use as drug target against pathogenic organisms in view of their essential role in the survival of organisms. Among P450s, CYP51 is a drug target since its reaction is an essential step in sterol biosynthesis (Lepesheva et al., 2008, Lepesheva et al., 2018) (Figure 2.3) for fungi and protozoan parasites. Most anti-fungal drugs, especially the azole drugs, have been found to inhibit CYP51 activity, thus ergosterol, an essential component of fungal cell wall synthesis, will be inhibited, leading to the disruption of the membrane and eventually fungi death (Lepesheva et al., 2018). Studies have indicated that another P450, CYP53, can serve as an alternative anti-fungal drug target where drugs developed against this P450 may have an advantage over CYP51 owing to non-cross-reactivity with human P450s (Jawallapersand et al., 2014). CYP53 P450s detoxify benzoate into para-hydroxy benzoate in organisms (Faber et al., 2001). Apart from the CYP51 and CYP53 P450s, quite a number of P450s were found to play a key role, including that of drug target in *Mycobacterium tuberculosis*, the deadliest and oldest human lung pathogen that causes a lung disease known as tuberculosis (TB).

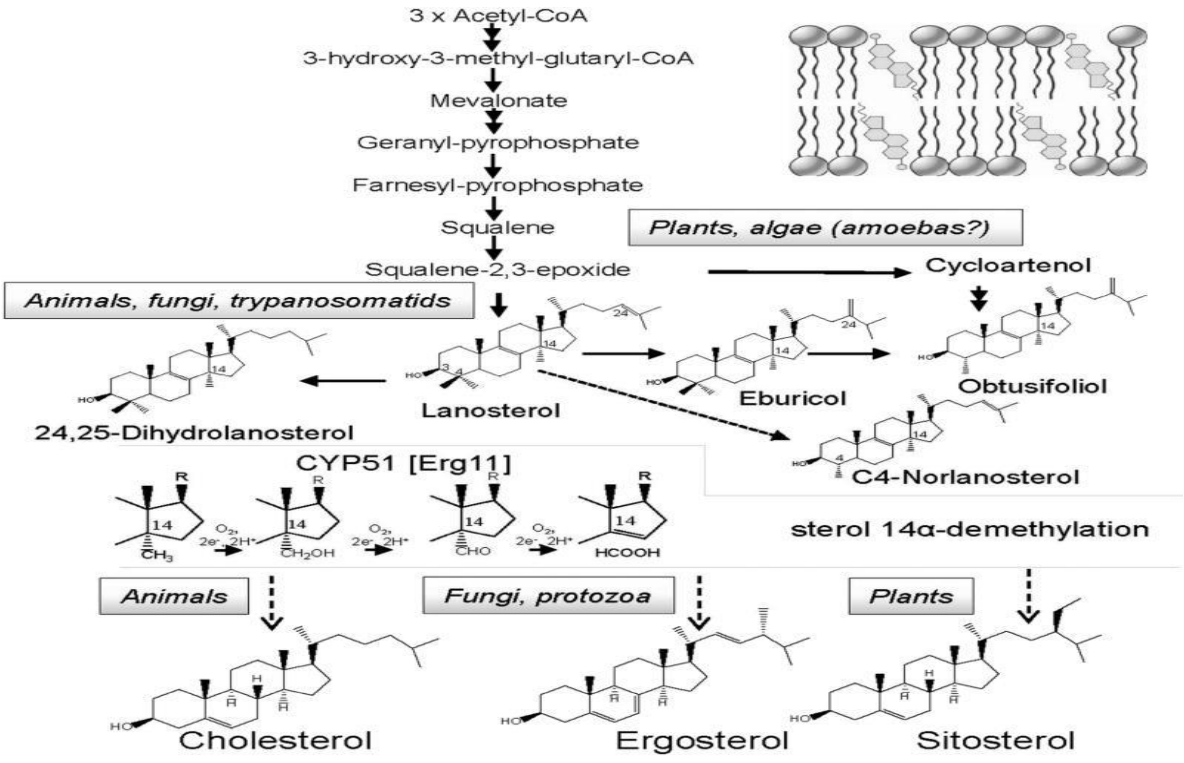

Figure 2. 3 CYP51's role in synthesis of sterols in different organisms (Lepesheva et al., 2018).

2.4. *Mycobacterium tuberculosis*

TB, a prehistoric disease, remains one of the top 10 causes of death and the leading cause from a single infectious agent, *Mycobacterium tuberculosis*, despite global efforts in disease control programs during the past 20 years (WHO, 2018). TB is a global disease, found in every country in the world (WHO, 2018) (Figure 2.4). It became mankind's oldest and worst enemy owing to its widespread nature across the world and developing resistance to known and available drugs (WHO, 2018) (Figure 2.5). In 2017, 10 million people developed TB, and an estimated 1.3 million deaths among human immunodeficiency virus (HIV)-negative people and an additional 300 000 deaths from TB among HIV-positive people occurred (WHO, 2018). The latest data from Statistics South Africa show that TB is one of the top killers in South Africa (SSA, 2018) (Figure 2.6), suggesting an urgent need to understand *M. tuberculosis* physiology to be able to come up with novel drugs and drug targets.

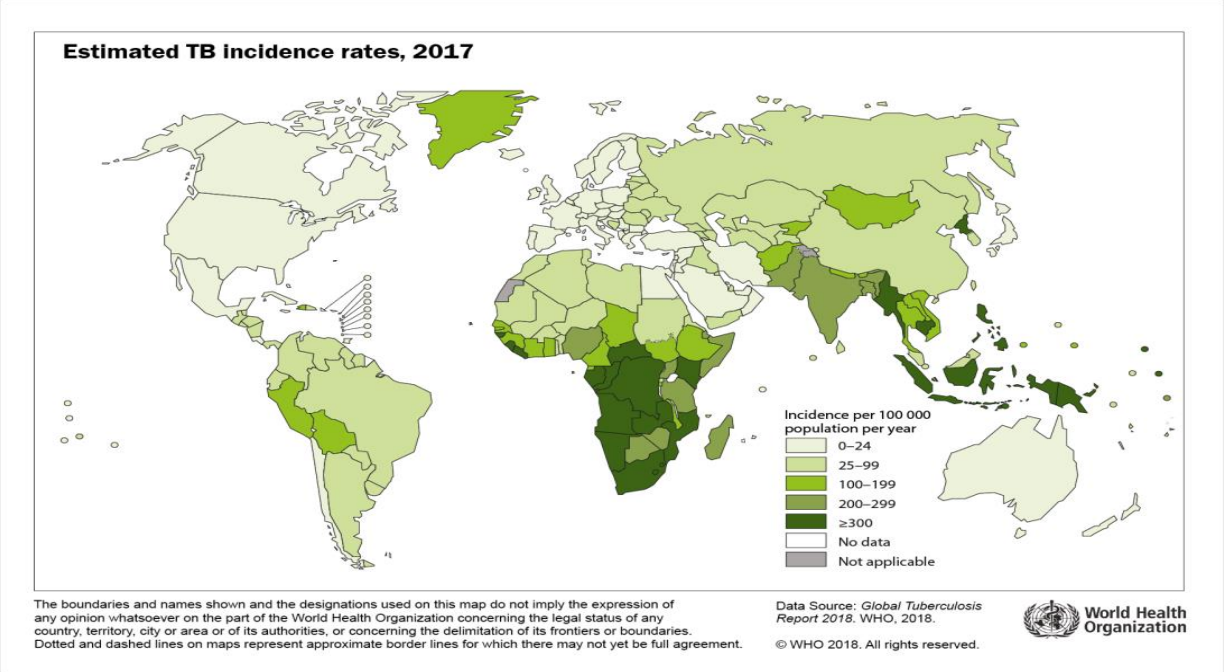

Figure 2. 4 Global burden of tuberculosis (WHO, 2018).

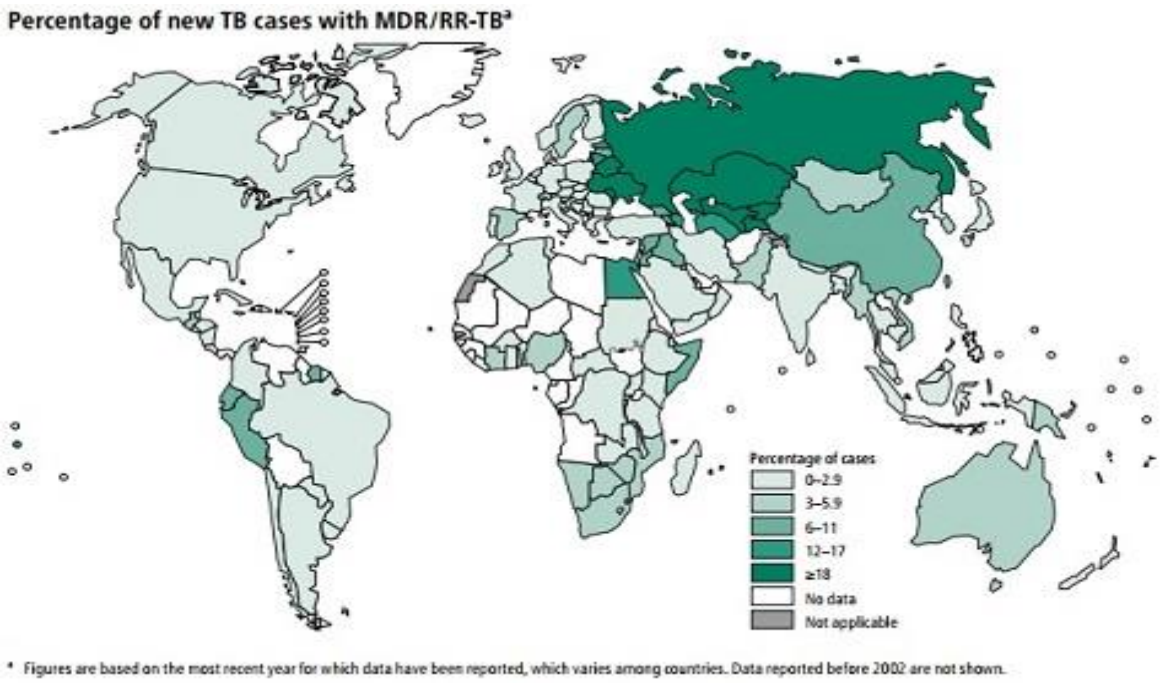

Figure 2. 5 World-wide prevalence of drug-resistant tuberculosis (WHO, 2018).

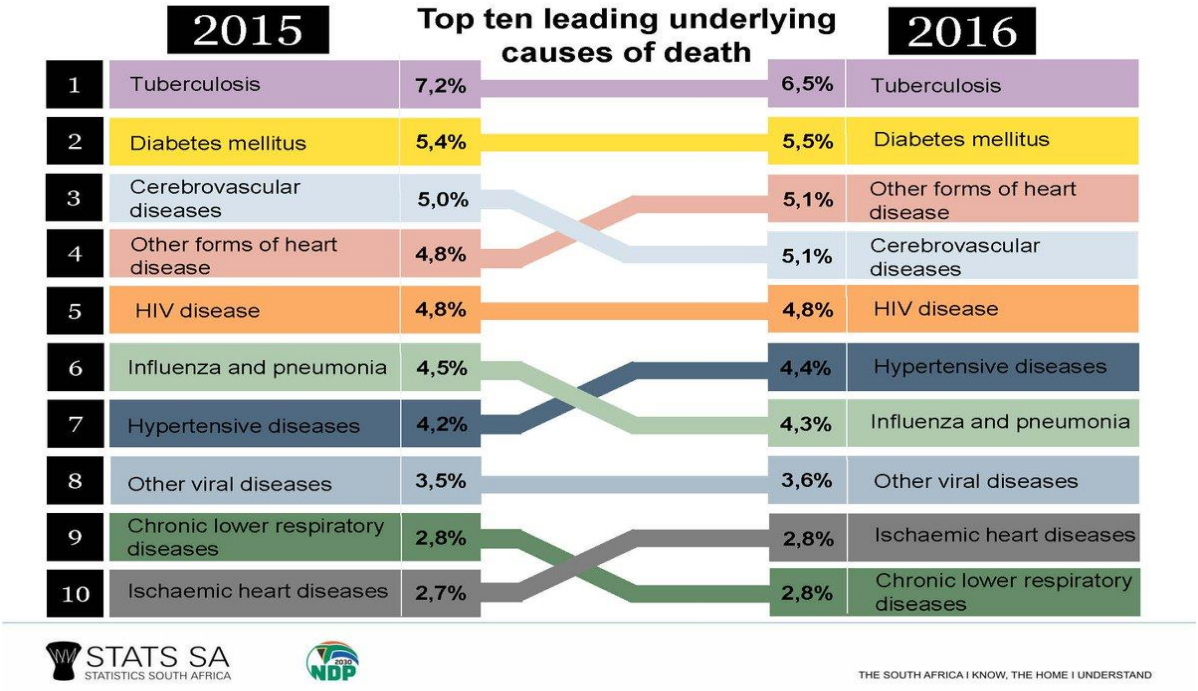

Figure 2. 6 Top ten death-causing diseases in South Africa (SSA, 2018).

2.5. P450s of *M. tuberculosis*

Despite living in the most advanced medicine era, TB remains a major threat to human health (WHO, 2018). Despite 21 years of *M. tuberculosis* genome sequencing (Cole et al., 1998), to date, its physiology remains poorly understood and many proteins are orphans. Genome sequencing analysis of *M. tuberculosis* H37Rv revealed the presence of 20 cytochrome P450 monooxygenases (CYPs/P450s) in its genome (Cole et al., 1998). P450s are mixed function oxidoreductases ubiquitously distributed across the biological kingdoms (Nelson, 2018). P450s are well known for their role in essential cellular anabolic and catabolic processes and have been found to serve as drug target against pathogenic organisms, as described earlier.

Among 20 P450s, to date, the role of only six *M. tuberculosis* H37Rv P450s in their physiology has been elucidated (Ortiz de Montellano, 2018). CYP51B1, a highly conserved P450 family across microbes, has been found to catalyse the 14α-demethylation of lanosterol (Bellamine et al., 1999, Bellamine et al., 2001, McLean et al., 2006); CYP121A1 catalyses oxidative crosslinking of the two tyrosines in a cyclodipeptide (Belin et al., 2009); CYP125A1 and CYP142A1 catalyse the 26-hydroxylation of cholesterol and cholest-4-en-3-one (Driscoll et al., 2010, Johnston et al., 2010); CYP124A1 catalyses the terminal hydroxylation of methyl-branched hydrocarbons such as those of phytanic acid and farnesol (Johnston et al., 2009), cholesterol and related sterols (Johnston et al., 2010, Johnston et al., 2012), and vitamin D_3 and CYP128A1 are involved in oxidation of menaquinone MK9 (Sogi et al., 2016).

2.5.1. CYP139

Among *M. tuberculosis* H37Rv P450s, the *CYP139A1* gene was found downstream of polyketide synthase genes (*pks10*, *pks7*, *pks8*, *pks17*, *pks9* and *pks11*) and situated next to macrolide transport protein (McLean and Munro, 2008, Ouellet et al., 2010). Two of the polyketide synthases, *pks7* and *pks8*, were found to be essential for the survival of *M. tuberculosis* (Sassetti et al., 2003, Griffin et al., 2011). Polyketide synthases along with other genes were found to be part of biosynthetic gene clusters (BGCs). According to Medema et al. (2015), a BGC can be defined as a physically clustered group of two or more genes in a particular genome that together encode a biosynthetic pathway for the production of a specialised metabolite (including its chemical variants). Bacteria, fungi and plants are known to possess different types of BGCs

producing a variety of secondary metabolites that are beneficial to humans. Among the genes that are part of a BGC, P450s play a key role in contributing to the diversity of a secondary metabolite owing to their regio- and stereo-specific oxidation (Greule et al., 2018). Recently, comprehensive comparative analysis of P450s and those associated with secondary metabolism revealed a large number of P450s involved in the production of secondary metabolites in different bacterial species (Mthethwa et al., 2018, Senate et al., 2019).

Based on *CYP139A1*'s location, this P450 is assumed to be involved in oxidative tailoring of the macrolide structure. In the latest study involving comprehensive comparative analysis of P450s in bacterial species belonging to the genera *Mycobacterium* and *Streptomyces*, CYP139 P450s were found to be dominantly located in different secondary metabolite BGCs (Senate et al., 2019) (Figure 2.7). This strongly indicates that CYP139 P450s are possibly involved in the synthesis of secondary metabolites. This study is aimed at using an *in silico* approach to unravel the CYP139 P450 family's role in mycobacterial species physiology.

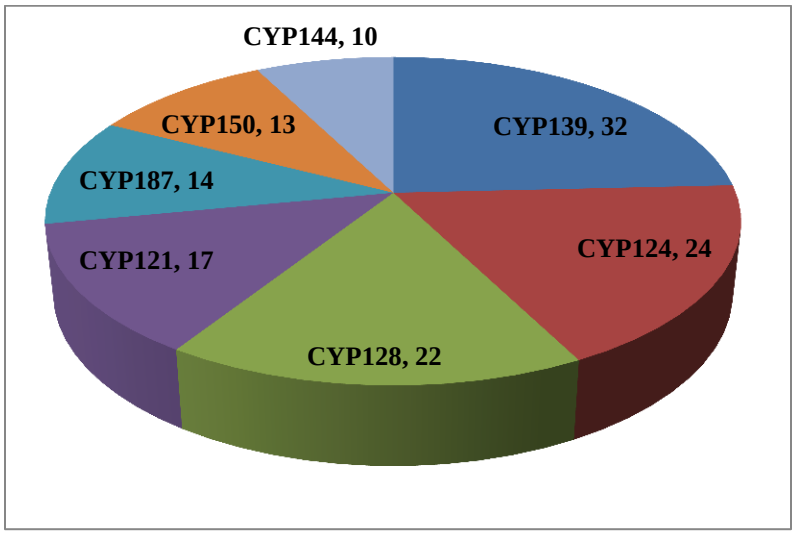

Figure 2. 7 The P450 families that are dominantly present in different biosynthetic gene clusters in mycobacterial species (Senate et al., 2019). The number after the P450 name indicates the number of member P450s.

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CHAPTER 3: METHODOLOGY

3.1. Mycobacterial species and genome databases

In total, 1111 mycobacterial species genomes that are available for public use (as of 12 June 2018) at Integrated Microbial Genomes & Microbiomes (IMG/M) (Chen et al., 2019) were used in the study (Supplementary Table). Mycobacterial species used in the study, along with their name, genome ID and mycobacterial categories they belong as described elsewhere (Parvez et al., 2016) is presented in Supplementary Table.

3.2. Genome data mining and annotation of CYP139 P450s

The *Mycobacterium tuberculosis* H37Rv CYP139A1 (Rv1666c) P450 sequence has been blasted with the default settings against individual mycobacterial species genomes at IMG/M (Chen et al., 2019). However, each time, only 20 mycobacterial species were selected for BLAST analysis. The hit proteins with more than 40% identity were selected and then subjected to BLAST analysis at the P450 BLAST server (https://ksyed.weebly.com/p450-blast.html) to identify the homolog P450. Hit proteins were then grouped into families and subfamilies based on the International Cytochrome P450 Nomenclature criteria, i.e., P450s showing >40% identity were assigned to the same P450 family and P450s that showed >55% identity were grouped under the same P450 subfamily (Nelson et al., 1993, Nelson, 1998, Nelson, 2006). Protein with more than 90% identity considered as ortholog and assigned the same subfamily number.

3.3. Phylogenetic analysis of CYP139A P450s

The phylogenetic tree of CYP139 family members was built with *M. tuberculosis* CYP51B1 (Rv0764c) protein as outgroup. First, the protein sequences were aligned by MAFFT v6.864 (Katoh et al., 2005), embedded on the Trex web server (Boc et al., 2012). Then, the alignments were automatically subjected to infer the best tree by the Trex web server with its embedded weighting procedure. Finally, the tree was visualised and colored by iTOL (http://itol.embl.de/about.cgi) (Letunic and Bork, 2016).

3.4. Analysis of homology and amino acid conservation

Analysis of percentage identity among CYP139A P450s from species belonging to MAC and NTM categories was carried out as described elsewhere (Jawallapersand et al., 2014, Parvez et al., 2016). Briefly, the percentage identity between CYP139 P450s was determined using the Clustal Omega (McWilliam et al., 2013). The Clustal Omega percentage identity matrix was downloaded and pasted into an Excel sheet by converting the text into a column option.

Amino acid conservation among CYP139A P450s was carried out following the method described elsewhere (Sello et al., 2015, Parvez et al., 2016, Bamal et al., 2018). Briefly, CYP139 P450s were subjected to PROMALS3D (Pei et al., 2008) to identify invariantly conserved amino acids (Pei and Grishin, 2001). The conservation index follows numbers from 5–9, where 9 is the invariantly conserved amino acid across the sequences. The total number of conserved residues indicated by number 9 was recorded. The conserved nature of the CYP139 family was compared to other P450 families from different biological kingdoms, as reported elsewhere (Parvez et al., 2016, Bamal et al., 2018).

3.5. Generation of EXXR and CXG sequence logo

CYP139 P450 family EXXR and CXG sequence logos were generated following the method described elsewhere (Syed and Mashele, 2014, Sello et al., 2015, Bamal et al., 2018). Briefly, CYP139 P450 sequences were aligned using ClustalW multiple alignments using MEGA7 (Kumar et al., 2016). After sequence alignment the EXXR and CXG region amino acids (4 and 10 amino acids, respectively), were selected and entered in the WebLogo program (http://weblogo.berkeley.edu/logo.cgi). As a selection parameter, the image format was selected as PNG (bitmap) at 300 dpi resolution. The percentage predominance of amino acids at particular positions was calculated considering the total number of amino acids as 100%. The generated EXXR and CXG logos were used for analysis and compared to the different P450 family EXXR and CXG logos that have been published and are available to the public (Syed and Mashele, 2014, Sello et al., 2015, Bamal et al., 2018).

3.6. Identification of CYP139 P450 secondary metabolite BGCs

BGCs listed on the IMG/M (Chen et al., 2019) website for each of the mycobacterial species were manually searched for the presence of CYP139 P450s using the protein ID. The BGCs that have CYP139 P450 were selected for further study. The listed BGCs at IMG/M are general (Chen et al., 2019) and in order to identify the specific type of BGCs, the selected BGCs genome sequences were subjected to secondary metabolite BGCs analysis, as described elsewhere (Mthethwa et al., 2018). Briefly, the individual BGC genome sequences downloaded from IMG/M (Chen et al., 2019) were submitted to anti-SMASH (Blin et al., 2019). The type of BGC, percentage similarity to a known cluster and the cluster name were noted. Standard BGC abbreviation terminology developed by anti-SMASH (Blin et al., 2019) was used in the study.

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CHAPTER 4: RESULTS AND DISCUSSION

4.1. CYP139 P450s are present only in certain mycobacterial category species

Comprehensive comparative analysis of CYP139 P450s in 1111 mycobacterial species belonging to six different categories (Supplementary Table) revealed that CYP139 P450s are present in 894 mycobacterial species belonging to three categories, namely the *Mycobacterium tuberculosis* complex (MTBC), *M. avium* complex (MAV) and non-tuberculosis mycobacteria (NTM) (Figure 4.1 and Table 4.1). This phenomenon of identifying CYP139 P450s only in these three mycobacterial categories was also observed previously when 60 mycobacterial species were analysed (Parvez et al., 2016). Results from this study, which involved such a large data set, not only supported, but also confirmed that CYP139 is not present in mycobacterial species belonging to categories such as *Mycobacterium* causing leprosy (MCL), Saprophytes (SAP) and the *Mycobacterium chelonae-abscessus* complex (MCAC) (Figure 4.1). Interestingly, not all mycobacterial species of MTBC, NTM and MAC categories have CYP139 P450 (Figure 4.1). Among 956 mycobacterial species, only 850 mycobacterial species of MTBC have CYP139 P450; 10 of 14 and 34 of 57 mycobacterial species of NTM and MAC, respectively, have this P450 (Figure 4.1 and Table 4.1). A detailed analysis of CYP139 P450s along with species names and protein ID is presented in Table 4.1.

Analysis of *CYP139* P450s in the genomes of mycobacterial species revealed that only a single copy of the *CYP139* P450 gene is present in all mycobacterial species (Table 4.2). Furthermore, P450 subfamily analysis revealed that all CYP139 P450s found in 894 mycobacterial species belong to the subfamily "A" (Figure 4.2). Phylogenetic analysis of CYP139A P450s revealed that CYP139A P450s grouped per their mycobacterial category, indicating after speciation CYP139A P450s were subjected to amino acid changes specific to their category (Figure 4.1), similar to what was observed for other P450s described elsewhere (Jawallapersand et al., 2014; Parvez et al., 2016).

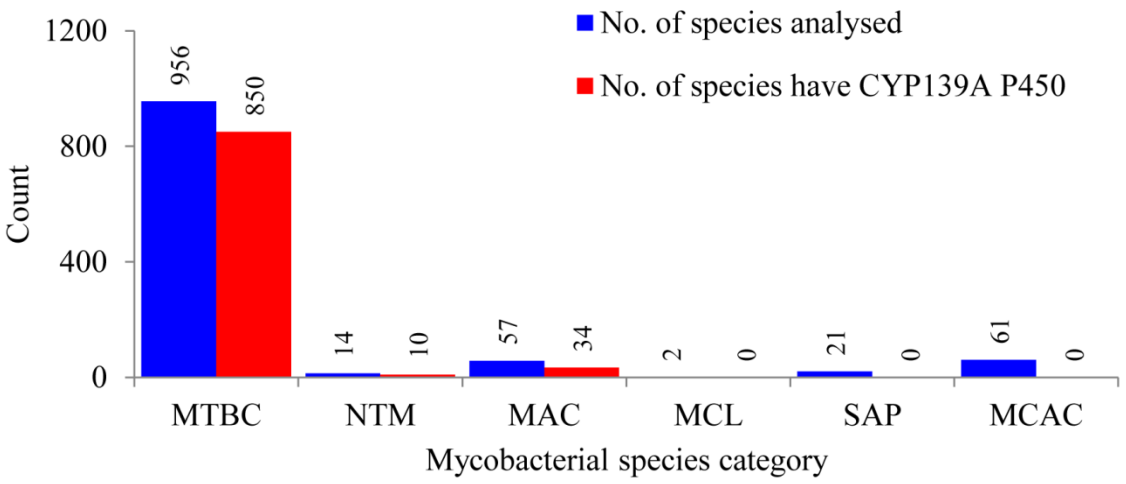

Figure 4. 1 Comparative analysis of CYP139A P450s in species belonging to six different mycobacterial categories. Abbreviations: MTBC, *Mycobacterium tuberculosis* complex; MAV, *M. avium* complex; NTM, non-tuberculosis mycobacteria; MCL, *Mycobacterium* causing leprosy; SAP, Saprophytes and MCAC, *Mycobacterium chelonae-abscessus* complex. Information on mycobacterial species and CYP139A P450s is presented in Supplementary Tables 3.1 and 4.1, respectively.

Table 4. 1 Genome-wide data mining, identification, annotation and secondary metabolite BGC analysis of CYP139 P450s in mycobacterial species. A blank space indicates CYP139A P450s that were not found to be part of BGCs.

Species name	**CYP139A Protein ID**	**Cluster type**	**Reference BGC**	
			% similarity	**BGC name**
***Mycobacterium tuberculosis* complex (MTBC)**				
Mycobacterium africanum GM041182	651025167	T3pks-T1pks	19	Lorneic acid A
Mycobacterium africanum K85	2584196432	T3pks-T1pks	33	ML-449
Mycobacterium africanum K85	646018681	T3pks, T1pks	100	MAR/MAP
Mycobacterium africanum MAL010070	2583719805	T3pks-T1pks	33	ML-449
Mycobacterium africanum MAL010071	2582018155	T3pks-T1pks	33	ML-449
Mycobacterium africanum MAL010074	2582415442	T3pks-T1pks	33	ML-449
Mycobacterium africanum MAL010079	2580939152	T3pks-T1pks	33	ML-449
Mycobacterium africanum MAL010081	2580669105	T3pks-T1pks	10	Abyssomicin
Mycobacterium africanum MAL010084	2581510874	T3pks-T1pks	19	Lorneic acid A
Mycobacterium africanum MAL010099	2583723841	T3pks-T1pks	33	ML-449
Mycobacterium africanum MAL010100	2574968392			
Mycobacterium africanum MAL010102	2577175183	T3pks-T1pks	33	ML-449
Mycobacterium africanum MAL010111	2575938969	T3pks-T1pks	33	ML-449

Mycobacterium africanum MAL010112	2575198589	T3pks-T1pks	33	ML-449
Mycobacterium africanum MAL010118	2581869776	T3pks-T1pks	33	ML-449
Mycobacterium africanum MAL010120	2580366102	T3pks-T1pks	10	Abyssomicin
Mycobacterium africanum MAL010123	2581807696	T3pks-T1pks	33	ML-449
Mycobacterium africanum MAL010128	2582001898	T3pks-T1pks	10	Abyssomicin
Mycobacterium africanum MAL010129	2581901399	T3pks-T1pks	33	ML-449
Mycobacterium africanum MAL010131	2581377024	T3pks-T1pks	27	Nystatin
Mycobacterium africanum MAL010136	2583727889	T3pks-T1pks	33	ML-449
Mycobacterium africanum MAL010137	2575705222	T3pks-T1pks	33	ML-449
Mycobacterium africanum MAL020107	2581930746	T3pks-T1pks	19	Lorneic acid A
Mycobacterium africanum MAL020130	2583735989	T3pks-T1pks	33	ML-449
Mycobacterium africanum MAL020135	2583731958			
Mycobacterium africanum MAL020148	2581562358	T3pks-T1pks	19	Lorneic acid A
Mycobacterium africanum MAL020173	2581366557	T3pks-T1pks	33	ML-449
Mycobacterium africanum MAL020176	2583740670	T3pks-T1pks	29	Amphotericin
Mycobacterium africanum MAL020185	2580467795	T3pks-T1pks	50	Spirangien
Mycobacterium bovis AF 2122/97	637139034	T3pks-T1pks	33	ML-449
Mycobacterium bovis B2 7505	2580301723			
Mycobacterium bovis BCG China	2547306531	T3pks-T1pks	33	ML-449
Mycobacterium bovis BCG Korea 1168P	2540803840	T3pks-T1pks	33	ML-449
Mycobacterium bovis BCG Mexico	2511811274	T3pks-T1pks	33	ML-449
Mycobacterium bovis BCG Moreau RDJ	2620699696	T3pks, T1pks	100	MAR/MAP

Mycobacterium bovis BCG Pasteur 1173P2	639830617	T3pks-T1pks	33	ML-449
Mycobacterium bovis BCG str. Tokyo 172	643734506	T3pks-T1pks	33	ML-449
Mycobacterium bovis BCG-Denmark TMC 1010, ATCC 35733	2547311116	T3pks-T1pks	33	ML-449
Mycobacterium bovis BCG-Russia TMC 1022 , ATCC 35740	2547317188	T3pks-T1pks	31	Stenothricin
Mycobacterium bovis BCG-Tice, TMC 1028	2547314995	T3pks-T1pks	38	Oligomycin
Mycobacterium bovis D 4155	2580744928	T3pks-T1pks	20	Kendomycin
Mycobacterium bovis Kc 32216	2584107430			
Mycobacterium bovis Kc 9614	2580123929	T3pks-T1pks	33	ML-449
Mycobacterium bovis MAL010093	2583745288	T3pks-T1pks	33	ML-449
Mycobacterium bovis Wt 21419	2581355094	T3pks-T1pks	33	ML-449
Mycobacterium canettii CIPT 140070002	2566980890	T1pks	32	ECO-02301
Mycobacterium canettii CIPT 140070007	2566972350	T3pks-T1pks	23	Cyclizidine
Mycobacterium canettii CIPT 140070008	2541569776	T3pks-T1pks	50	Spirangien
Mycobacterium canettii CIPT 140070010	2540554561	T3pks	21	ECO-02301
Mycobacterium canettii CIPT 140010059	651039004	T3pks-T1pks	20	JBIR-100
Mycobacterium canettii CIPT 140060008	2541578033	T1pks	18	Natamycin
Mycobacterium canettii CIPT 140070005	2566985178	T1pks	12	Apoptolidin
Mycobacterium canettii CIPT 140070013	2566976623	T3pks-T1pks	23	Cyclizidine
Mycobacterium canettii CIPT 140070017	2541573920	T3pks-T1pks	32	ECO-02301
Mycobacterium kansasii 662	2567131988	T3pks-T1pks	33	Mycolactone

Mycobacterium tuberculosis 02_1987	2577462548	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis 1010SM	2584791771	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis 1173CS	2576559538	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis 1615	2577954418			
Mycobacterium tuberculosis 16955	2575106637	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis 2091HD	2584726832	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis 2094HD	2577143911	T3pks-T1pks	31	Stenothricin
Mycobacterium tuberculosis 210	647209603	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis 2483AR	2575162612	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis 2541MS	2576373809	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis 3280CJ	2575655283	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis 3499MM	2584875064	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis 44503	2584613792			
Mycobacterium tuberculosis 49375	2577429481	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis 51628	2584638962			
Mycobacterium tuberculosis 94_M4241A	643019022	T3pks-T1pks	71	Tylactone
Mycobacterium tuberculosis Beijing/NITR203	2546188127	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis BS1	2559163499	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis BT2	2566259019	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis BTB03-012	2577075963	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis BTB03-143	2576644886	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis BTB03-144	2576947708	T3pks-T1pks	23	Jerangolid

Mycobacterium tuberculosis BTB04-452	2576009184	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis BTB05-013	2576564801	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis BTB05-285	2577185436	T3pks-T1pks	20	Kendomycin
Mycobacterium tuberculosis BTB05-552	2548033169	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis BTB05-559	2548037418	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis BTB06-001	2578107196	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis BTB07-034	2577454945	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis BTB07-206	2574693694	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis BTB07-246	2584678567	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis BTB07-254	2584990570	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis BTB07-325	2578099005	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis BTB08-022	2577659800	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis BTB08-148	2576609942	T3pks-T1pks	38	Oligomycin
Mycobacterium tuberculosis BTB08-362	2575157076	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis BTB09-058	2578111269	T3pks-T1pks	12	Tiacumicin B
Mycobacterium tuberculosis BTB09-565	2578062326	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis BTB10-308	2576293562	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis BTB10-357	2584631822	T3pks-T1pks	12	Tiacumicin B
Mycobacterium tuberculosis BTB10-487	2576967330	T3pks	32	ECO-02301
Mycobacterium tuberculosis BTB11-001	2575520720	T3pks-T1pks	20	Kendomycin
Mycobacterium tuberculosis BTB11-214	2576717872	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis BTB11-236	2578170996	T3pks-T1pks	41	Piericidin A1

Mycobacterium tuberculosis BTB11-343	2575647889	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis BTB12-001	2575016195	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis BTB12-206	2584890677	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis BTB12-314	2577060340	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis BTB12-384	2584970624	T3pks-T1pks	27	Neoaureothin
Mycobacterium tuberculosis BTB12-400	2576684060	T3pks-T1pks	36	Neoaureothin
Mycobacterium tuberculosis BTB12-449	2577098384	T3pks-T1pks	20	Tirandamycin
Mycobacterium tuberculosis BTB13-063	2576196505	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis BTB13-128	2574880930	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis BTB13-206	2584748012	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis BTB13-222	2576431117	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis C	638726892	T1pks	7	Abyssomicin
Mycobacterium tuberculosis CAS/NITR204	2546202077			
Mycobacterium tuberculosis CCDC5079	651084428	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis CCDC5180	651088108	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis CDC1551	637096038	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis CDC1551A	2537735281	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis CPHL_A	646014426	T1pks	10	Abyssomicin
Mycobacterium tuberculosis CPHL_A	2577093117	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis CTRI-2	2511736071	T3pks-T1pks	29	ML-449
Mycobacterium tuberculosis CTRI-4	2547880750	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis EAI/OSDD271	2554692349	T1pks	33	JBIR-100

Mycobacterium tuberculosis EAI5	2555960457			
Mycobacterium tuberculosis EAI5/NITR206	2546206123	T3pks-T1pks	19	Jerangolid
Mycobacterium tuberculosis EAS054	643031783			
Mycobacterium tuberculosis Erdman	2540619998	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis Erdman, ATCC 35801	2590317674	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis F11 (ExPEC)	640606444	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis FJ05194	2545499027	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis G-12-005	2577281457	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis GM 1503	643045086	T1pks	16	Elaiophylin
Mycobacterium tuberculosis GM 1503	2577893113	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis GuangZ0019	2546454904	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis H1578	2574790496	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis H2398	2577684900	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis H2438	2584962435	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis H2581	2576392640	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis H3361	2575023271	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis H37Ra	641814886	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis H37Ra	640602381	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis H37Rv	637026884 (Rv1666c)	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis H37Rv	2527056892	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis H37RvCO	2547164190	T3pks-T1pks	33	ML-449

Mycobacterium tuberculosis Haarlem	641783198	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis Haarlem	2590313607	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis Haarlem3/NITR202	2546192085	T3pks	62	FD-891
Mycobacterium tuberculosis HN878	2547959756	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis INS_XDR	2573562450			
Mycobacterium tuberculosis K	2588538927	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis Korean KIT87190	2588591267	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0001	2578084434	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0002	2590294228	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis KT-0003	2576199760	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0004	2575255926	T3pks-T1pks	50	Spirangien
Mycobacterium tuberculosis KT-0006	2590288661	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis KT-0007	2590283895	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis KT-0008	2590279314	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0011	2584911080	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0014	2590276448	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis KT-0015	2590272661	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis KT-0016	2590266966	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0019	2584846770	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0022	2590260165	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0023	2590256393	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis KT-0024	2577110129	T3pks-T1pks	33	ML-449

Mycobacterium tuberculosis KT-0026	2590252317	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis KT-0027	2577997123			
Mycobacterium tuberculosis KT-0028	2590249475	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis KT-0034	2575869049	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0035	2590243884	T3pks-T1pks	29	ML-449
Mycobacterium tuberculosis KT-0037	2576522568	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0039	2590240089	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis KT-0040	2575964273	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0041	2584681396	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0042	2574949227	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0043	2590237321	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0045	2590231653	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0047	2590227570	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis KT-0048	2590223019	T3pks-T1pks	32	ECO-02301
Mycobacterium tuberculosis KT-0051	2575094331	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0053	2590219901	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis KT-0056	2576712596	T3pks-T1pks	27	Neoaureothin
Mycobacterium tuberculosis KT-0057	2584721998	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0058	2590214646	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis KT-0063	2590211264	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0064	2590563570	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis KT-0067	2574703562	T3pks-T1pks	33	ML-449

Mycobacterium tuberculosis KT-0069	2574911407	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0070	2577655387	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0071	2590559932	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis KT-0072	2576101264	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0075	2590554696	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis KT-0077	2590552289	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis KT-0078	2590548005	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis KT-0079	2590543931	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis KT-0080	2590539845	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0083	2590535240	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis KT-0084	2590531681	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0085	2590526411	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0086	2574780327	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0087	2574834868	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0089	2590523531	T3pks-T1pks	32	ECO-02301
Mycobacterium tuberculosis KT-0091	2575468742	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis KT-0092	2590519464	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis KT-0094	2590513765	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis KT-0096	2578189802	T3pks-T1pks	50	Piericidin A1
Mycobacterium tuberculosis KT-0098	2584878425	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0099	2590510255	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis KT-0100	2577733463	T3pks-T1pks	33	ML-449

Mycobacterium tuberculosis KT-0102	2590505688	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0104	2590501611	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KT-0106	2590499050	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis KT-0107	2590493738	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis KT-0108	2575418829	T3pks-T1pks	50	Spirangien
Mycobacterium tuberculosis KT-0109	2584998642	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis KT-0110	2576250927	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KZN 1435 (MDR)	644880084	T3pks-T1pks	32	ECO-02301
Mycobacterium tuberculosis KZN 4207	647086307	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KZN 4207 (DS)	2511553315	T3pks-T1pks	32	ECO-02301
Mycobacterium tuberculosis KZN 605 (XDR)	645120373	T3pks-T1pks	11	Borrelidin
Mycobacterium tuberculosis KZN R506	648335985	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis KZN V2475	647090515	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis M1004	2577269438	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M1007	2576553939	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M1008	2576566954	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M1017	2577884547			
Mycobacterium tuberculosis M1025	2578155745	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M1213	2575561335	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M1221	2575515927	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M1233	2575663406	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M1283	2577803488	T3pks-T1pks	23	Jerangolid

Mycobacterium tuberculosis M1340	2584623655	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M1415	2584983051	T3pks-T1pks	33	JBIR-100
Mycobacterium tuberculosis M1418	2577009596			
Mycobacterium tuberculosis M1438	2574663269	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M1444	2576015739	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M1449	2575361778	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M1475	2584769363	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M1481	2575252379	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M1559	2575794202	T3pks-T1pks	13	Lasalocid
Mycobacterium tuberculosis M1700	2584913651	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis M1703	2584732271	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis M1762	2574901332	T3pks-T1pks	20	Kendomycin
Mycobacterium tuberculosis M1787	2579818167	T3pks-T1pks	20	Kendomycin
Mycobacterium tuberculosis M1848	2574773054	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis M1906	2576123248	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M1913	2576927477	T3pks-T1pks	20	Kendomycin
Mycobacterium tuberculosis M1956	2584633235	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis M1961	2584689961	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M1978	2578086064	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M2006	2577302440	T3pks-T1pks	20	Kendomycin
Mycobacterium tuberculosis M2085	2577905307	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis M2113	2577069926	T3pks-T1pks	23	Jerangolid

Mycobacterium tuberculosis M2116	2578033540	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M2128	2577613318	T3pks-T1pks	33	Jerangolid
Mycobacterium tuberculosis M2129	2584995097	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M2131	2576731741	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis M2136	2575984510	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M2137	2577497204	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M2203	2584649146	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M2248	2577218717	T3pks-T1pks	20	Kendomycin
Mycobacterium tuberculosis M2249	2577918576	T3pks-T1pks	20	Kendomycin
Mycobacterium tuberculosis M2343	2575345775	T3pks-T1pks	14	Ambruticin
Mycobacterium tuberculosis M2346	2584928246	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M2402	2574854728			
Mycobacterium tuberculosis M2416	2574830606	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis M2479	2577720788	T3pks-T1pks	20	Kendomycin
Mycobacterium tuberculosis M2508	2577236838	T3pks-T1pks	20	Kendomycin
Mycobacterium tuberculosis M995	2579808474	T3pks-T1pks	33	JBIR-100
Mycobacterium tuberculosis MAL010080	2590014899	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL010086	2590012031	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL010087	2590007914	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL010088	2590025444	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MAL010103	2576151818	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis MAL010105	2590040558	T3pks-T1pks	33	ML-449

Mycobacterium tuberculosis MAL010108	2590032388	T3pks-T1pks	29	ML-449
Mycobacterium tuberculosis MAL010109	2576459372	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MAL010110	2590028529	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL010117	2590044637	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL010124	2590048710	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MAL010130	2590052832	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis MAL010133	2575280304	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MAL010134	2590075971	T3pks-T1pks	33	JBIR-100
Mycobacterium tuberculosis MAL020102	2590073317	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis MAL020110	2590070071	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL020120	2577195360	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MAL020131	2574754194	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis MAL020132	2590064965	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL020136	2590061112	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL020138	2590057066	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL020141	2590089378	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL020142	2590093450	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL020144	2576703024	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MAL020145	2584763258	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MAL020147	2590101605	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL020150	2590104693	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL020152	2590109466	T3pks-T1pks	33	ML-449

Mycobacterium tuberculosis MAL020156	2590113796	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MAL020157	2590117900	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MAL020160	2590081259	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL020162	2575533703	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis MAL020167	2590086658	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL020172	2590125975	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL020174	2590121989	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL020179	2576601719	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MAL020181	2574682482	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MAL020186	2590134192	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MAL020187	2590154524	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MAL020192	2590142346	T3pks-T1pks	38	Oligomycin
Mycobacterium tuberculosis MAL020193	2590146409	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL020194	2590150448	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MAL020195	2590137275	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL020196	2590162679	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MAL020197	2590158810	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL020199	2590166763	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MAL020200	2590169218	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL020201	2590174897	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MAL020205	2590181544	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis MAL020206	2590187116	T3pks, T1pks	100	MAR/MAP

Mycobacterium tuberculosis MAL020208	2590190898	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MAL020209	2590195268	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MAL020211	2590198349	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis MD13878	2575051511	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MD14435	2577821955	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MD15050	2584946269	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MD15212	2577519304	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MD15597	2584949783	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MD15855	2577448440	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MD15956	2584942354	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis MD15974	2577198903	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis MD15977	2574560432	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MD16265	2577422627	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis MD16277	2576172216	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis MD16553	2574586310	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis MD16555	2584870715	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MD16577	2584931720	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MD16728	2577697067	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis MD16775	2575988382	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis MD17517	2577632297	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis MD17615	2584812089	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis MD17888	2575084753	T3pks-T1pks	41	Piericidin A1

Mycobacterium tuberculosis MD17902	2575138339	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis MD18096	2576274603	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MD18478	2577879644	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis MD18498	2574987296	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis MD19043	2574761421	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MD19964	2575185207	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis MTB-476	2573574061	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis NA-A0009	2551812688	T3pks-T1pks	100	Leucanicidin
Mycobacterium tuberculosis NCGM2209	2549401785	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis NRITLD09	2584831832			
Mycobacterium tuberculosis NRITLD14	2577923998	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis NRITLD15	2578094092	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis NRITLD44	2575709449			
Mycobacterium tuberculosis NRITLD56	2577468911	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis OFXR-1	2590207004	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis OFXR-10	2578230674	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis OFXR-11	2589154518	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis OFXR-12	2589158600	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis OFXR-13	2576534922	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis OFXR-14	2589146274	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis OFXR-15	2576477081	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis OFXR-16	2589165303	T3pks-T1pks	33	ML-449

Mycobacterium tuberculosis OFXR-18	2590382529	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis OFXR-2	2589142105	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis OFXR-20	2590377218	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis OFXR-21	2590374347	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis OFXR-22	2590370532	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis OFXR-23	2590366449			
Mycobacterium tuberculosis OFXR-29	2590356674	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis OFXR-3	2576471218	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis OFXR-30	2590354422	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis OFXR-31	2590350138	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis OFXR-32	2590345757	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis OFXR-33	2577373328	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis OFXR-4	2589161189	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis OFXR-5	2589148607	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis OFXR-6	2575325434	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis OFXR-7	2575619239	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis OFXR-8	2575465536	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis OFXR-9	2590203420	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis OSDD071	2549407735			
Mycobacterium tuberculosis OSDD504	2549410800			
Mycobacterium tuberculosis OSDD518	2549413118			
Mycobacterium tuberculosis PanR0201	2555578867	T3pks-T1pks	33	ML-449

Mycobacterium tuberculosis PanR0202	2598067418	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis PanR0203	2555148489	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0205	2555140094	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0206	2555144317	T3pks-T1pks	27	Neoaureothin
Mycobacterium tuberculosis PanR0207	2555160272	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0208	2555152706	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0209	2555164435	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0301	2555282371	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0304	2555278104	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0305	2555299255	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0306	2555303475	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0307	2555290904	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0308	2555273883	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0309	2555295099	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0311	2555286609	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0313	2555346108	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0314	2555307696	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0315	2555311951	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis PanR0316	2555329342	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0317	2555560826	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0401	2555599804	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0403	2555543565	T3pks-T1pks	33	ML-449

Mycobacterium tuberculosis PanR0404	2555556540	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0405	2555516018	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0407	2555547894	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0409	2555587223	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0410	2555583039	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0411	2555520186	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0412	2555591399	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0501	2555333539	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0503	2555350295	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0505	2555354513	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0601	2555320646			
Mycobacterium tuberculosis PanR0602	2555337752	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0603	2555316223	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0604	2555325132	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0605	2555341950	T3pks-T1pks	71	Tylactone
Mycobacterium tuberculosis PanR0606	2555358731	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0607	2555409181	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0610	2555396597	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0611	2555413387	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0702	2555417623	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0703	2555400811	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0704	2555528546	T3pks-T1pks	33	ML-449

Mycobacterium tuberculosis PanR0707	2555388140	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0708	2555371358	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0801	2555379694	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0802	2555524372	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0803	2555367201	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0804	2555392373	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0805	2555362970	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0902	2555383921	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0903	2555375511	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0904	2555442648	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0906	2555446824	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR0907	2555455224	T3pks-T1pks	27	Neoaureothin
Mycobacterium tuberculosis PanR0909	2555430098	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR1005	2555595572	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR1006	2555451004	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR1007	2555434304	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PanR1101	2555438445	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis PR05	2554700949	T3pks-T1pks	11	Borrelidin
Mycobacterium tuberculosis R1207	2547951333	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis RGTB423	2514118145	T3pks-T1pks	13	Lasalocid
Mycobacterium tuberculosis SK-B	2576735552	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis SK-C	2592445915	T3pks-T1pks	12	Streptomycin

Mycobacterium tuberculosis SK-E	2584652546	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis SUMu001	648443266	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis SUMu002	648446923	T3pks	100	Micromonolactam
Mycobacterium tuberculosis SUMu004	648456112	T3pks		
Mycobacterium tuberculosis SUMu005	648460473	T3pks	100	Micromonolactam
Mycobacterium tuberculosis SUMu006	648464907			
Mycobacterium tuberculosis SUMu007	648469578	T3pks	100	Micromonolactam
Mycobacterium tuberculosis SUMu008	648473432	T3pks	100	Micromonolactam
Mycobacterium tuberculosis SUMu009	648476944			
Mycobacterium tuberculosis SUMu010	648481186	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis SUMu012	648490022	T1pks	10	Abyssomicin
Mycobacterium tuberculosis T17	643049582			
Mycobacterium tuberculosis T46	2574757270	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis T46	646010237			
Mycobacterium tuberculosis T67	2588659602	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis T85	643035957			
Mycobacterium tuberculosis T92	2584885951	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis T92	643028176			
Mycobacterium tuberculosis TB_RSA01	2584711251	T3pks-T1pks	27	Neoaureothin
Mycobacterium tuberculosis TB_RSA03	2574700588	T3pks-T1pks	27	Neoaureothin
Mycobacterium tuberculosis TB_RSA07	2577872587	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TB_RSA09	2576886343	T3pks-T1pks	27	Neoaureothin

Mycobacterium tuberculosis TB_RSA102	2575862603	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis TB_RSA104	2584806904	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis TB_RSA107	2584893836	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis TB_RSA111	2574614619	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis TB_RSA118	2575426848	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TB_RSA12	2577091164	T3pks-T1pks	27	Neoaureothin
Mycobacterium tuberculosis TB_RSA120	2577400922	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TB_RSA123	2578002537			
Mycobacterium tuberculosis TB_RSA124	2578200424	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis TB_RSA127	2577551091	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TB_RSA132	2577988240	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TB_RSA134	2575627312			
Mycobacterium tuberculosis TB_RSA136	2576443603	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis TB_RSA138	2577900964	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis TB_RSA140	2576163842	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis TB_RSA148	2575295342	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TB_RSA149	2576981010	T3pks-T1pks	20	Kendomycin
Mycobacterium tuberculosis TB_RSA15	2575772716	T3pks-T1pks	27	Neoaureothin
Mycobacterium tuberculosis TB_RSA161	2577569748	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TB_RSA163	2576882264	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TB_RSA165	2575409751	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TB_RSA166	2584715344	T3pks-T1pks	33	ML-449

Mycobacterium tuberculosis TB_RSA173	2574937709	T3pks-T1pks	27	Neoaureothin
Mycobacterium tuberculosis TB_RSA174	2575142685	T3pks-T1pks	27	Neoaureothin
Mycobacterium tuberculosis TB_RSA178	2577038023	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TB_RSA18	2576589126	T3pks-T1pks	27	Neoaureothin
Mycobacterium tuberculosis TB_RSA194	2574784397	T3pks-T1pks	27	Neoaureothin
Mycobacterium tuberculosis TB_RSA195	2576399693	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TB_RSA199	2576059958	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TB_RSA21	2577812038	T3pks-T1pks	27	Neoaureothin
Mycobacterium tuberculosis TB_RSA25	2584737038	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis TB_RSA32	2578013153	T3pks-T1pks	27	Neoaureothin
Mycobacterium tuberculosis TB_RSA45	2584743940	T3pks-T1pks	27	Neoaureothin
Mycobacterium tuberculosis TB_RSA46	2584865918	T3pks-T1pks	27	Neoaureothin
Mycobacterium tuberculosis TB_RSA51	2577689111	T3pks-T1pks	27	Neoaureothin
Mycobacterium tuberculosis TB_RSA59	2576630848	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TB_RSA62	2584902930			
Mycobacterium tuberculosis TB_RSA64	2579798813	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TB_RSA66	2576613004	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis TB_RSA67	2576051820	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TB_RSA68	2574872651	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TB_RSA70	2577641910	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis TB_RSA74	2578073775	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis TB_RSA76	2576321347	T3pks-T1pks	20	Kendomycin

Mycobacterium tuberculosis TB_RSA77	2577203844	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis TB_RSA78	2578053379	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis TB_RSA79	2584923296	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis TB_RSA82	2576583109	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TB_RSA83	2576158036			
Mycobacterium tuberculosis TB_RSA90	2575476916	T3pks-T1pks	20	Kendomycin
Mycobacterium tuberculosis TB_RSA96	2574738070	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TB_RSA97	2576585830	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TB_RSA99	2575611823	T3pks-T1pks	20	Kendomycin
Mycobacterium tuberculosis TBR10	2579813772	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TBR11	2589040293	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TBR23	2589053585	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TBR24	2589048312	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TBR26	2577792721	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TBR28	2575381682	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TBR29	2589056454	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TBR30	2589060525	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TBR31	2574635031	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TBR35	2589068752	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis TBR37	2576759003	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TBR4	2589036086	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TBR40	2589064595	T3pks-T1pks	33	ML-449

Mycobacterium tuberculosis TBR41	2575888575	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TBR42	2589073023	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis TBR43	2589077872	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TBR44	2589082097	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TBR48	2589089021	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TBR49	2589093094	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TBR5	2589032800	T3pks-T1pks	9	Stenothricin
Mycobacterium tuberculosis TBR50	2576156796	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TBR51	2584609065	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TBR53	2589106145	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TBR55	2575230562	T3pks-T1pks	27	Neoaureothin
Mycobacterium tuberculosis TBR56	2589100068	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TBR57	2589098383	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TBR58	2574876573	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TBR60	2589117553	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TBR65	2574886309	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TBR66	2589113575	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis TBR7	2575978404	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TBR74	2589121735	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis TBR75	2589125802	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TBR76	2589139119	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TBR79	2589134136	T3pks-T1pks	27	Nystatin

Mycobacterium tuberculosis TBR8	2589026697	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TBR80	2589130082	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TBR9	2589044237	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_02_0001	2592442711	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_02_0002	2584801008	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_02_0003	2592438630	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_02_0006	2592435284	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_02_0012	2592430392	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_02_0013	2592426321	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_02_0014	2584939524	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_02_0015	2574726119	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_02_0016	2592422247	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_02_0017	2592417392	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_02_0018	2592414205	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_02_0019	2575329342	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_02_0020	2592410032	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_02_0021	2592405959	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_02_0022	2592403099	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_02_0025	2592397895	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_02_0027	2592393538	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_02_0033	2592389699	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_02_0034	2592385592	T3pks, T1pks	100	MAR/MAP

Mycobacterium tuberculosis TKK_02_0036	2592381635	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_02_0038	2577651582	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_02_0039	2592377452	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_02_0045	2576366402	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_02_0046	2592373455	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_02_0061	2592364277	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_02_0062	2592361217	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_02_0063	2592357110	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_02_0067	2592353030	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_02_0068	2592348241	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_02_0069	2592344179	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_02_0071	2574860198	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK_02_0073	2592337997	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_02_0077	2592332604	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_03_0018	2592328029	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_03_0020	2592324422	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_03_0022	2592319784	T3pks-T1pks	31	Stenothricin
Mycobacterium tuberculosis TKK_03_0024	2577168470	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_03_0025	2592316279	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_03_0026	2574803240	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_03_0027	2592312197	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_03_0029	2592308116	T3pks, T1pks	100	MAR/MAP

Mycobacterium tuberculosis TKK_03_0030	2592303254	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_03_0031	2577816400	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_03_0033	2592299949	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_03_0034	2592295853	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_03_0036	2592291479	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_03_0040	2584674477	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_03_0042	2575858812	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis TKK_03_0043	2592287696	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_03_0045	2592283614	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_03_0059	2584670398	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis TKK_03_0078	2584666311	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_03_0081	2592280664	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_03_0082	2592275464	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_03_0083	2577673179	T3pks-T1pks	18	Neoaureothin
Mycobacterium tuberculosis TKK_03_0090	2576708817	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_03_0094	2578246558	T3pks-T1pks	32	ECO-02301
Mycobacterium tuberculosis TKK_03_0096	2578195506	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_03_0099	2575806159	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis TKK_03_0103	2577796885	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_03_0109	2575455196	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_03_0116	2576936333	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis TKK_03_0118	2577936335			

Mycobacterium tuberculosis TKK_03_0156	2575103505	T3pks-T1pks	18	Neoaureothin
Mycobacterium tuberculosis TKK_03_0158	2576932272	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis TKK_04_0001	2592271382	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_04_0002	2584967006	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis TKK_04_0003	2576388909	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis TKK_04_0005	2592267285	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_04_0006	2592261699	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_04_0007	2592259141	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_04_0008	2592254166	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_04_0013	2592250930	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_04_0014	2592246876	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_04_0015	2592242791	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_04_0017	2592238712	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_04_0018	2592234638	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_04_0019	2575132657	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_04_0020	2592230560	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_04_0021	2575542837	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis TKK_04_0022	2592226489	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_04_0023	2592222422	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_04_0024	2576077839	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis TKK_04_0029	2592579018	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_04_0030	2592574645	T3pks, T1pks	100	MAR/MAP

Mycobacterium tuberculosis TKK_04_0031	2592570555	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_04_0033	2578177805	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_04_0034	2592566477	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_04_0036	2592562396	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_04_0037	2592558321	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_04_0038	2584836956	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_04_0039	2592553482	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_04_0040	2576940434	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_04_0042	2584906709	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis TKK_04_0043	2592549349	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_04_0044	2575935659	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_04_0045	2584858071	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis TKK_04_0046	2592546111	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_04_0047	2592542016	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK_04_0048	2592537861	T3pks-T1pks	12	Streptomycin
Mycobacterium tuberculosis TKK_04_0051	2576378950	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_04_0054	2577386815	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_04_0060	2584841030	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_04_0064	2575920420	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_04_0066	2584694835	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_04_0067	2584979253	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis TKK_04_0072	2584703088	T3pks-T1pks	33	ML-449

Mycobacterium tuberculosis TKK_04_0075	2574928549	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_04_0080	2574734007			
Mycobacterium tuberculosis TKK_04_0082	2584759228	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK_04_0094	2584974532	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_04_0103	2576247251	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis TKK_04_0108	2576671439	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_04_0117	2576665707	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_04_0120	2574640348			
Mycobacterium tuberculosis TKK_04_0129	2584776403	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_04_0132	2577516047	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_04_0140	2576497080			
Mycobacterium tuberculosis TKK_04_0157	2574843285	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_05MA_0009	2584785697			
Mycobacterium tuberculosis TKK_05MA_0012	2577215885			
Mycobacterium tuberculosis TKK_05MA_0020	2574799840	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis TKK_05MA_0025	2575674521	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_05MA_0033	2577593438			
Mycobacterium tuberculosis TKK_05MA_0040	2584752944			
Mycobacterium tuberculosis TKK_05MA_0052	2577129296	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_05SA_0012	2575601683			
Mycobacterium tuberculosis TKK_05SA_0014	2577856904	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_05SA_0016	2574985446			

Mycobacterium tuberculosis TKK_05SA_0017	2578040087	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_05SA_0019	2577030827	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_05SA_0020	2584781205	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis TKK_05SA_0042	2584860925	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_05SA_0048	2575790354	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK_05SA_0050	2577381729	T3pks-T1pks	20	Kendomycin
Mycobacterium tuberculosis TKK_05SA_0058	2575028161			
Mycobacterium tuberculosis TKK-01-0001	2589491285	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0002	2589486069	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0003	2589514641	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0004	2589506393	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0005	2589502409	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0006	2577241442	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0007	2589498327	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0008	2588974834	T3pks-T1pks	11	Borrelidin
Mycobacterium tuberculosis TKK-01-0010	2575495357	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0011	2575538950	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0012	2589509569	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0013	2589518744	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0014	2589522796	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0015	2589539130	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis TKK-01-0016	2589535085			

Mycobacterium tuberculosis TKK-01-0019	2575786887	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0020	2588987052			
Mycobacterium tuberculosis TKK-01-0021	2584833644	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0022	2589526877	T3pks-T1pks	16	Akaeolide
Mycobacterium tuberculosis TKK-01-0023	2588982991	T3pks-T1pks	26	JBIR-100
Mycobacterium tuberculosis TKK-01-0024	2589543202	T3pks-T1pks	26	JBIR-100
Mycobacterium tuberculosis TKK-01-0025	2578182623	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0026	2578008273	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0027	2589547247	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0028	2589563529	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0029	2589559459	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis TKK-01-0030	2589555384			
Mycobacterium tuberculosis TKK-01-0031	2589551314	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis TKK-01-0032	2584825730	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis TKK-01-0033	2589568736	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0034	2589592089	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis TKK-01-0035	2579825786	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0036	2589572815	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0037	2577861791	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0038	2584645880			
Mycobacterium tuberculosis TKK-01-0039	2589575466	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0040	2589580598	T3pks-T1pks	27	Nystatin

Mycobacterium tuberculosis TKK-01-0042	2589583955	T3pks	83	MAR/MAP
Mycobacterium tuberculosis TKK-01-0043	2589588224	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0044	2589595990	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0045	2589620637	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis TKK-01-0046	2589616566	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0047	2577322951	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0048	2589613612	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK-01-0049	2589608377	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0050	2589604293	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK-01-0052	2589598915	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK-01-0054	2589658610	T3pks-T1pks	41	Piericidin A1
Mycobacterium tuberculosis TKK-01-0055	2589650472	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0056	2589654545	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0057	2589624713			
Mycobacterium tuberculosis TKK-01-0058	2589629003	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0060	2589638476	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0062	2589642534	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis TKK-01-0063	2589646609	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0064	2584625495			
Mycobacterium tuberculosis TKK-01-0065	2584898862	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0066	2589687166	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0068	2577751179	T3pks-T1pks	27	Nystatin

Mycobacterium tuberculosis TKK-01-0069	2588992251	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0070	2589679190			
Mycobacterium tuberculosis TKK-01-0071	2589676017	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK-01-0072	2588999278	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis TKK-01-0073	2589671952	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0074	2589663797	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0075	2575508785	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0076	2589666655	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0077	2575447433	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0078	2589699410	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK-01-0079	2577256179	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0080	2588995218	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis TKK-01-0081	2589691243	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK-01-0082	2589707360	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0083	2589711853	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0084	2589715710	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK-01-0086	2589724111	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0087	2589719807	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK-01-0088	2589703490	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0089	2589695547	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TKK-01-0090	2575205306	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TKK-01-0091	2577024745	T3pks-T1pks	33	ML-449

Mycobacterium tuberculosis TKK-01-0093	2589736180	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TKK-01-0094	2589727979	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis TRUG0004	2574675630	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TRUG0037	2576105631	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TRUG0040	2576986616	T3pks-T1pks	23	Apoptolidin
Mycobacterium tuberculosis TRUG0070	2575285636	T3pks-T1pks	20	Kendomycin
Mycobacterium tuberculosis TRUG0072	2584660713	T3pks-T1pks	20	Kendomycin
Mycobacterium tuberculosis TRUG0076	2576070324	T3pks-T1pks	20	Kendomycin
Mycobacterium tuberculosis TRUG0080	2584772421	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TRUG0083	2584849650	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis TRUG0085	2577313382	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis TRUG0088	2575638157	T3pks-T1pks	20	Kendomycin
Mycobacterium tuberculosis TRUG0095	2584954771	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TRUG0098	2574905673	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TRUG0101	2576675825	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TRUG0116	2584617586	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis TRUG0117	2584987406	T3pks-T1pks	50	Piericidin A1
Mycobacterium tuberculosis TRUG0124	2584854188	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis Uganda 1	2575403392	T3pks-T1pks	27	Bafilomycin
Mycobacterium tuberculosis UG-C	2575304538	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis UG-D	2584795634	T3pks-T1pks	28	Laidlomycin
Mycobacterium tuberculosis UM 1072388579	2553261414	T3pks	62	FD-891

Mycobacterium tuberculosis UT205	2512786915	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis VRF CWCF XDRTB 1028	2598813154	T3pks, T1pks	100	MAR/MAP
Mycobacterium tuberculosis W-148	2547759833	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis WX1	2560451827	T1pks	10	Abyssomicin
Mycobacterium tuberculosis WX3	2560461324	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis X122	2547955540	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis XDR1219	2560449536	T3pks-T1pks	32	ECO-02301
Mycobacterium tuberculosis XDR1221	2560454644	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis XTB13-081	2576698280	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis XTB13-082	2584718757	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis XTB13-086	2584755863	T3pks-T1pks	7	Streptolydigin
Mycobacterium tuberculosis XTB13-088	2584641128	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis XTB13-092	2584739857	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis XTB13-093	2576513411	T3pks-T1pks	27	Nystatin
Mycobacterium tuberculosis XTB13-094	2575998368	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis XTB13-096	2576207497	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis XTB13-100	2584918375	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis XTB13-110	2584936325	T3pks-T1pks	12	Tiacumicin B
Mycobacterium tuberculosis XTB13-113	2584816678	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis XTB13-114	2574794413	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis XTB13-123	2578237814	T3pks-T1pks	12	Tiacumicin B

Mycobacterium tuberculosis XTB13-127	2575365848	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis XTB13-131	2575697737	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis XTB13-136	2576746511	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis XTB13-143	2576316581	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis XTB13-156	2576649037	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis XTB13-161	2577627248	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis XTB13-162	2577876445	T3pks-T1pks	12	Tiacumicin B
Mycobacterium tuberculosis XTB13-167	2577390930	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis XTB13-175	2584686721	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis XTB13-194	2584659187	T3pks-T1pks	12	Tiacumicin B
Mycobacterium tuberculosis XTB13-195	2576084283	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis XTB13-198	2584883084	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis XTB13-199	2577845812	T3pks-T1pks	23	Jerangolid
Mycobacterium tuberculosis XTB13-200	2575942274	T3pks-T1pks	27	Neoaureothin
Mycobacterium tuberculosis XTB13-203	2584808933	T3pks-T1pks	12	Tiacumicin B
Mycobacterium tuberculosis XTB13-209	2575060404	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis XTB13-214	2577974906	T3pks-T1pks	33	ML-449
Mycobacterium tuberculosis XTB13-238	2584822720	T3pks-T1pks	12	Tiacumicin B
Mycobacterium tuberculosis XTB13-241	2576544659	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis XTB13-251	2575099885	T3pks-T1pks	30	Nanchangmycin
Mycobacterium tuberculosis XTB13-252	2584698776	T3pks-T1pks	12	Tiacumicin B
Mycobacterium tuberculosis XTB13-255	2578213104	T3pks-T1pks	33	ML-449

Mycobacterium tuberculosis XTB13-290	2584960744	T3pks-T1pks	12	Tiacumicin B
Mycobacterium bovis Bz 31150	2581587072			
Mycobacterium bovis Mr 4387	2580771058			
Mycobacterium bovis Wt 21231	2584003651	T3pks-T1pks	23	Jerangolid
Mycobacterium orygis 112400015	2546436155			
Non-tuberculosis Mycobacteria (NTM)				
Mycobacterium sinense JDM601	650873455			
Mycobacterium marinum Europe	2543277028			
Mycobacterium marinum M, ATCC BAA-535	641717750	T3pks-T1pks	9	Chalcomycin
Mycobacterium marinum E11	2588629254	T3pks-T1pks	60	Meridamycin
Mycobacterium marinum MB2	2546369014	T3pks-T1pks	26	Nystatin
Mycobacterium liflandii 128FXT	2563569217	T3pks-T1pks	17	Apoptolidin
Mycobacterium kansasii SMC1	2587480388	T1pks	23	FR-008
Mycobacterium kansasii 732	2567124714	T3pks-T1pks	10	Abyssomicin
Mycobacterium kansasii ATCC 12478	2563577345	T3pks-T1pks	38	Oligomycin
Mycobacterium genavense ATCC 51234	2545768030	T3pks-T1pks	28	FR-008
***Mycobacterium avium* complex (MAC)**				
Mycobacterium avium hominissuis 100	2580974538	T3PKS	66	MAR/MAP
Mycobacterium avium hominissuis 101	2580006443	T3pks-T1pks	100	MAR/MAP
Mycobacterium avium 05-4293	2581913245	T3pks-T1pks	30	Nanchangmycin
Mycobacterium avium 09-5983	2573433552			
Mycobacterium avium 104	639736419	T3pks-T1pks	17	Apoptolidin

Mycobacterium avium 10-5581	2572767979	T3pks		
Mycobacterium avium 2285 (R)	2567079276	T3pks	10	Meridamycin
Mycobacterium avium hominissuis A5	2580783837	T3pks-T1pks	17	Apoptolidin
Mycobacterium avium hominissuis MAH 27-1	2581110378			
Mycobacterium avium MAV_061107_1842	2582181025	T3pks-T1pks	30	Nanchangmycin
Mycobacterium avium MAV_120709_2344	2582391300	T3pks-T1pks	17	Apoptolidin
Mycobacterium avium MAV_120809_2495	2580742569	T3pks-T1pks	17	Apoptolidin
Mycobacterium avium para tuberculosis 10-4404	2592485489	T3PKS	100	MAR/MAP
Mycobacterium avium para tuberculosis 10-5864	2570865822	T3pks		
Mycobacterium avium para tuberculosis 4B	2550738610			
Mycobacterium avium para tuberculosis CLIJ623	2548578292			
Mycobacterium avium para tuberculosis CLIJ644	2547368463			
Mycobacterium avium para tuberculosis DT 3	2549377452	T3pks-T1pks	55	Nigericin
Mycobacterium avium subsp. *para tuberculosis* K-10	637134331			
Mycobacterium avium para tuberculosis MAP4	2555735619	T3pks-T1pks	30	Nanchangmycin
Mycobacterium avium para tuberculosis Pt139	2548515815	T3pks		
Mycobacterium avium para tuberculosis Pt146	2548530385			
Mycobacterium avium para tuberculosis Pt154	2548535921			
Mycobacterium avium para tuberculosis Pt164	2548547272	T1pks	100	Micromonolactam
Mycobacterium avium para tuberculosis S5	2543326887			
Mycobacterium sp. MAC_011194_8550	2582203743	T3pks		
Mycobacterium sp. MAC_080597_8934	2576976958	T3pks-T1pks	23	Apoptolidin

Mycobacterium sp. UM_CSW	2555481387			
Mycobacterium avium subsp. *avium* 3388	2581397788	T3pks-T1pks	17	Apoptolidin
Mycobacterium avium subsp. *avium* ATCC 25291	645425415			
Mycobacterium *avium avium* DT 78	2549389164			
Mycobacterium avium avium Env 77	2549393401			
Mycobacterium avium para tuberculosis Env 210	2549383420			
Mycobacterium avium silvaticum ATCC 49884	2569618768			

Abbreviations: MAR/MAP, Methylated alkyl-resorcinol/methylated acyl-phloroglucinol; T1pks, Type 1 polyketide synthase; T2pks, Type 2 polyketide synthase.

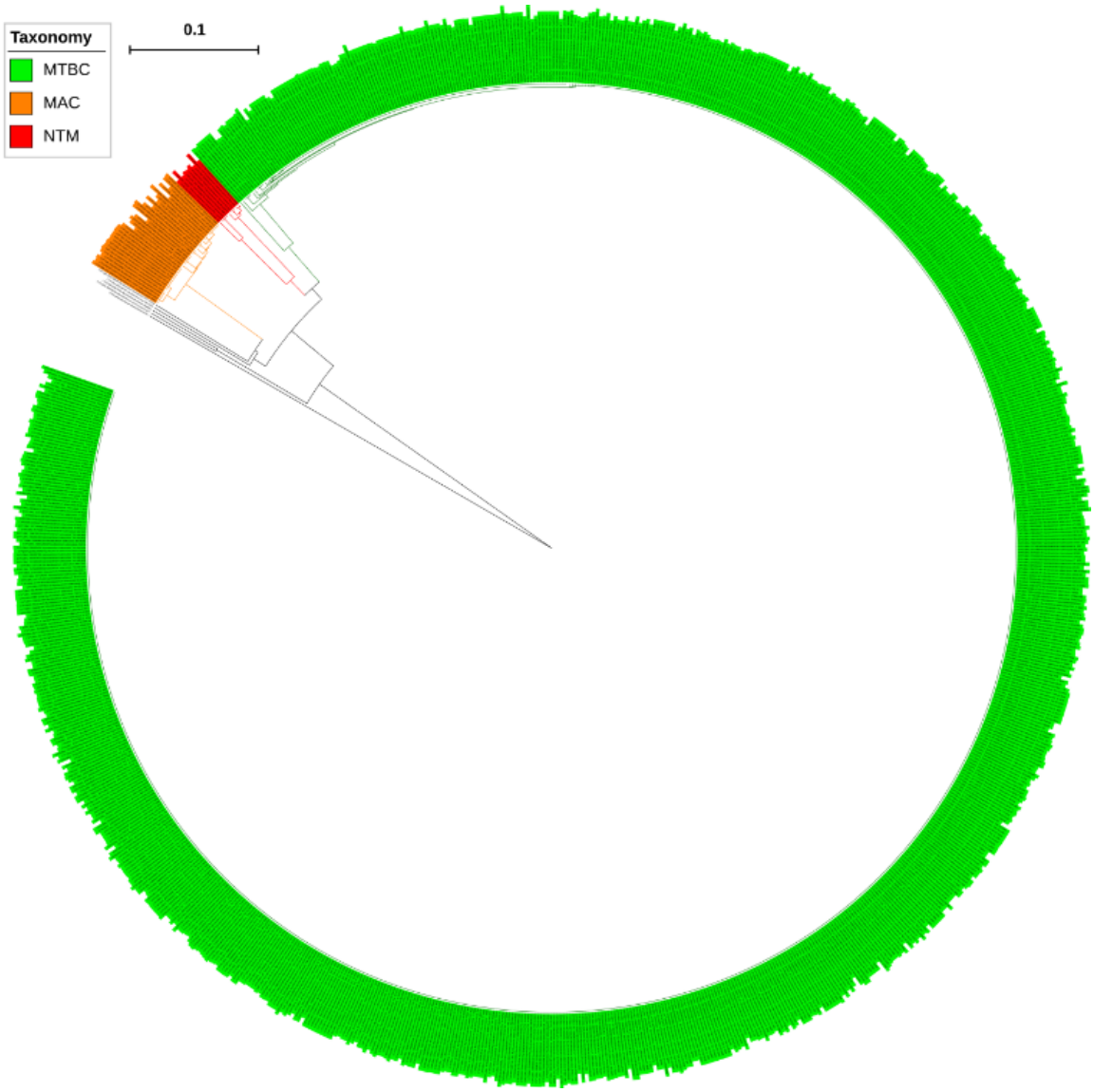

Figure 4. 2 Phylogenetic analysis of CYP139A P450s. Different mycobacterial categories were indicated in different colours. CYP51B1 from *Mycobacterium tuberculosis* H37Rv is used as an outgroup. Abbreviations: MTBC, *Mycobacterium tuberculosis* complex; MAV, *M. avium* complex; NTM, non-tuberculosis mycobacteria.

However, four CYP139A P450s belonging to *M. genavense* ATCC 51234 and *Mycobacterium sp*. JDM601 of NTM and *Mycobacterium sp*. UM CSW and *M. avium avium* Env 77 of MAC were aligned separately, suggesting that these CYP139A P450s had deviated from their counterparts (Figure 4.2). Percentage identity among CYP139 P450s further confirmed that CYP139A P450s from these species have a low percentage identity with their counterparts. CYP139A P450s of *Mycobacterium* sp. UM CSW and *M. avium avium* Env 77 have an average of ~77% and ~63% identity, whereas CYP139A P450s of *M. genavense* ATCC 51234 and *Mycobacterium* sp. JDM601 have an average of 75% and 60% with their counterparts suggesting these P450s have been subjected to significant amino acid changes. The phenomenon of P450s not grouping with their counterpart species was also observed in fungal species, where CYP53D1 has been subjected to extensive amino acid changes (Jawallapersand et al., 2014), the same as what was observed for the four CYP139A P450s identified in this study. Determining the effect of these amino acid changes on functional specificity of four CYP139A P450s, if any, will be interesting future work.

4.2. CYP139 P450 family ranked among top 10 P450 families

Ranking of P450 families belonging to different biological kingdoms, based on the number of conserved amino acids in their protein sequence, placed the CYP139 P450 family in the twelfth rank (Parvez et al., 2016, Bamal et al., 2018). While ranking the CYP139 P450 family, only 54 CYP139A P450s were used (Parvez et al., 2016, Bamal et al., 2018). Identification of quite a large number of CYP139A P450s in this study necessitated re-analysis of the ranking of this P450 family. In order to identify the conservation rank, CYP139A P450s were subjected to PROfile Multiple Alignment with Local Structures and 3D constraints (PROMALS3D) (Pei et al., 2008) analysis. PROMALS3D analysis revealed the presence of 165 amino acids invariantly conserved in CYP139 P450s (Table 4.2). Comparative analysis with other P450 families from different biological kingdoms revealed that the CYP139 P450 family now occupies the eighth rank compared to the twelfth rank as assigned previously (Table 4.2).

Table 4. 2 Comparative amino acid conservation analysis of CYP139 P450 family with top 10 ranked P450 families (Parvez et al., 2016, Bamal et al., 2018).

P450 Family	Number of Member P450s	Kingdom	PROMALS3D Conservation Index					Rank (Highest to Lowest Conservation)
			5	6	7	8	9	
CYP141	29	Bacteria	0	0	0	0	389	1
CYP51	50	Bacteria	11	102	0	0	264	2
CYP137	38	Bacteria	145	0	0	0	251	3
CYP121	34	Bacteria	0	0	0	0	233	4
CYP132	39	Bacteria	175	0	0	0	217	5
CYP5619	23	Stramenopila (oomycetes)	118	38	170	0	199	6
CYP124	71	Bacteria	52	35	59	0	170	7
CYP139	**894**	**Bacteria**	**0**	**127**	**0**	**0**	**165**	**8 (formerly 12)**
CYP188	67	Bacteria	62	0	100	0	141	9
CYP123	74	Bacteria	62	0	82	0	137	10

Footnotes: The conservation index score is obtained as described in the section on materials and methods, following the procedure described elsewhere (Pei and Grishin, 2001). The conservation score (5–9) obtained via PROMALS3D is presented in the table, where the number 9 indicates invariantly conserved amino acids in P450 members. P450 families were arranged from the highest to the lowest number of amino acids conserved. CYP139 P450 family is indicated in bold.

4.3. CYP139 family has unique amino acid patterns at CXG motif

In a study by Syed and Mashele (2014), analysis of the P450 signature motifs, EXXR and CXG, among different P450 families led to the discovery of amino acid patterns characteristic of a P450 family. The authors proposed that "during the divergence of P450 families from a common ancestor, these amino acids patterns evolved and are retained in each P450 family as a signature of that family" (Syed and Mashele, 2014). However, in that study, the CYP139 P450 family was not included. Furthermore, identification of a large number of CYP139A P450s, in this study, gives us an opportunity to identify CYP139 P450 family characteristic amino acid patterns at EXXR and CXG motifs, if any.

Analysis of EXXR and CXG motifs in 894 CYP139A P450s revealed that the CYP139 P450 family EXXR domain is absolutely conserved with amino acid patterns E-T-L-R, whereas, eight amino acids were invariantly conserved in CXG motifs with amino acid patterns of F-S-G(96%)/A(4%)-G-L-H-R-C-I(96%)/V(4%)-G (Figure 4.3). It is interesting to note that the CYP139 P450 family EXXR motif amino acid pattern absolutely matched with the CYP5 family (Syed and Mashele, 2014) and amino acid patterns at the CXG motif were unique and not matched with any P450 families described in the literature (Syed and Mashele, 2014, Sello et al., 2015, Bamal et al., 2018). The CYP139 P450 family amino acid patterns at the EXXR and CXG motifs further strongly support the above hypothesis proposed by Syed and Mashele (2014) that each P450 family contains unique amino acid patterns in these motifs.

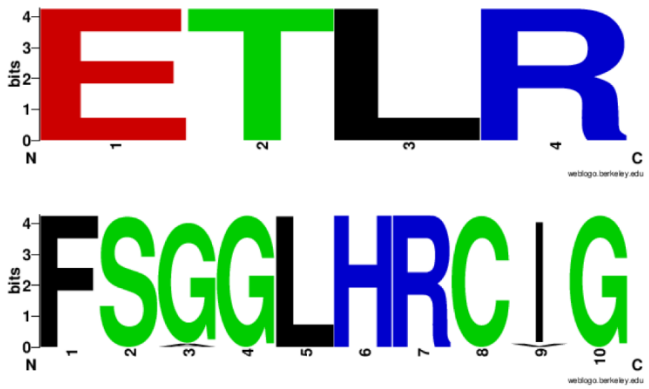

Figure 4. 3 Analysis of amino acid patterns at the EXXR and CXG motif in CYP139 P450 family. In total 894 CYP139 P450 sequences were analysed for EXXR and CXG signature sequences.

4.4. Most CYP139A P450s are part of secondary metabolite biosynthetic gene clusters

Analysis of CYP139A P450s as part of secondary metabolite BGCs in mycobacterial species revealed that most of the CYP139A P450s are part of different BGCs (Figure 4.4A and Table 4.1). Among 894 CYP139A P450s, 824 CYP139A P450s (92%) were found to be part of secondary metabolic BGCs (Figure 4.4A). This means 70 CYP139A P450s were not found to be part of any secondary metabolite BGCs. Comparison of CYP139A P450s that are part of BGCs in three categories revealed that most of the CYP139A P450s in MTBC and NTM species were part of BGCs, compared to species of MAC, where fewer than half of CYP139A P450s were part of secondary metabolite BGCs (Figure 4.4B).

Analysis of secondary metabolite BGCs revealed that CYP139A P450s were part of only three different cluster types (Figure 4.4C and Table 4.1). Among three different cluster types, CYP139A P450s were found to be present dominantly as part of Type 3-Type 1 polyketide synthase (T3PKS-T1PKS) (97%) compared to T3 PKS (2%) and T1 PKS (1%) (Figure 4.4C and Table 4.1). There were 796 CYP139A P450s found to be part of T3PKS-T1PKS, followed by 17 and 11 CYP139 P450s found to be part of T3 PKS and T1 PKS, respectively (Figure 4.4C and Table 4.1). Analysis of gene clusters revealed that 824 CYP139A P450s were part of 39 different gene clusters (Figure 4.4). There were 34 CYP139A P450 gene clusters found in MTBC species, followed by seven gene clusters in NTM species and six gene clusters in MAC (Figure 4B). Among different gene clusters, ML-449 was dominant, with 349 CYP139A P450s followed by methylated alkyl-resorcinol/methylated acyl-phloroglucinol (MAR/MAP) with 104 CYP139A P450s, Nystatin with 74 CYP139A P450s and Jerangolid with 55 CYP139A P450s (Figure 4.5).

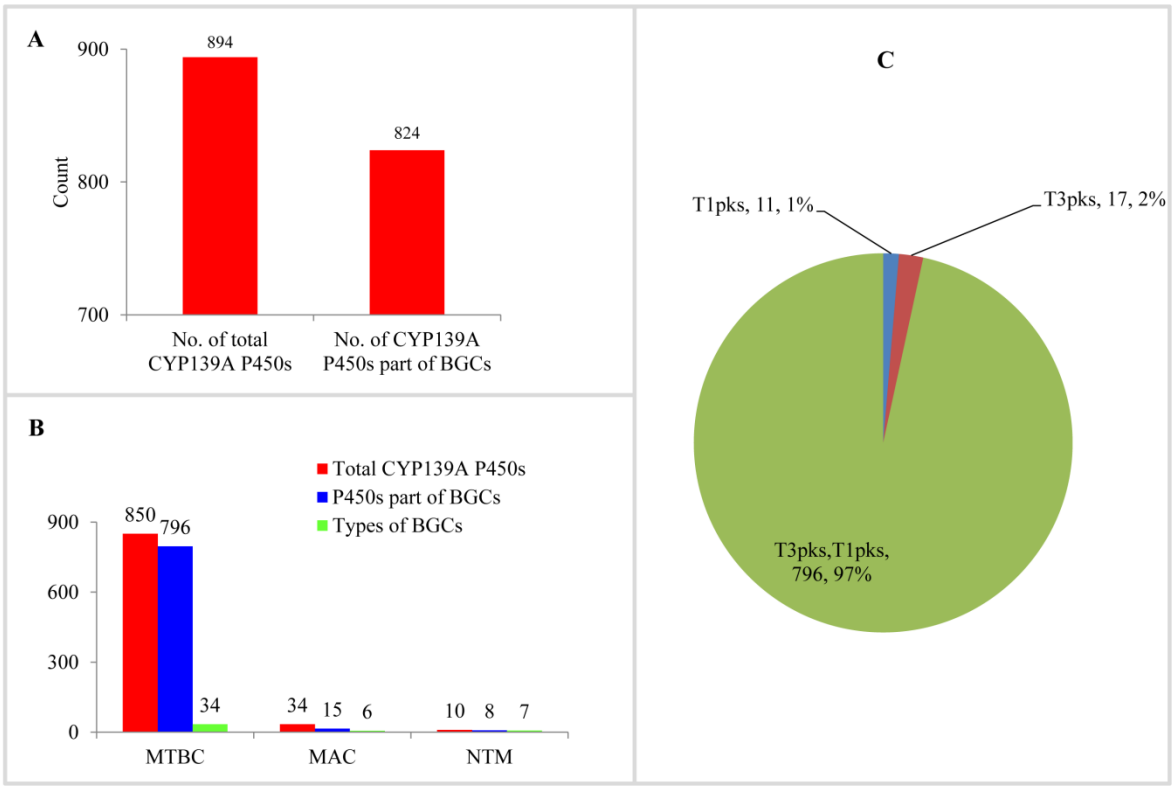

Figure 4. 4 CYP139A P450s secondary metabolite BGCs analysis in mycobacterial species. (A) Analysis of CYP139A P450s that are part of BGCs. (B) Comparative analysis of CYP139A P450s that are part of BGCs and types of BGCs in different mycobacterial categories. Abbreviations: MTBC, *Mycobacterium tuberculosis* complex; MAV, *M. avium* complex; NTM, non-tuberculosis mycobacteria. (C) Comparative analysis of CYP139A P450 cluster types. The type of cluster and the number of CYP139A P450s and their percentage in the total number of P450s were presented in the figure. Abbreviation: T1pks, Type 1 polyketide synthase; T2pks, Type 2 polyketide synthase.

Among 39 gene clusters only 11 gene clusters were found to have 10 or more CYP139A P450s (Figure 4.5). Analysis of DNA sequence percentage identity between CYP139A P450 gene clusters compared to known gene clusters revealed that some of the gene clusters have 100% identity, such as Leucanicidin, MAR/MAP and Micromonolactam (Figure 4.5), indicating CYP139A P450s are indeed involved in the synthesis of these secondary metabolites.

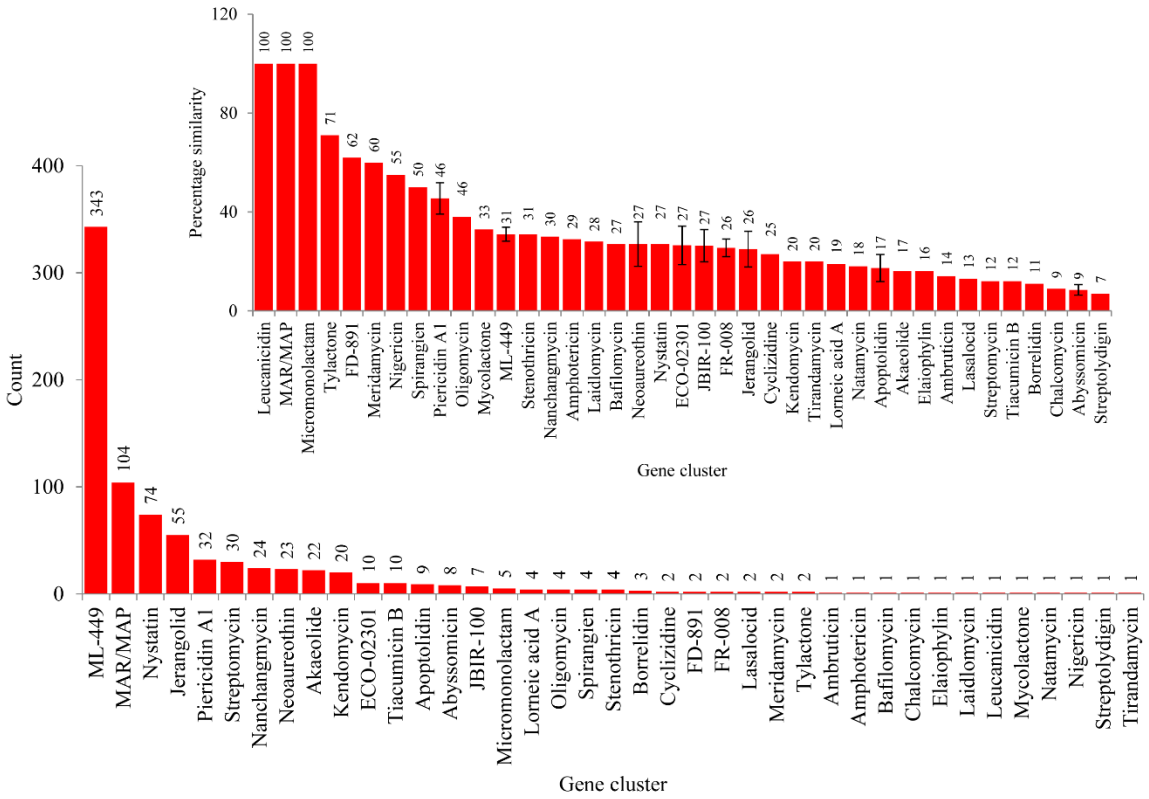

Figure 4. 5 CYP139A P450 gene cluster analysis in mycobacterial species. The 39 gene clusters were presented with their standard abbreviated names as per anti-SMASH. The number next to bars represents the number of CYP139A P450s that is part of that gene cluster. The inset figure shows the percentage identity of CYP139A P450 gene clusters to the known gene clusters available at anti-SMASH. The number next to the bars represents the percentage identity. For some gene clusters the percentage identity is represented with standard deviation (indicated with bars).

4.5. CYP139A P450s involved in the synthesis of secondary metabolites in mycobacterial Species

Comprehensive comparative analysis of CYP139A P450s secondary BGCs in mycobacterial species revealed that CYP139A P450s are indeed involved in the synthesis of different secondary metabolites, as 92% of CYP139A P450s were found to be part of secondary metabolite BGCs (Figures 4.4 and 4.5 and Table 4.1). To understand the role of CYP139A P450s

in mycobacterial species' physiology well, a functional comparison of CYP139A P450s gene clusters' homolog secondary metabolites was carried out (Table 4.3). As shown in Table 4.3, it is clear that CYP139A P450s are involved in the production of chemicals that have antibacterial, antifungal, antiviral and antitumor properties. Interestingly, some of these metabolites in fact showed antimycobacterial activity (Table 4.3). This indicates that CYP139A P450s are possibly helping mycobacterial species to kill other bacteria, including other mycobacterial species, thus gaining the upper hand in the niche area for their survival. It is interesting to note that CYP139A P450s are present only in MTBC, NTM and MAC categories, but not present in SAP, MCAC or MCL. This necessitates understanding its role in mycobacterial species when they are surviving in hosts such as humans or other animals. In this direction, analysis of some secondary metabolite functions pointed out that some secondary metabolites are certainly helping mycobacterial species to survive in their hosts. For example, MAR/MAP BGC products are found to be part of the cell envelope in *M. marinum*, possibly complicating its access to host immune system or drug actions (Parvez et al., 2018); Akaeolide has cytotoxic activity against fibroblasts, suggesting it may play a role in tissue weakening in the host (Zhou et al., 2015); JBIR-100 exhibits cytotoxic activities and inhibition of proton pumps such as vacuolar-type ATPases (V-ATPases) activities and is thus linked with an increasing number of diseases such as osteopetrosis, male infertility and renal acidosis (Huss and Wieczorek, 2009, Ueda et al., 2010). Lorneic acid A inhibits phosphodiesterase PDE5 blocking the degradation of cGMP (Iwata et al., 2009) and thus it might be playing a role in pulmonary hypertension. Meridamycin has been found to bind FK506-binding proteins (FKBP12) (Salituro et al., 1995). FKBP12 proteins play a key role in regulating fundamental aspects of cell biology and have been found to be critical in mice survival (Aghdasi et al., 2001). Nigericin inhibits the Golgi functions in eukaryotic cells and is a well-known activator of the NLRP3 inflammasome (Rao et al., 2008, Katsnelson et al., 2015, Wawrocki and Druszczynska, 2017), indicating bacterial infection. One secondary metabolite, namely mycolactone, a lipid-like toxin with cytotoxic, immunosuppressive and tissue necrosis activity, has been shown to be involved in the development of Buruli ulcer by *M. ulcerans* (Sarfo et al., 2016).

Table 4. 3 Functional analysis of homolog CYP139A P450 gene clusters.

Gene Cluster	Function	Reference
ML-449	Macrolactam antifungal-antibiotic production.	Jorgensen et al., 2010
MAR/MAP	Synthesis of methylated alkyl-resorcinol and methylated acyl-phloroglucinol products found to be part of cell envelope in *M. marinum.*	Parvez et al., 2018
Nystatin	Polyene antifungal antibiotic.	Brautaset et al., 2000
Jerangolid	Antifungal polyketide.	Julien et al., 2006
Piericidin A1	A member of α-pyridone antibiotics, exhibits various biological activities such as antimicrobial, antifungal, and antitumour properties and possesses potent respiration-inhibitory activity against insects owing to its competitive binding capacity to mitochondrial complex I.	Li et al., 2019
Streptomycin	Antibiotic used to treat bacterial infections, including tuberculosis.	Distler et al., 1987
Nanchangmycin	A polyether ionophore antibiotic produced by *Streptomyces nanchangensis* NS3226 that has insecticidal and in vitro antibacterial properties. Nanchangmycin exhibits antiviral properties against the Zika virus.	Sun et al., 2003, Liu et al., 2008, Rausch et al., 2017
Neoaureothin	Neoaureothin is an unusual chain-extended analog of aureothin. It was first reported	Cassinelli et al., 1967

	as a co-metabolite of neoantimycin in *Streptomyces orinoci.* It has been reported to have anti-HIV and antifungal activity.	
Akaeolide	A carbocyclic polyketide with moderate antimicrobial activity and cytotoxicity to rat fibroblasts.	Zhou et al., 2015
Kendomycin	Macrolide antibiotic with antibacterial activity.	Elnakady et al., 2016
ECO-02301	Antifungal agent.	McAlpine et al., 2005
Tiacumicin B	Macrolide antibiotic, which is used for the treatment of *Clostridium difficile* infections.	Xiao et al., 2011, Glaus and Altmann, 2015
Apoptolidin	Macrolide antibiotic well known as apoptosis inducer and inhibitor of F0F1-ATPase. It is a promising new therapeutic lead that exhibits remarkable selectivity against cancer cells relative to normal cells.	Kim et al., 1997, Salomon et al., 2001, Wender et al., 2005
Abyssomicin	A novel spirotetronate polyketide Class I antimicrobial. The biological activity of abyssomicins includes their antimicrobial activity against Gram-positive bacteria and mycobacteria, antitumour properties, latent HIV reactivator, anti-HIV and HIV replication inducer properties	Sadaka et al., 2018
JBIR-100	A new 16-membered tetraene macrolide from the *Streptomyces* species. Its structure is identical to TS155-2, which is an inhibitor of the thrombin-induced calcium influx. It exhibits cytotoxic and V-ATPases inhibition activities. V-ATPases are	Huss and Wieczorek, 2009, Ueda et al., 2010

	ubiquitous proton pumps present in the endomembrane system of all eukaryotic cells and in the plasma membranes of many animal cells that have been correlated with an increasing number of diseases such as osteopetrosis, male infertility and renal acidosis.	
Micromonolactam	A new polyene macrolactam antibiotic	Skellam et al., 2013
Lorneic acid A	It has a fatty acid-like structure in which a benzene ring is embedded. It inhibits phosphodiesterases (PDE) with selectivity toward PDE5, thus, blocking the degradation of cGMP and having a possible linkage to pulmonary hypertension	Iwata et al., 2009
Leucanicidin	A potent nematocide and insecticide macrolide	Isogai A., 1984
Oligomycin	A natural antibiotic that inhibits mitochondrial ATP synthase, thus affecting the electron transport chain.	Symersky et al., 2012
Spirangien	Highly cytotoxic and antifungal spiroketal	Niggemann et al., 2005
Stenothricin	A peptide antibiotic inhibiting bacterial cell wall synthesis	Hasenbohler et al., 1974
Borrelidin	A small molecule nitrile-containing macrolide, which is an inhibitor of bacterial and eukaryal threonyl-tRNA synthetase. It exhibits among others antibacterial and anti-angiogenesis activities, suppresses growth and induces apoptosis in malignant acute lymphoblastic leukemia cells.	Habibi et al., 2012, Olano et al., 2004
FD-891	Profoundly blocked both perforin- and FasL-dependent cytotoxicity by cytotoxic T	Kataoka et al., 2000

	lymphocytes—immunosuppressive.	
FR-008	Macrolide antibiotic with antifungal activity.	Zhou et al., 2008
Meridamycin	A 27-membered macrolide that acts as non-immunosuppressive FK506-binding proteins *(*FKBP12) ligand.	Salituro et al., 1995
Ambruticin	Antifungal polyketide	Vetcher et al., 2007
Nigericin	Nigericin acts as an H^+, K^+, Pb^{2+} ionophore. Most commonly it is an antiporter of H^+ and K^+. In the past nigericin was used as an antibiotic active against Gram-positive bacteria. It inhibits Golgi functions in eukaryotic cells. Its ability to induce K^+ efflux also makes it a potent activator of the NLRP3 inflammasome.	Rao et al., 2008, Katsnelson et al., 2015, Wawrocki and Druszczynska, 2017
Mycolactone	Lipid-like toxin with cytotoxic, immunosuppressive and tissue necrosis activity. It plays a key role in the development of Buruli ulcer by *M. ulcerans*.	Brautaset et al., 2000

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CHAPTER 5: CONCLUSIONS AND FUTURE PERSPECTIVES

5.1. Conclusion

The advancement of genome sequencing and bioinformatics tools helps significantly in understanding the role of orphan proteins in organisms. This study is an attempt to use the availability of quite a large number of mycobacterial species' genome sequences and different bioinformatics tools to understand the role of the orphan CYP139 family in mycobacterial species. This study revealed that the CYP139 family indeed plays a role in the synthesis of secondary metabolites in mycobacterial species. Based on the functions of homolog CYP139 P450 gene clusters' secondary metabolites, it can be assumed that these metabolites help mycobacterial species to survive in the host, being part of the cell envelope and inhibiting fibroblast, thus causing tissue weakening and causing ulcers *via* tissue necrosis. The metabolites that exhibit antibacterial (including antimycobacterial), antifungal and antiviral properties certainly help mycobacterial species to gain the upper hand in the niche area compared to those agents.

5.2. Future studies

Predictions made in the study are based on the functions of homolog secondary metabolites. However, wet laboratory biosynthesis and functional analysis of secondary metabolites should be carried out to understand the role of these metabolites in mycobacterial physiology. To better understand the role of CYP139A P450 and the secondary metabolite produced by its gene cluster in *Mycobacterium tuberculosis* H37Rv cloning, expression and functional analysis of the entire biosynthetic gene cluster need to be carried out. Furthermore, the purified metabolite structure and its toxic properties should be assessed.

Supplementary Table

Mycobacterial species used in the study. Integrated Microbial Genomes & Microbiomes database (Chen et al., 2019) genome IDs for each species are listed. Mycobacterial species were categorized into different groups as following the criteria described elsewhere (Parvez et al., 2016).

No.	Species name	Genome ID	No.	Species name	Genome ID
***Mycobacterium tuberculosis* complex (MTBC)**					
1.	*Mycobacterium tuberculosis* BT2	2565956582	479.	*Mycobacterium tuberculosis* M1787	2579778511
2.	*Mycobacterium tuberculosis* PanR0604	2554235249	480.	*Mycobacterium tuberculosis* F11 (ExPEC)	640427123
3.	*Mycobacterium tuberculosis* M1283	2576861262	481.	*Mycobacterium tuberculosis* UM 1072388579	2551306486
4.	*Mycobacterium tuberculosis* TKK_02_0022	2590828642	482.	*Mycobacterium tuberculosis* TBR58	2574179887
5.	*Mycobacterium tuberculosis* CDC1551A	2537561546	483.	*Mycobacterium tuberculosis* XTB13-082	2582581155
6.	*Mycobacterium bovis* Wt 21419	2579778875	484.	*Mycobacterium tuberculosis* TKK_02_0003	2590828651
7.	*Mycobacterium tuberculosis* KZN R506	648276692	485.	*Mycobacterium tuberculosis* TKK-01-0029	2588253994
8.	*Mycobacterium tuberculosis* M1415	2582581220	486.	*Mycobacterium tuberculosis* TKK_04_0039	2590828676

9.	*Mycobacterium tuberculosis* TRUG0117	2582581221	487.	*Mycobacterium tuberculosis* TKK_04_0031	2590828680
10.	*Mycobacterium tuberculosis* TKK_05MA_0033	2576861202	488.	*Mycobacterium tuberculosis* TKK-01-0044	2588254003
11.	*Mycobacterium bovis* BCG Tokyo 172	643692028	489.	*Mycobacterium tuberculosis* TKK_04_0054	2576861144
12.	*Mycobacterium tuberculosis* TKK_02_0016	2590828647	490.	*Mycobacterium tuberculosis* TKK-01-0063	2588254015
13.	*Mycobacterium tuberculosis* TBR5	2588253868	491.	*Mycobacterium tuberculosis* XTB13-290	2582581214
14.	*Mycobacterium tuberculosis* TKK_04_0003	2574180319	492.	*Mycobacterium tuberculosis* TKK_04_0046	2590828674
15.	*Mycobacterium* sp. MOTT36Y	2518645550	493.	*Mycobacterium tuberculosis* M1481	2574179996
16.	*Mycobacterium mageritense* JR2009	2548876798	494.	*Mycobacterium tuberculosis* 1010SM	2582581173
17.	*Mycobacterium tuberculosis* PanR0402	2554235300	495.	*Mycobacterium tuberculosis* TBR43	2588253879
18.	*Mycobacterium tuberculosis* TRUG0106	2582581172	496.	*Mycobacterium tuberculosis* TKK-01-0042	2588254000

19.	*Mycobacterium tuberculosis* TRUG0107	2574180353	497.	*Mycobacterium bovis Bz* 31150	2579778928
20.	*Mycobacterium tuberculosis* XTB13-229	2574180114	498.	*Mycobacterium tuberculosis* TKK_04_0080	2574179845
21.	*Mycobacterium tuberculosis* MAL010078	2588254096	499.	*Mycobacterium tuberculosis* TB_RSA74	2576861342
22.	*Mycobacterium tuberculosis* TBR59	2588253887	500.	*Mycobacterium tuberculosis* XTB13-081	2574180407
23.	*Mycobacterium tuberculosis* TB_RSA06	2574180201	501.	*Mycobacterium tuberculosis* SUMu011	648276703
24.	*Mycobacterium tuberculosis* OFXR-19	2576861001	502.	*Mycobacterium tuberculosis* TKK_04_0117	2574180398
25.	*Mycobacterium tuberculosis* MAL020182	2588254123	503.	*Mycobacterium tuberculosis* TKK-01-0026	2576861324
26.	*Mycobacterium tuberculosis* TKK-01-0067	2588254024	504.	*Mycobacterium tuberculosis* M1703	2582581158
27.	*Mycobacterium tuberculosis* TKK-01-0092	2588254036	505.	*Mycobacterium tuberculosis* TBR37	2574180426
28.	*Mycobacterium tuberculosis* TKK_02_0052	2590828634	506.	*Mycobacterium tuberculosis* KT-0045	2588254148

29.	*Mycobacterium tuberculosis* KT-0017	2588254156	507.	*Mycobacterium tuberculosis* TKK_03_0035	2585427842
30.	*Mycobacterium tuberculosis* OFXR-17	2588254187	508.	*Mycobacterium tuberculosis* TKK_04_0019	2574179963
31.	*Mycobacterium tuberculosis* 7199-99	2540341146	509.	*Mycobacterium tuberculosis* XTB13-251	2574179953
32.	*Mycobacterium tuberculosis* OFXR-25	2588254181	510.	*Mycobacterium tuberculosis* TKK_03_0118	2576861301
33.	*Mycobacterium tuberculosis* MAL020131	2574179850	511.	*Mycobacterium tuberculosis* PanR0311	2554235240
34.	*Mycobacterium tuberculosis* TKK-01-0008	2588253844	512.	*Mycobacterium tuberculosis* MAL020120	2576861089
35.	*Mycobacterium tuberculosis* MAL020179	2574180380	513.	*Mycobacterium indicuspranii* MTCC 9506	2521172703
36.	*Mycobacterium massiliense* 2B-0626	2526164657	514.	*Mycobacterium tuberculosis* PanR1101	2554235276
37.	*Mycobacterium africanum* MAL010111	2574180196	515.	*Mycobacterium tuberculosis* CCDC5079	651053043
38.	*Mycobacterium tuberculosis* OFXR-21	2588254184	516.	*Mycobacterium tuberculosis* TKK_03_0025	2590828621

39.	*Mycobacterium africanum* K85	645951854	517.	*Mycobacterium tuberculosis* OFXR-5	2588253897
40.	*Mycobacterium tuberculosis* PanR0209	2554235214	518.	*Mycobacterium tuberculosis* BTB11-001	2574180074
41.	*Mycobacterium tuberculosis* XTB13-198	2582581195	519.	*Mycobacterium tuberculosis* M1023	2576861102
42.	*Mycobacterium tuberculosis* PanR0410	2554235306	520.	*Mycobacterium tuberculosis* OFXR-8	2574180057
43.	*Mycobacterium tuberculosis* BTB12-449	2576861060	521.	*Mycobacterium africanum* MAL010137	2574180130
44.	*Mycobacterium tuberculosis* OFXR-4	2588253900	522.	*Mycobacterium tuberculosis* KZN 605 (XDR)	645058861
45.	*Mycobacterium tuberculosis* PanR0309	2554235242	523.	*Mycobacterium tuberculosis* M1956	2582581134
46.	*Mycobacterium iranicum* UM_TJL	2585427704	524.	*Mycobacterium tuberculosis* TKK-01-0069	2588253848
47.	*Mycobacterium tuberculosis* TBR29	2588253874	525.	*Mycobacterium tuberculosis* KT-0007	2588254161
48.	*Mycobacterium tuberculosis* BTB06-001	2576861352	526.	*Mycobacterium tuberculosis* PanR0316	2554235250

49.	*Mycobacterium tuberculosis* TKK-01-0077	2574180051	527.	*Mycobacterium tuberculosis* KT-0040	2574180203
50.	*Mycobacterium tuberculosis* OFXR-15	2574180344	528.	*Mycobacterium tuberculosis* TKK_03_0083	2576861224
51.	*Mycobacterium tuberculosis* TKK-01-0051	2576861218	529.	*Mycobacterium tuberculosis* MAL020194	2588254128
52.	*Mycobacterium tuberculosis* TKK_04_0132	2576861181	530.	*Mycobacterium tuberculosis* TKK-01-0013	2588253984
53.	*Mycobacterium tuberculosis* SUMu009	648276701	531.	*Mycobacterium* sp. UNC410CL29Cvi84	2563366507
54.	*Mycobacterium tuberculosis* PanR0602	2554235252	532.	*Mycobacterium tuberculosis* PanR0308	2554235237
55.	*Mycobacterium* sp. UNC267MFSha1.1M11	2593339259	533.	*Mycobacterium tuberculosis* TKK-01-0037	2576861280
56.	*Mycobacterium tuberculosis* PanR0405	2554235292	534.	*Mycobacterium tuberculosis* TKK-01-0062	2588254014
57.	*Mycobacterium tuberculosis* XTB13-255	2576861384	535.	*Mycobacterium tuberculosis* KT-0002	2588254163
58.	*Mycobacterium tuberculosis* TKK-01-0050	2588254005	536.	*Mycobacterium tuberculosis* SK-B	2574180419

59.	*Mycobacterium tuberculosis* MD15974	2576861090	537.	*Mycobacterium tuberculosis* KT-0092	2588254231
60.	*Mycobacterium tuberculosis* TKK_04_0103	2574180277	538.	*Mycobacterium tuberculosis* TKK_04_0051	2574180317
61.	*Mycobacterium tuberculosis* TRUG0037	2574180240	539.	*Mycobacterium tuberculosis* KT-0023	2588254154
62.	*Mycobacterium tuberculosis* XTB13-209	2574179941	540.	*Mycobacterium tuberculosis* TKK_05SA_0042	2582581190
63.	*Mycobacterium tuberculosis* T92	642979311	541.	*Mycobacterium tuberculosis* MAL020162	2574180078
64.	*Mycobacterium tuberculosis* TB_RSA01	2582581153	542.	*Mycobacterium tuberculosis* TB_RSA21	2576861264
65.	*Mycobacterium tuberculosis* CPHL_A	2576861059	543.	*Mycobacterium bovis* BCG Pasteur 1173P2	639633040
66.	*Mycobacterium tuberculosis* BTB13-063	2574180264	544.	*Mycobacterium tuberculosis* MAL020132	2588254107
67.	*Mycobacterium xenopi* 4042	2565956798	545.	*Mycobacterium tuberculosis* M1444	2574180216
68.	*Mycobacterium tuberculosis* TBR35	2588253877	546.	*Mycobacterium tuberculosis* TBR53	2588253886

69.	*Mycobacterium tuberculosis* XTB13-113	2582581179	547.	*Mycobacterium tuberculosis* MAL020174	2588254121
70.	*Mycobacterium tuberculosis* TB_RSA149	2576861030	548.	*Mycobacterium bovis* AF 2122/97	637000169
71.	*Mycobacterium tuberculosis* BTB03-144	2576861021	549.	*Mycobacterium tuberculosis* TKK_04_0040	2576861019
72.	*Mycobacterium tuberculosis* MD15050	2582581211	550.	*Mycobacterium tuberculosis* KT-0042	2574179907
73.	*Mycobacterium tuberculosis* TB_RSA120	2576861148	551.	*Mycobacterium tuberculosis* TKK_02_0014	2582581209
74.	*Mycobacterium tuberculosis* KT-0086	2574179857	552.	*Mycobacterium tuberculosis* M2137	2576861176
75.	*Mycobacterium tuberculosis* TKK_04_0082	2582581165	553.	*Mycobacterium bovis* D 4155	2579778729
76.	*Mycobacterium tuberculosis* GM 1503	2576861289	554.	*Mycobacterium tuberculosis* TKK-01-0089	2588254027
77.	*Mycobacterium tuberculosis* EAI5/NITR206	2545824630	555.	*Mycobacterium tuberculosis* TB_RSA78	2576861336
78.	*Mycobacterium tuberculosis* MAL020208	2588254138	556.	*Mycobacterium tuberculosis* SUMu002	648276694

79.	*Mycobacterium tuberculosis* TKK-01-0056	2588254017	557.	*Mycobacterium tuberculosis* MD17888	2574179949
80.	*Mycobacterium tuberculosis* CTRI-2	2511231130	558.	*Mycobacterium tuberculosis* KT-0106	2588254226
81.	*Mycobacterium tuberculosis* TKK_02_0002	2582581175	559.	*Mycobacterium tuberculosis* KT-0078	2588254238
82.	*Mycobacterium tuberculosis* TKK_04_0005	2590828609	560.	*Mycobacterium tuberculosis* SUMu007	648276699
83.	*Mycobacterium tuberculosis* TKK_04_0029	2590828682	561.	*Mycobacterium tuberculosis* TKK-01-0081	2588254026
84.	*Mycobacterium tuberculosis* PanR0909	2554235274	562.	*Mycobacterium tuberculosis* TB_RSA76	2574180299
85.	*Mycobacterium tuberculosis* MD18478	2576861285	563.	*Mycobacterium tuberculosis* XTB13-114	2574179861
86.	*Mycobacterium tuberculosis* TRUG0101	2574180401	564.	*Mycobacterium tuberculosis* MTB-476	2571042747
87.	*Mycobacterium tuberculosis* TBR7	2574180207	565.	*Mycobacterium tuberculosis* G-12-005	2576861111
88.	*Mycobacterium tuberculosis* TBR75	2588253891	566.	*Mycobacterium tuberculosis* TKK_04_0120	2574179819

89.	*Mycobacterium tuberculosis* PanR0702	2554235271	567.	*Mycobacterium tuberculosis* KZN 4207 (DS)	2511231070
90.	*Mycobacterium tuberculosis* MAL020144	2574180408	568.	*Mycobacterium africanum* MAL010136	2582580876
91.	*Mycobacterium tuberculosis* TKK-01-0083	2588254031	569.	*Mycobacterium tuberculosis* BTB03-143	2574180392
92.	*Mycobacterium tuberculosis* MD17902	2574179965	570.	*Mycobacterium tuberculosis* TKK-01-0024	2588253990
93.	*Mycobacterium tuberculosis* TKK_02_0046	2590828635	571.	*Mycobacterium tuberculosis* MD18498	2574179919
94.	*Mycobacterium tuberculosis* TKK-01-0059	2588254012	572.	*Mycobacterium africanum* MAL010131	2579778881
95.	*Mycobacterium tuberculosis* TKK_03_0026	2574179863	573.	*Mycobacterium tuberculosis* TB_RSA134	2574180106
96.	*Mycobacterium tuberculosis* BTB13-276	2585427841	574.	*Mycobacterium tuberculosis* TKK_04_0023	2590828598
97.	*Mycobacterium tuberculosis* SK-C	2590828653	575.	*Mycobacterium tuberculosis* XTB13-110	2582581208
98.	*Mycobacterium tuberculosis* MAL020156	2588254119	576.	*Mycobacterium tuberculosis* OSDD071	2548876689

99.	*Mycobacterium tuberculosis* TKK-01-0064	2582581132	577.	*Mycobacterium massiliense* 1S-151-0930	2526164659
100.	*Mycobacterium tuberculosis* 2094HD	2576861074	578.	*Mycobacterium tuberculosis* MAL020200	2588254133
101.	*Mycobacterium tuberculosis* 1615	2576861307	579.	*Mycobacterium tuberculosis* H3986	2574180065
102.	*Mycobacterium tuberculosis* TKK-01-0022	2588253986	580.	*Mycobacterium tuberculosis* BTB12-206	2582581197
103.	*Mycobacterium tuberculosis* TKK_03_0020	2590828623	581.	*Mycobacterium tuberculosis* PanR0902	2554235263
104.	*Mycobacterium tuberculosis* TKK_02_0073	2590828626	582.	*Mycobacterium tuberculosis* TB_RSA97	2574180375
105.	*Mycobacterium tuberculosis* CTRI-4	2547132221	583.	*Mycobacterium tuberculosis* TKK_03_0034	2590828616
106.	*Mycobacterium africanum* MAL010102	2576861083	584.	*Mycobacterium tuberculosis* PanR0317	2554235302
107.	*Mycobacterium tuberculosis* BS1	2558860211	585.	*Mycobacterium tuberculosis* TRUG0070	2574180005
108.	*Mycobacterium tuberculosis* TKK_04_0044	2574180195	586.	*Mycobacterium tuberculosis* TKK_04_0018	2590828601
109.	*Mycobacterium tuberculosis* M1004	2576861107	587.	*Mycobacterium tuberculosis* TKK-01-0005	2588253980
110.	*Mycobacterium tuberculosis* MAL020147	2588254116	588.	*Mycobacterium tuberculosis* PanR0315	2554235246
111.	*Mycobacterium canettii* CIPT 140070010	2540341073	589.	*Mycobacterium tuberculosis* TBR24	2588253872
112.	*Mycobacterium tuberculosis* TB_RSA03	2574179837	590.	*Mycobacterium tuberculosis* T85	642979364
113.	*Mycobacterium tuberculosis* M2416	2574179873	591.	*Mycobacterium bovis* BCG Korea 1168P	2540341164

114.	*Mycobacterium bovis* BCG-Russia TMC 1022 , ATCC 35740	2547132087	592.	*Mycobacterium tuberculosis* BTB10-308	2574180291
115.	*Mycobacterium tuberculosis* TBR28	2574180031	593.	*Mycobacterium tuberculosis* 210	647000279
116.	*Mycobacterium tuberculosis* MD16555	2582581192	594.	*Mycobacterium tuberculosis* TKK_04_0067	2582581219
117.	*Mycobacterium tuberculosis* M1007	2574180366	595.	*Mycobacterium tuberculosis* TKK_02_0063	2590828631
118.	*Mycobacterium massiliense* 2B-0912-R	2526164655	596.	*Mycobacterium tuberculosis* PanR0313	2554235254
119.	*Mycobacterium tuberculosis* SUMu012	648276704	597.	*Mycobacterium* sp. 141	2540341250
120.	*Mycobacterium tuberculosis* PanR0306	2554235244	598.	*Mycobacterium massiliense* 1S-152-0914	2526164580
121.	*Mycobacterium tuberculosis* TRUG0004	2574179830	599.	*Mycobacterium tuberculosis* TKK_02_0069	2590828628
122.	*Mycobacterium tuberculosis* BTB13-222	2574180330	600.	*Mycobacterium septicum* DSM 44393	2551306423
123.	*Mycobacterium tuberculosis* OFXR-30	2588254179	601.	*Mycobacterium tuberculosis* M1848	2574179855
124.	*Mycobacterium tuberculosis* TKK_04_0075	2574179902	602.	*Mycobacterium tuberculosis* TKK_04_0001	2590828610
125.	*Mycobacterium* sp. UM_WWY	2554235288	603.	*Mycobacterium tuberculosis* VRF CWCF XDRTB 1028	2597490246
126.	*Mycobacterium tuberculosis* HN878	2547132240	604.	*Mycobacterium tuberculosis* M2136	2574180209
127.	*Mycobacterium tuberculosis* H37Rv	2526164708	605.	*Mycobacterium tuberculosis* M1475	2582581167
128.	*Mycobacterium tuberculosis* M1233	2574180118	606.	*Mycobacterium tuberculosis* TRUG0098	2574179895

129.	*Mycobacterium tuberculosis* TBR4	2588253869	607.	*Mycobacterium tuberculosis* PanR0703	2554235267
130.	*Mycobacterium tuberculosis* TBR11	2588253870	608.	*Mycobacterium tuberculosis* Beijing/NITR203	2545824625
131.	*Mycobacterium tuberculosis* TKK-01-0019	2574180154	609.	*Mycobacterium tuberculosis* MAL020205	2588254136
132.	*Mycobacterium tuberculosis* KT-0084	2588254234	610.	*Mycobacterium tuberculosis* TKK-01-0075	2574180070
133.	*Mycobacterium canettii* CIPT 140070005	2565956759	611.	*Mycobacterium tuberculosis* KT-0096	2576861377
134.	*Mycobacterium africanum* MAL020130	2582580878	612.	*Mycobacterium tuberculosis* TKK-01-0036	2588253997
135.	*Mycobacterium tuberculosis* M1340	2582581131	613.	*Mycobacterium tuberculosis* TKK-01-0023	2588253846
136.	*Mycobacterium tuberculosis* XTB13-161	2576861213	614.	*Mycobacterium tuberculosis* MAL020110	2588254108
137.	*Mycobacterium tuberculosis* TKK_05MA_0012	2576861094	615.	*Mycobacterium tuberculosis* KZN 1435 (MDR)	644736391
138.	*Mycobacterium bovis* Wt 21231	2582580936	616.	*Mycobacterium tuberculosis* M2402	2574179880
139.	*Mycobacterium tuberculosis* M2346	2582581206	617.	*Mycobacterium tuberculosis* TBR30	2588253875
140.	*Mycobacterium tuberculosis* TB_RSA163	2576861005	618.	*Mycobacterium intracellulare* MOTT-02	2512564050
141.	*Mycobacterium tuberculosis* OFXR-7	2574180104	619.	*Mycobacterium tuberculosis* BTB11-214	2574180413
142.	*Mycobacterium tuberculosis* H3361	2574179930	620.	*Mycobacterium tuberculosis* OFXR-13	2574180360
143.	*Mycobacterium tuberculosis* TKK_04_0045	2582581189	621.	*Mycobacterium tuberculosis* 2483AR	2574179972
144.	*Mycobacterium tuberculosis* TKK-01-0054	2588254018	622.	*Mycobacterium tuberculosis* TKK_04_0064	2574180190

145.	*Mycobacterium tuberculosis* MAL020196	2588254131	623.	*Mycobacterium tuberculosis* TKK_04_0034	2590828679
146.	*Mycobacterium tuberculosis* KT-0035	2588254151	624.	*Mycobacterium tuberculosis* OFXR-1	2588254142
147.	*Mycobacterium tuberculosis* NRITLD14	2576861298	625.	*Mycobacterium tuberculosis* W-148	2547132198
148.	*Mycobacterium tuberculosis* PanR0804	2554235265	626.	*Mycobacterium tuberculosis* WX3	2558860632
149.	*Mycobacterium tuberculosis* XTB13-092	2582581160	627.	*Mycobacterium africanum* MAL010112	2574179981
150.	*Mycobacterium tuberculosis* TB_RSA111	2574179811	628.	*Mycobacterium tuberculosis* TKK-01-0087	2588254033
151.	*Mycobacterium tuberculosis* TB_RSA59	2574180388	629.	*Mycobacterium tuberculosis* MAL020142	2588254114
152.	*Mycobacterium tuberculosis* BTB12-001	2574179928	630.	*Mycobacterium tuberculosis* TKK-01-0079	2576861103
153.	*Mycobacterium tuberculosis* KT-0102	2588254228	631.	*Mycobacterium africanum* MAL020185	2579778664
154.	*Mycobacterium tuberculosis* XDR1219	2558860629	632.	*Mycobacterium tuberculosis* TKK-01-0016	2588253988
155.	*Mycobacterium tuberculosis* NRITLD56	2576861167	633.	*Mycobacterium tuberculosis* TRUG0040	2576861031
156.	*Mycobacterium tuberculosis* H37Rv	637000173	634.	*Mycobacterium tuberculosis* TKK_02_0036	2590828637
157.	*Mycobacterium tuberculosis* BTB09-565	2576861338	635.	*Mycobacterium tuberculosis* TKK_02_0020	2590828644
158.	*Mycobacterium tuberculosis* RGTB423	2513237185	636.	*Mycobacterium africanum* MAL010120	2579778639
159.	*Mycobacterium tuberculosis* TKK_02_0067	2590828630	637.	*Mycobacterium tuberculosis* TBR48	2588253882
160.	*Mycobacterium tuberculosis* TBR80	2588253892	638.	*Mycobacterium tuberculosis* M1700	2582581203

161.	*Mycobacterium tuberculosis* TKK-01-0034	2588254002	639.	*Mycobacterium tuberculosis* MD15956	2582581210
162.	*Mycobacterium tuberculosis* TKK_04_0038	2582581184	640.	*Mycobacterium tuberculosis* KT-0014	2588254159
163.	*Mycobacterium tuberculosis* TB_RSA118	2574180046	641.	*Mycobacterium tuberculosis* TKK_03_0109	2574180053
164.	*Mycobacterium tuberculosis* MAL010130	2588254104	642.	*Mycobacterium tuberculosis* BTB07-325	2576861349
165.	*Mycobacterium tuberculosis* PanR0805	2554235258	643.	*Mycobacterium tuberculosis* X122	2547132239
166.	*Mycobacterium tuberculosis* KT-0109	2582581224	644.	*Mycobacterium tuberculosis* 44503	2582581129
167.	*Mycobacterium tuberculosis* XTB13-214	2576861314	645.	*Mycobacterium tuberculosis* TB_RSA166	2582581154
168.	*Mycobacterium tuberculosis* PanR0208	2554235211	646.	*Mycobacterium tuberculosis* TKK-01-0074	2588254019
169.	*Mycobacterium tuberculosis* TKK-01-0025	2576861375	647.	*Mycobacterium tuberculosis* TBR49	2588253883
170.	*Mycobacterium tuberculosis* TBR65	2574179889	648.	*Mycobacterium tuberculosis* TKK-01-0073	2588254021
171.	*Mycobacterium tuberculosis* TKK_03_0022	2590828622	649.	*Mycobacterium tuberculosis* TKK_02_0018	2590828645
172.	*Mycobacterium tuberculosis* PanR0403	2554235298	650.	*Mycobacterium tuberculosis* BTB05-285	2576861086
173.	*Mycobacterium bovis* Mr 4387	2579778734	651.	*Mycobacterium tuberculosis* XTB13-094	2574180212
174.	*Mycobacterium tuberculosis* TKK-01-0007	2588253979	652.	*Mycobacterium tuberculosis* H37RvCO	2547132039
175.	*Mycobacterium tuberculosis* TB_RSA32	2576861325	653.	*Mycobacterium tuberculosis* TB_RSA82	2574180374
176.	*Mycobacterium tuberculosis* OFXR-20	2588254185	654.	*Mycobacterium tuberculosis* KT-0108	2574180043

177.	*Mycobacterium tuberculosis* KT-0056	2574180411	655.	*Mycobacterium tuberculosis* TB_RSA09	2576861006
178.	*Mycobacterium tuberculosis* TRUG0072	2582581141	656.	*Mycobacterium tuberculosis* XTB13-162	2576861284
179.	*Mycobacterium tuberculosis* M1906	2574180244	657.	*Mycobacterium tuberculosis* PanR0607	2554235269
180.	*Mycobacterium tuberculosis* BTB12-384	2582581217	658.	*Mycobacterium tuberculosis* OFXR-33	2576861140
181.	*Mycobacterium tuberculosis* TBR23	2588253873	659.	*Mycobacterium tuberculosis* TKK_04_0014	2590828604
182.	*Mycobacterium tuberculosis* TB_RSA148	2574180007	660.	*Mycobacterium tuberculosis* KT-0041	2582581146
183.	*Mycobacterium tuberculosis* M2203	2582581138	661.	*Mycobacterium tuberculosis* TB_RSA64	2579778506
184.	*Mycobacterium tuberculosis* TKK_05SA_0014	2576861279	662.	*Mycobacterium tuberculosis* M2508	2576861098
185.	*Mycobacterium tuberculosis* MAL020160	2588254111	663.	*Mycobacterium tuberculosis* T67	2588253770
186.	*Mycobacterium tuberculosis* TKK_03_0045	2590828613	664.	*Mycobacterium tuberculosis* MD16277	2574180259
187.	*Mycobacterium tuberculosis* TKK-01-0028	2588253995	665.	*Mycobacterium tuberculosis* XTB13-086	2582581164
188.	*Mycobacterium tuberculosis* XTB13-200	2574180197	666.	*Mycobacterium tuberculosis* KT-0001	2576861345
189.	*Mycobacterium tuberculosis* XTB13-088	2582581136	667.	*Mycobacterium* sp. URHD0025	2522572101
190.	*Mycobacterium tuberculosis* TKK_04_0002	2582581216	668.	*Mycobacterium tuberculosis* TKK_03_0082	2590828611
191.	*Mycobacterium tuberculosis* TKK-01-0065	2582581199	669.	*Mycobacterium tuberculosis* M1961	2582581148
192.	*Mycobacterium tuberculosis* TB_RSA51	2576861229	670.	*Mycobacterium africanum* MAL010129	2579779005

193.	*Mycobacterium tuberculosis* M1449	2574180026	671.	*Mycobacterium tuberculosis* MAL010080	2588254095
194.	*Mycobacterium tuberculosis* TKK_02_0068	2590828629	672.	*Mycobacterium tuberculosis* PanR0708	2554235260
195.	*Mycobacterium canettii* CIPT 140070002	2565956758	673.	*Mycobacterium tuberculosis* TB_RSA174	2574179966
196.	*Mycobacterium bovis* BCG-Denmark TMC 1010, ATCC 35733	2547132085	674.	*Mycobacterium tuberculosis* PanR0501	2554235251
197.	*Mycobacterium tuberculosis* TKK_02_0015	2574179843	675.	*Mycobacterium tuberculosis* BTB11-343	2574180113
198.	*Mycobacterium bovis* Kc 32216	2582580974	676.	*Mycobacterium tuberculosis* TB_RSA127	2576861191
199.	*Mycobacterium tuberculosis* TKK-01-0068	2576861246	677.	*Mycobacterium tuberculosis* MAL020181	2574179832
200.	*Mycobacterium tuberculosis* KT-0058	2588254144	678.	*Mycobacterium tuberculosis* TKK-01-0011	2574180079
201.	*Mycobacterium tuberculosis* XTB13-199	2576861274	679.	*Mycobacterium canettii* CIPT 140070017	2541047046
202.	*Mycobacterium tuberculosis* MAL020192	2588254126	680.	*Mycobacterium tuberculosis* Haarlem	2588254170
203.	*Mycobacterium tuberculosis* TB_RSA138	2576861291	681.	*Mycobacterium tuberculosis* OFXR-32	2588254177
204.	*Mycobacterium tuberculosis* KT-0048	2588254146	682.	*Mycobacterium tuberculosis* KT-0064	2588254242
205.	*Mycobacterium tuberculosis* KZN 4207	647000280	683.	*Mycobacterium tuberculosis* TBR60	2588253889
206.	*Mycobacterium tuberculosis* TKK_04_0129	2582581169	684.	*Mycobacterium tuberculosis* TKK_04_0140	2574180349
207.	*Mycobacterium tuberculosis* BTB08-362	2574179970	685.	*Mycobacterium tuberculosis* TBR74	2588253890
208.	*Mycobacterium tuberculosis* TB_RSA132	2576861318	686.	*Mycobacterium tuberculosis* TB_RSA77	2576861091

209.	*Mycobacterium* sp. UNC280MFTsu5.1	2579778519	687.	*Mycobacterium tuberculosis* KT-0098	2582581194
210.	*Mycobacterium tuberculosis* 16955	2574179955	688.	*Mycobacterium tuberculosis* MD16265	2576861154
211.	*Mycobacterium tuberculosis* PanR0301	2554235239	689.	*Mycobacterium tuberculosis* TKK_03_0042	2574180172
212.	*Mycobacterium tuberculosis* TKK_04_0072	2582581151	690.	*Mycobacterium tuberculosis* H2581	2574180320
213.	*Mycobacterium tuberculosis* BTB04-452	2574180214	691.	*Mycobacterium tuberculosis* OFXR-3	2574180342
214.	*Mycobacterium tuberculosis* M2131	2574180418	692.	*Mycobacterium tuberculosis* MAL010117	2588254102
215.	*Mycobacterium tuberculosis* KT-0016	2588254157	693.	*Mycobacterium tuberculosis* OSDD518	2548876691
216.	*Mycobacterium tuberculosis* XTB13-123	2576861391	694.	*Mycobacterium bovis* B2 7505	2579778623
217.	*Mycobacterium tuberculosis* MAL010133	2574180004	695.	*Mycobacterium tuberculosis* BTB07-254	2582581222
218.	*Mycobacterium tuberculosis* OFXR-2	2588253895	696.	*Mycobacterium tuberculosis* BTB13-206	2582581162
219.	*Mycobacterium tuberculosis* TKK_04_0042	2582581201	697.	*Mycobacterium tuberculosis* TKK-01-0047	2576861124
220.	*Mycobacterium africanum* MAL020148	2579778922	698.	*Mycobacterium intracellulare* 1956	2565956792
221.	*Mycobacterium tuberculosis* TKK_05SA_0012	2574180098	699.	*Mycobacterium tuberculosis* TB_RSA173	2574179905
222.	*Mycobacterium tuberculosis* MAL010088	2588254097	700.	*Mycobacterium tuberculosis* 49375	2576861156
223.	*Mycobacterium tuberculosis* TKK_05MA_0009	2582581171	701.	*Mycobacterium tuberculosis* TB_RSA178	2576861046
224.	*Mycobacterium tuberculosis* BTB05-559	2547132260	702.	*Mycobacterium tuberculosis* TB_RSA199	2574180228

225.	*Mycobacterium tuberculosis* BTB05-552	2547132259	703.	*Mycobacterium tuberculosis* MAL020195	2588254125
226.	*Mycobacterium tuberculosis* M1008	2574180370	704.	*Mycobacterium tuberculosis* TKK-01-0004	2588253981
227.	*Mycobacterium tuberculosis* MAL010105	2588254101	705.	*Mycobacterium tuberculosis* MD13878	2574179939
228.	*Mycobacterium tuberculosis* TBR44	2588253880	706.	*Mycobacterium tuberculosis* TBR50	2574180254
229.	*Mycobacterium tuberculosis* TKK_04_0048	2590828672	707.	*Mycobacterium tuberculosis* 02_1987	2576861165
230.	*Mycobacterium tuberculosis* TKK_02_0061	2590828633	708.	*Mycobacterium tuberculosis* NA-A0009	2551306109
231.	*Mycobacterium tuberculosis* TKK_04_0008	2590828606	709.	*Mycobacterium tuberculosis* MAL020141	2588254113
232.	*Mycobacterium tuberculosis* TKK-01-0082	2588254030	710.	*Mycobacterium tuberculosis* TKK-01-0032	2582581181
233.	*Mycobacterium tuberculosis* TB_RSA83	2574180255	711.	*Mycobacterium tuberculosis* KT-0037	2574180357
234.	*Mycobacterium tuberculosis* T46	2574179851	712.	*Mycobacterium tuberculosis* 1173CS	2574180368
235.	*Mycobacterium tuberculosis* EAS054	642979363	713.	*Mycobacterium intracellulare* M.i.198	2547132171
236.	*Mycobacterium tuberculosis* OFXR-22	2588254183	714.	*Mycobacterium tuberculosis* PanR0505	2554235256
237.	*Mycobacterium tuberculosis* TRUG0116	2582581130	715.	*Mycobacterium tuberculosis* SUMu010	648276702
238.	*Mycobacterium tuberculosis* SP21	2554235011	716.	*Mycobacterium chelonae* 1518	2565956796
239.	*Mycobacterium tuberculosis* TKK_03_0018	2590828624	717.	*Mycobacterium tuberculosis* TKK_05SA_0019	2576861044
240.	*Mycobacterium tuberculosis* NRITLD44	2574180131	718.	*Mycobacterium tuberculosis* TBR76	2588253894

241.	*Mycobacterium tuberculosis* PanR0801	2554235262	719.	*Mycobacterium tuberculosis* TKK_03_0099	2574180159
242.	*Mycobacterium tuberculosis* XTB13-238	2582581180	720.	*Mycobacterium tuberculosis* TKK_04_0006	2590828608
243.	*Mycobacterium tuberculosis* M2479	2576861239	721.	*Mycobacterium canettii* CIPT 140070007	2565956756
244.	*Mycobacterium tuberculosis* PanR0305	2554235243	722.	*Mycobacterium tuberculosis* PanR0601	2554235248
245.	*Mycobacterium aromaticivorans* JS19b1	2558309009	723.	*Mycobacterium tuberculosis* PanR0304	2554235238
246.	*Mycobacterium tuberculosis* TKK_04_0157	2574179876	724.	*Mycobacterium tuberculosis* MAL020145	2582581166
247.	*Mycobacterium tuberculosis* 51628	2582581135	725.	*Mycobacterium tuberculosis* M2006	2576861118
248.	*Mycobacterium tuberculosis* MD16577	2582581207	726.	*Mycobacterium tuberculosis* MD15855	2576861161
249.	*Mycobacterium tuberculosis* PanR0409	2554235307	727.	*Mycobacterium tuberculosis* TKK-01-0080	2588253849
250.	*Mycobacterium tuberculosis* MAL020187	2588254129	728.	*Mycobacterium tuberculosis* TKK_03_0156	2574179954
251.	*Mycobacterium tuberculosis* TKK-01-0060	2588254013	729.	*Mycobacterium tuberculosis* TB_RSA62	2582581200
252.	*Mycobacterium tuberculosis* TKK-01-0049	2588254006	730.	*Mycobacterium tuberculosis* OFXR-14	2588253896
253.	*Mycobacterium tuberculosis* TKK_04_0021	2574180080	731.	*Mycobacterium tuberculosis* TKK_05SA_0016	2574179918
254.	*Mycobacterium massiliense* 2B-0307	2526164658	732.	*Mycobacterium bovis* BCG Moreau RDJ	2619619103
255.	*Mycobacterium canettii* CIPT 140070008	2541047045	733.	*Mycobacterium tuberculosis* M1221	2574180073
256.	*Mycobacterium canettii* CIPT 140010059	650716060	734.	*Mycobacterium tuberculosis* CPHL_A	645951826

257.	*Mycobacterium intracellulare* MIN_052511_1280	2568526126	735.	*Mycobacterium tuberculosis* T92	2582581196
258.	*Mycobacterium tuberculosis* MAL020201	2588254134	736.	*Mycobacterium tuberculosis* XTB13-252	2582581150
259.	*Mycobacterium tuberculosis* KT-0022	2588254155	737.	*Mycobacterium tuberculosis* TKK_04_0017	2590828602
260.	*Mycobacterium tuberculosis* PanR0412	2554235308	738.	*Mycobacterium tuberculosis* MD15597	2582581212
261.	*Mycobacterium tuberculosis* TB_RSA67	2574180226	739.	*Mycobacterium tuberculosis* KT-0006	2588254162
262.	*Mycobacterium tuberculosis* TKK_02_0013	2590828648	740.	*Mycobacterium hassiacum* DSM 44199	2531839488
263.	*Mycobacterium tuberculosis* TKK_04_0066	2582581149	741.	*Mycobacterium tuberculosis* KT-0094	2588254230
264.	*Mycobacterium tuberculosis* OFXR-16	2588253901	742.	*Mycobacterium tuberculosis* TKK_03_0116	2576861018
265.	*Mycobacterium africanum* MAL020173	2579778878	743.	*Mycobacterium tuberculosis* TKK_05SA_0050	2576861143
266.	*Mycobacterium tuberculosis* Haarlem	641736194	744.	*Mycobacterium tuberculosis* BTB07-246	2582581145
267.	*Mycobacterium tuberculosis* TKK-01-0066	2588254025	745.	*Mycobacterium tuberculosis* TKK_02_0027	2590828640
268.	*Mycobacterium tuberculosis* NRITLD15	2576861348	746.	*Mycobacterium tuberculosis* FJ05194	2541047993
269.	*Mycobacterium tuberculosis* KT-0080	2588254236	747.	*Mycobacterium tuberculosis* TKK_02_0025	2590828641
270.	*Mycobacterium intracellulare* MIN_061107_1834	2568526481	748.	*Mycobacterium tuberculosis* TKK_04_0043	2590828675
271.	*Mycobacterium tuberculosis* PanR0611	2554235270	749.	*Mycobacterium tuberculosis* SUMu006	648276698
272.	*Mycobacterium tuberculosis* GuangZ0019	2545824696	750.	*Mycobacterium tuberculosis* MAL010109	2574180338

273.	*Mycobacterium tuberculosis* M2248	2576861095	751.	*Mycobacterium tuberculosis* GM 1503	642979350
274.	*Mycobacterium tuberculosis* TKK_03_0033	2590828617	752.	*Mycobacterium tuberculosis* TBR9	2588253871
275.	*Mycobacterium tuberculosis* TKK_05MA_0020	2574179862	753.	*Mycobacterium tuberculosis* TKK_05MA_0025	2574180121
276.	*Mycobacterium tuberculosis* TB_RSA107	2582581198	754.	*Mycobacterium tuberculosis* MD17615	2582581178
277.	*Mycobacterium tuberculosis* TKK_02_0021	2590828643	755.	*Mycobacterium tuberculosis* H37Ra	641736240
278.	*Mycobacterium tuberculosis* TKK_02_0039	2590828636	756.	*Mycobacterium tuberculosis* TKK-01-0030	2588253993
279.	*Mycobacterium tuberculosis* M1025	2576861368	757.	*Mycobacterium tuberculosis* PanR1005	2554235309
280.	*Mycobacterium tuberculosis* M1017	2576861286	758.	*Mycobacterium tuberculosis* XTB13-127	2574180027
281.	*Mycobacterium tuberculosis* TBR10	2579778510	759.	*Mycobacterium tuberculosis* KT-0069	2574179897
282.	*Mycobacterium tuberculosis* CCDC5180	651053044	760.	*Mycobacterium tuberculosis* KT-0047	2588254147
283.	*Mycobacterium tuberculosis* OFXR-11	2588253898	761.	*Mycobacterium tuberculosis* TKK-01-0033	2588253996
284.	*Mycobacterium tuberculosis* TRUG0080	2582581168	762.	*Mycobacterium tuberculosis* TKK_02_0012	2590828649
285.	*Mycobacterium tuberculosis* KT-0027	2576861321	763.	*Mycobacterium tuberculosis* KT-0053	2588254145
286.	*Mycobacterium bovis* BCG China	2547132084	764.	*Mycobacterium tuberculosis* TRUG0095	2582581213
287.	*Mycobacterium tuberculosis* MAL020152	2588254118	765.	*Mycobacterium tuberculosis* PanR0704	2554235295
288.	*Mycobacterium* sp. 05-1390	2541047007	766.	*Mycobacterium tuberculosis* M2113	2576861053

289.	*Mycobacterium tuberculosis* KT-0072	2574180239	767.	*Mycobacterium tuberculosis* XTB13-167	2576861145
290.	*Mycobacterium tuberculosis* T46	645951864	768.	*Mycobacterium tuberculosis* OFXR-10	2576861389
291.	*Mycobacterium tuberculosis* TKK_04_0015	2590828603	769.	*Mycobacterium intracellulare* ATCC 35771	651716583
292.	*Mycobacterium tuberculosis* TKK-01-0091	2576861042	770.	*Mycobacterium tuberculosis* TKK_03_0024	2576861081
293.	*Mycobacterium xenopi* 3993	2565956797	771.	*Mycobacterium tuberculosis* TKK_03_0043	2590828614
294.	*Mycobacterium tuberculosis* TBR8	2588253867	772.	*Mycobacterium tuberculosis* TKK_02_0038	2576861219
295.	*Mycobacterium massiliense* 2B-1231	2531839069	773.	*Mycobacterium tuberculosis* M2343	2574180021
296.	*Mycobacterium africanum* MAL010123	2579778981	774.	*Mycobacterium tuberculosis* KT-0003	2574180265
297.	*Mycobacterium africanum* MAL010071	2579779036	775.	*Mycobacterium tuberculosis* KT-0091	2574180058
298.	*Mycobacterium tuberculosis* M1418	2576861038	776.	*Mycobacterium tuberculosis* TB_RSA96	2574179846
299.	*Mycobacterium tuberculosis* TKK_04_0020	2590828600	777.	*Mycobacterium tuberculosis* TKK-01-0084	2588254032
300.	*Mycobacterium tuberculosis* TB_RSA07	2576861283	778.	*Mycobacterium tuberculosis* TB_RSA123	2576861323
301.	*Mycobacterium tuberculosis* PanR0404	2554235301	779.	*Mycobacterium tuberculosis* TKK_03_0036	2590828615
302.	*Mycobacterium tuberculosis* WX1	2558860630	780.	*Mycobacterium tuberculosis* MD16553	2574179804
303.	*Mycobacterium tuberculosis* TKK-01-0003	2588253983	781.	*Mycobacterium tuberculosis* BTB13-128	2574179888
304.	*Mycobacterium tuberculosis* OM-V02_005	2568526658	782.	*Mycobacterium tuberculosis* TKK-01-0035	2579778513

305.	*Mycobacterium tuberculosis* MAL020211	2588254140	783.	*Mycobacterium tuberculosis* MAL020172	2588254122
306.	*Mycobacterium tuberculosis* SUMu004	648276696	784.	*Mycobacterium tuberculosis* M2128	2576861209
307.	*Mycobacterium tuberculosis* TKK_04_0037	2590828677	785.	*Mycobacterium tuberculosis* TB_RSA15	2574180150
308.	*Mycobacterium tuberculosis* TKK-01-0045	2588254009	786.	*Mycobacterium tuberculosis* TKK-01-0072	2588253850
309.	*Mycobacterium tuberculosis* KT-0051	2574179952	787.	*Mycobacterium tuberculosis* TB_RSA79	2582581205
310.	*Mycobacterium tuberculosis* TKK-01-0027	2588253991	788.	*Mycobacterium tuberculosis* NCGM2209	2548876688
311.	*Mycobacterium tuberculosis* PanR0906	2554235278	789.	*Mycobacterium africanum* MAL010074	2579779131
312.	*Mycobacterium tuberculosis* PanR0202	2597489946	790.	*Mycobacterium tuberculosis* XTB13-241	2574180363
313.	*Mycobacterium tusciae* JS617	2508501052	791.	*Mycobacterium tuberculosis* PanR1007	2554235275
314.	*Mycobacterium tuberculosis* PanR0605	2554235253	792.	*Mycobacterium tuberculosis* H2398	2576861228
315.	*Mycobacterium tuberculosis* MAL020209	2588254139	793.	*Mycobacterium tuberculosis* Erdman	2588254171
316.	*Mycobacterium tuberculosis* TB_RSA195	2574180322	794.	*Mycobacterium tuberculosis* M1438	2574179826
317.	*Mycobacterium tuberculosis* M1913	2576861016	795.	*Mycobacterium tuberculosis* TKK-01-0010	2574180066
318.	*Mycobacterium africanum* MAL010084	2579778911	796.	*Mycobacterium tuberculosis* UG-D	2582581174
319.	*Mycobacterium africanum* MAL010079	2579778777	797.	*Mycobacterium tuberculosis* MAL010103	2574180253
320.	*Mycobacterium tuberculosis* TBR56	2588253885	798.	*Mycobacterium tuberculosis* PanR0707	2554235264

321.	*Mycobacterium tuberculosis* 98-R604 INH-RIF-EM	645058721	799.	*Mycobacterium tuberculosis* KT-0087	2574179874
322.	*Mycobacterium tuberculosis* KT-0043	2588254149	800.	*Mycobacterium tuberculosis* OFXR-12	2588253899
323.	*Mycobacterium tuberculosis* TB_RSA70	2576861217	801.	*Mycobacterium tuberculosis* BTB10-357	2582581133
324.	*Mycobacterium tuberculosis* PanR0411	2554235293	802.	*Mycobacterium tuberculosis* TB_RSA161	2576861195
325.	*Mycobacterium tuberculosis* KT-0110	2574180278	803.	*Mycobacterium tuberculosis* PanR0603	2554235247
326.	*Mycobacterium tuberculosis* M1213	2574180085	804.	*Mycobacterium tuberculosis* MAL020138	2588254105
327.	*Mycobacterium tuberculosis* BTB03-012	2576861055	805.	*Mycobacterium tuberculosis* MD15977	2574179798
328.	*Mycobacterium tuberculosis* CDC1551	637000172	806.	*Mycobacterium tuberculosis* XTB13-131	2574180128
329.	*Mycobacterium tuberculosis* MD19964	2574179977	807.	*Mycobacterium tuberculosis* KT-0019	2582581186
330.	*Mycobacterium tuberculosis* TRUG0083	2582581187	808.	*Mycobacterium tuberculosis* TKK_04_0022	2590828599
331.	*Mycobacterium tuberculosis* MD17517	2576861215	809.	*Mycobacterium tuberculosis* MAL010087	2588254093
332.	*Mycobacterium phlei* RIVM601174	2522572168	810.	*Mycobacterium tuberculosis* BTB09-058	2576861353
333.	*Mycobacterium tuberculosis* 02_1987	642979309	811.	*Mycobacterium tuberculosis* KT-0057	2582581156
334.	*Mycobacterium tuberculosis* MAL020157	2588254120	812.	*Mycobacterium tuberculosis* TKK_04_0030	2590828681
335.	*Mycobacterium tuberculosis* TB_RSA104	2582581176	813.	*Mycobacterium tuberculosis* TKK-01-0078	2588254028
336.	*Mycobacterium tuberculosis* TB_RSA194	2574179858	814.	*Mycobacterium tuberculosis* PanR0307	2554235241

337.	*Mycobacterium tuberculosis* TKK-01-0086	2588254034	815.	*Mycobacterium tuberculosis* MAL020136	2588254106
338.	*Mycobacterium tuberculosis* TB_RSA68	2574179886	816.	*Mycobacterium tuberculosis* Korean KIT87190	2588253748
339.	*Mycobacterium tuberculosis* TKK_03_0040	2582581144	817.	*Mycobacterium tuberculosis* SUMu008	648276700
340.	*Mycobacterium* sp. 360 MFTsu5.1	2521172630	818.	*Mycobacterium tuberculosis* TRUG0076	2574180230
341.	*Mycobacterium tuberculosis* XTB13-143	2574180298	819.	*Mycobacterium massiliense* 2B-0912-S	2526164654
342.	*Mycobacterium tuberculosis* EAI/OSDD271	2554235103	820.	*Mycobacterium tuberculosis* PanR0206	2554235209
343.	*Mycobacterium tuberculosis* PanR0401	2554235310	821.	*Mycobacterium tuberculosis* KT-0079	2588254237
344.	*Mycobacterium tuberculosis* KT-0034	2574180175	822.	*Mycobacterium tuberculosis* H1578	2574179860
345.	*Mycobacterium tuberculosis* MAL010124	2588254103	823.	*Mycobacterium tuberculosis* TKK-01-0048	2588254007
346.	*Mycobacterium tuberculosis* M995	2579778509	824.	*Mycobacterium africanum* MAL010099	2582580875
347.	*Mycobacterium tuberculosis* MAL020186	2588254124	825.	*Mycobacterium tuberculosis* MD16728	2576861232
348.	*Mycobacterium tuberculosis* OSDD504	2548876690	826.	*Mycobacterium tuberculosis* TKK-01-0055	2588254016
349.	*Mycobacterium tuberculosis* TKK_03_0158	2576861017	827.	*Mycobacterium tuberculosis* TB_RSA12	2576861058
350.	*Mycobacterium tuberculosis* TKK-01-0088	2588254029	828.	*Mycobacterium tuberculosis* TKK-01-0001	2588253977
351.	*Mycobacterium para scrofulaceum* ATCC BAA-614	647000278	829.	*Mycobacterium tuberculosis* OFXR-23	2588254182
352.	*Mycobacterium tuberculosis* PanR0610	2554235266	830.	*Mycobacterium tuberculosis* KT-0026	2588254153

353.	*Mycobacterium tuberculosis* TBR51	2582581128	831.	*Mycobacterium tuberculosis* TB_RSA66	2574180383
354.	*Mycobacterium tuberculosis* MAL020199	2588254132	832.	*Mycobacterium tuberculosis* MD16775	2574180210
355.	*Mycobacterium tuberculosis* OFXR-29	2588254180	833.	*Mycobacterium tuberculosis* TRUG0088	2574180110
356.	*Mycobacterium tuberculosis* Erdman	2540341098	834.	*Mycobacterium tuberculosis* TKK_03_0094	2576861394
357.	*Mycobacterium tuberculosis* TKK-01-0076	2588254020	835.	*Mycobacterium tuberculosis* TBR31	2574179818
358.	*Mycobacterium tuberculosis* TRUG0124	2582581188	836.	*Mycobacterium tuberculosis* XTB13-100	2582581204
359.	*Mycobacterium tuberculosis* TKK_02_0071	2574179882	837.	*Mycobacterium tuberculosis* SUMu005	648276697
360.	*Mycobacterium tuberculosis* KT-0070	2576861220	838.	*Mycobacterium* sp. 155	2516493018
361.	*Mycobacterium canettii* CIPT 140070013	2565956757	839.	*Mycobacterium tuberculosis* TBR57	2588253884
362.	*Mycobacterium tuberculosis* TKK-01-0090	2574179983	840.	*Mycobacterium tuberculosis* XTB13-096	2574180267
363.	*Mycobacterium tuberculosis* TKK-01-0043	2588254001	841.	*Mycobacterium* sp. URHB0044	2556921043
364.	*Mycobacterium tuberculosis* PanR0207	2554235213	842.	*Mycobacterium tuberculosis* TB_RSA25	2582581159
365.	*Mycobacterium tuberculosis* TB_RSA90	2574180060	843.	*Mycobacterium bovis* MAL010093	2582580880
366.	*Mycobacterium tuberculosis* TKK_04_0060	2582581185	844.	*Mycobacterium tuberculosis* TKK-01-0014	2588253985
367.	*Mycobacterium tuberculosis* BTB11-236	2576861372	845.	*Mycobacterium tuberculosis* TKK_02_0017	2590828646
368.	*Mycobacterium tuberculosis* PanR0407	2554235299	846.	*Mycobacterium tuberculosis* PanR1006	2554235279

369.	*Mycobacterium tuberculosis* MD15212	2576861182	847.	*Mycobacterium tuberculosis* M1559	2574180156
370.	*Mycobacterium tuberculosis* TB_RSA140	2574180256	848.	*Mycobacterium tuberculosis* MAL020150	2588254117
371.	*Mycobacterium tuberculosis* PanR0803	2554235259	849.	*Mycobacterium tuberculosis* MAL020206	2588254137
372.	*Mycobacterium* sp. UM_RHS	2554235287	850.	*Mycobacterium tuberculosis* R1207	2547132238
373.	*Mycobacterium tuberculosis* BTB08-148	2574180382	851.	*Mycobacterium tuberculosis* SK-E	2582581139
374.	*Mycobacterium tuberculosis* UG-C	2574180010	852.	*Mycobacterium africanum* MAL010118	2579778997
375.	*Mycobacterium massiliense* 1S-153-0915	2526164660	853.	*Mycobacterium intracellulare* ATCC 13950	2519103109
376.	*Mycobacterium africanum* MAL020135	2582580877	854.	*Mycobacterium tuberculosis* TKK-01-0046	2588254008
377.	*Mycobacterium tuberculosis* TKK_04_0024	2574180232	855.	*Mycobacterium tuberculosis* KT-0099	2588254229
378.	*Mycobacterium tuberculosis* TKK_03_0059	2582581143	856.	*Mycobacterium tuberculosis* BTB08-022	2576861221
379.	*Mycobacterium tuberculosis* BTB12-400	2574180403	857.	*Mycobacterium tuberculosis* OFXR-18	2588254186
380.	*Mycobacterium tuberculosis* KT-0024	2576861064	858.	*Mycobacterium tuberculosis* TKK-01-0006	2576861099
381.	*Mycobacterium tuberculosis* KT-0104	2588254227	859.	*Mycobacterium tuberculosis* BTB10-487	2576861026
382.	*Mycobacterium tuberculosis* KT-0089	2588254232	860.	*Mycobacterium tuberculosis* TKK-01-0002	2588253976
383.	*Mycobacterium tuberculosis* TRUG0085	2576861121	861.	*Mycobacterium tuberculosis* TKK-01-0020	2588253847
384.	*Mycobacterium tuberculosis* PanR0203	2554235210	862.	*Mycobacterium tuberculosis* TKK_03_0030	2590828618

385.	*Mycobacterium tuberculosis* TKK_03_0031	2576861265	863.	*Mycobacterium tuberculosis* MAL020167	2588254112
386.	*Mycobacterium tuberculosis* MAL010108	2588254099	864.	*Mycobacterium tuberculosis* M2116	2576861330
387.	*Mycobacterium tuberculosis* TB_RSA46	2582581191	865.	*Mycobacterium tuberculosis* TKK_04_0013	2590828605
388.	*Mycobacterium tuberculosis* TKK_03_0027	2590828620	866.	*Mycobacterium tuberculosis* PanR0503	2554235255
389.	*Mycobacterium tuberculosis* TKK_05SA_0048	2574180155	867.	*Mycobacterium tuberculosis* T17	642979349
390.	*Mycobacterium tuberculosis* KT-0100	2576861242	868.	*Mycobacterium tuberculosis* TKK_04_0094	2582581218
391.	*Mycobacterium tuberculosis* TKK_02_0006	2590828650	869.	*Mycobacterium tuberculosis* TKK_03_0096	2576861378
392.	*Mycobacterium tuberculosis* TKK-01-0057	2588254010	870.	*Mycobacterium tuberculosis* M2249	2576861297
393.	*Mycobacterium tuberculosis* XDR1221	2558860631	871.	*Mycobacterium tuberculosis* KT-0067	2574179838
394.	*Mycobacterium tuberculosis* TKK-01-0093	2588254037	872.	*Mycobacterium tuberculosis* TKK_03_0029	2590828619
395.	*Mycobacterium massiliense* 2B-0107	2526164656	873.	*Mycobacterium tuberculosis* TKK_04_0033	2576861374
396.	*Mycobacterium tuberculosis* 3280CJ	2574180115	874.	*Mycobacterium tuberculosis* TB_RSA136	2574180334
397.	*Mycobacterium bovis* BCG-Tice, TMC 1028	2547132086	875.	*Mycobacterium tuberculosis* TKK_02_0034	2590828638
398.	*Mycobacterium tuberculosis* KT-0085	2588254233	876.	*Mycobacterium massiliense* 1S-154-0310	2526164579
399.	*Mycobacterium tuberculosis* KT-0077	2588254239	877.	*Mycobacterium tuberculosis* EAI5	2554235430
400.	*Mycobacterium tuberculosis* 2541MS	2574180315	878.	*Mycobacterium tuberculosis* TKK_02_0077	2590828625

401.	*Mycobacterium tuberculosis* TBR55	2574179989	879.	*Mycobacterium tuberculosis* TBR42	2588253878
402.	*Mycobacterium tuberculosis* PanR0908	2554235272	880.	*Mycobacterium tuberculosis* OFXR-9	2588254141
403.	*Mycobacterium tuberculosis* NRITLD57	2574180032	881.	*Mycobacterium tuberculosis* TB_RSA165	2574180040
404.	*Mycobacterium bovis* BCG Mexico	2511231152	882.	*Mycobacterium tuberculosis* XTB13-136	2574180422
405.	*Mycobacterium mucogenicum* 261Sha1.1M5	2548877166	883.	*Mycobacterium tuberculosis* PR05	2554235105
406.	*Mycobacterium tuberculosis* BTB07-034	2576861163	884.	*Mycobacterium tuberculosis* TKK-01-0058	2588254011
407.	*Mycobacterium tuberculosis* NRITLD12	2574179824	885.	*Mycobacterium tuberculosis* MD18096	2574180286
408.	*Mycobacterium tuberculosis* OFXR-26	2576861035	886.	*Mycobacterium tuberculosis* KZN V2475	647000281
409.	*Mycobacterium tuberculosis* 2091HD	2582581157	887.	*Mycobacterium tuberculosis* TKK-01-0040	2588253999
410.	*Mycobacterium tuberculosis* PanR0609	2554235268	888.	*Mycobacterium tuberculosis* TKK-01-0031	2588253992
411.	*Mycobacterium tuberculosis* MAL020146	2588254115	889.	*Mycobacterium tuberculosis* PanR0205	2554235208
412.	*Mycobacterium tuberculosis* TBR47	2588253881	890.	*Mycobacterium tuberculosis* M1762	2574179894
413.	*Mycobacterium tuberculosis* KT-0011	2582581202	891.	*Mycobacterium massiliense* 1513	2565956791
414.	*Mycobacterium tuberculosis* TKK-01-0085	2574179808	892.	*Mycobacterium tuberculosis* TKK_04_0036	2590828678
415.	*Mycobacterium tuberculosis* TKK-01-0041	2574180165	893.	*Mycobacterium tuberculosis* MAL020193	2588254127
416.	*Mycobacterium tuberculosis* TKK-01-0018	2588253987	894.	*Mycobacterium tuberculosis* MAL010086	2588254094

417.	*Mycobacterium africanum* MAL010100	2574179914	895.	*Mycobacterium thermoresistibile* ATCC 19527	2519103087
418.	*Mycobacterium bovis* Kc 9614	2579778584	896.	*Mycobacterium tuberculosis* TKK_02_0019	2574180017
419.	*Mycobacterium tuberculosis* TKK_03_0028	2574180204	897.	*Mycobacterium tuberculosis* XTB13-156	2574180393
420.	*Mycobacterium tuberculosis* SUMu003	648276695	898.	*Mycobacterium tuberculosis* TKK-01-0012	2588253982
421.	*Mycobacterium* sp. H4Y	2531839247	899.	*Mycobacterium tuberculosis* TB_RSA102	2574180173
422.	*Mycobacterium tuberculosis* TKK-01-0017	2588253845	900.	*Mycobacterium tuberculosis* OFXR-6	2574180016
423.	*Mycobacterium tuberculosis* TB_RSA121	2582581152	901.	*Mycobacterium tuberculosis* TB_RSA124	2576861380
424.	*Mycobacterium tuberculosis* TKK-01-0053	2574180042	902.	*Mycobacterium africanum* MAL010070	2582580874
425.	*Mycobacterium tuberculosis* XTB13-121	2576861080	903.	*Mycobacteroides massiliense* GO 06	2517093032
426.	*Mycobacterium tuberculosis* 94_M4241A	642979310	904.	*Mycobacterium tuberculosis* TKK-01-0071	2588254022
427.	*Mycobacterium tuberculosis* BTB07-206	2574179835	905.	*Mycobacterium tuberculosis* TKK_03_0078	2582581142
428.	*Mycobacterium tuberculosis* MD20344	2576861179	906.	*Mycobacterium tuberculosis* KT-0015	2588254158
429.	*Mycobacterium tuberculosis* MAL020202	2588254135	907.	*Mycobacterium tuberculosis* TKK_05MA_0052	2576861070
430.	*Mycobacterium tuberculosis* TKK_05MA_2015	2574180371	908.	*Mycobacterium tuberculosis* PanR0201	2554235305
431.	*Mycobacterium tuberculosis* CAS/NITR204	2545824629	909.	*Mycobacterium tuberculosis* TKK_04_0047	2590828673
432.	*Mycobacterium tuberculosis* M2129	2582581223	910.	*Mycobacterium tuberculosis* Uganda 1	2574180039

433.	*Mycobacterium tuberculosis* MAL010106	2588254100	911.	*Mycobacterium tuberculosis* TKK-01-0021	2582581183
434.	*Mycobacterium africanum* MAL020107	2579779012	912.	*Mycobacterium tuberculosis* PanR0903	2554235261
435.	*Mycobacterium hassiacum* DSM 44199	2515154012	913.	*Mycobacterium tuberculosis* KT-0083	2588254235
436.	*Mycobacterium tuberculosis* TKK_02_0070	2590828627	914.	*Mycobacterium tuberculosis* TB_RSA45	2582581161
437.	*Mycobacterium tuberculosis* TKK-01-0009	2588253978	915.	*Mycobacterium tuberculosis* TB_RSA18	2574180376
438.	*Mycobacterium tuberculosis* H2438	2582581215	916.	*Mycobacterium paraintracellulare* MOTT-64	2512564041
439.	*Mycobacterium tuberculosis* NA-A0008	2551306118	917.	*Mycobacterium tuberculosis* UT205	2512564056
440.	*Mycobacterium tuberculosis* BTB12-314	2576861051	918.	*Mycobacterium tuberculosis* TKK_05SA_0020	2582581170
441.	*Mycobacterium tuberculosis* S96-129	2547132258	919.	*Mycobacterium tuberculosis* MAL010110	2588254098
442.	*Mycobacterium tuberculosis* TKK-01-0061	2574179969	920.	*Mycobacterium tuberculosis* PanR0606	2554235257
443.	*Mycobacterium tuberculosis* H37Ra	640427124	921.	*Mycobacterium tuberculosis* TKK_05MA_0040	2582581163
444.	*Mycobacterium africanum* K85	2582580994	922.	*Mycobacterium africanum* MAL010081	2579778712
445.	*Mycobacterium tuberculosis* TKK_04_0007	2590828607	923.	*Mycobacterium tuberculosis* MD14435	2576861267
446.	*Mycobacterium africanum* MAL010128	2579779032	924.	*Mycobacterium tuberculosis* TBR79	2588253893
447.	*Mycobacterium vaccae* RIVM	2534681942	925.	*Mycobacterium tuberculosis* TKK_02_0062	2590828632
448.	*Mycobacterium tuberculosis* INS_XDR	2571042743	926.	*Mycobacterium tuberculosis* OFXR-31	2588254178

449.	*Mycobacterium tuberculosis* TKK-01-0039	2588253998	927.	*Mycobacterium tuberculosis* TKK-01-0052	2588254004
450.	*Mycobacterium tuberculosis* PanR0314	2554235245	928.	*Mycobacterium tuberculosis* SUMu001	648276693
451.	*Mycobacterium tuberculosis* TKK_02_0033	2590828639	929.	*Mycobacterium tuberculosis* M1978	2576861346
452.	*Mycobacterium tuberculosis* PanR0907	2554235280	930.	*Mycobacterium tuberculosis* BTB05-013	2574180369
453.	*Mycobacterium tuberculosis* K	2588253735	931.	*Mycobacterium tuberculosis* C	638341130
454.	*Mycobacterium tuberculosis* TKK_03_0081	2590828612	932.	*Mycobacterium tuberculosis* TKK_02_0001	2590828652
455.	*Mycobacterium tuberculosis* TBR41	2574180180	933.	*Mycobacterium tuberculosis* KT-0075	2588254240
456.	*Mycobacterium tuberculosis* MAL010134	2588254110	934.	*Mycobacterium africanum* MAL020176	2582580879
457.	*Mycobacterium intracellulare* ATCC 13950	645058739	935.	*Mycobacterium tuberculosis* TKK_02_0045	2574180313
458.	*Mycobacterium tuberculosis* XTB13-194	2582581140	936.	*Mycobacterium tuberculosis* MD19043	2574179852
459.	*Mycobacterium tuberculosis* TKK_03_0090	2574180410	937.	*Mycobacterium tuberculosis* TKK-01-0015	2588253989
460.	*Mycobacterium tuberculosis* MAL020102	2588254109	938.	*Mycobacterium tuberculosis* NRITLD09	2582581182
461.	*Mycobacterium tuberculosis* TKK-01-0038	2582581137	939.	*Mycobacterium tuberculosis* XTB13-175	2582581147
462.	*Mycobacterium africanum* GM041182	650716059	940.	*Mycobacterium tuberculosis* TKK_03_0103	2576861260
463.	*Mycobacterium tuberculosis* TKK_05SA_0017	2576861332	941.	*Mycobacterium tuberculosis* XTB13-093	2574180354
464.	*Mycobacterium tuberculosis* TBR40	2588253876	942.	*Mycobacterium tuberculosis* TKK-01-0094	2588254035

465.	*Mycobacterium tuberculosis* TBR66	2588253888	943.	*Mycobacterium* sp. UM_WGJ	2554235289
466.	*Mycobacterium* sp. UNCCL9	2576861824	944.	*Mycobacterium canettii* CIPT 140060008	2541047047
467.	*Mycobacterium tuberculosis* KT-0028	2588254152	945.	*Mycobacterium colombiense* CECT 3035	2562617111
468.	*Mycobacterium tuberculosis* KT-0063	2588254143	946.	*Mycobacterium tuberculosis* TBR26	2576861259
469.	*Mycobacterium tuberculosis* Haarlem3/NITR202	2545824626	947.	*Mycobacterium tuberculosis* TKK-01-0070	2588254023
470.	*Mycobacterium xenopi* RIVM700367	2522572167	948.	*Mycobacterium tuberculosis* KT-0039	2588254150
471.	*Mycobacterium tuberculosis* KT-0071	2588254241	949.	*Mycobacterium tuberculosis* RGTB327	2512564073
472.	*Mycobacterium orygis* 112400015	2545824691	950.	*Mycobacterium tuberculosis* XTB13-195	2574180234
473.	*Mycobacterium tuberculosis* TKK_05SA_0058	2574179931	951.	*Mycobacterium tuberculosis* TB_RSA99	2574180102
474.	*Mycobacterium tuberculosis* M2085	2576861292	952.	*Mycobacterium tuberculosis* XTB13-203	2582581177
475.	*Mycobacterium tuberculosis* PanR0904	2554235277	953.	*Mycobacterium tuberculosis* TKK_04_0108	2574180399
476.	*Mycobacterium tuberculosis* PanR0802	2554235294	954.	*Mycobacterium tuberculosis* KT-0107	2588254225
477.	*Mycobacterium tuberculosis* KT-0008	2588254160	955.	*Mycobacterium tuberculosis* MAL020197	2588254130
478.	*Mycobacterium tuberculosis* KT-0004	2574179997	956.	*Mycobacterium tuberculosis* 3499MM	2582581193
Mycobacterium causing leprosy (MCL)					
1.	*Mycobacterium leprae* TN	637000170	2.	*Mycobacterium leprae* Br4923	643348566

Saprophytes (SAP)					
1.	*Mycobacterium smegmatis* MKD8	2545824527	12.	*Mycobacterium* sp. KMS	639633042
2.	*Mycobacterium smegmatis* MC2 51	2585427824	13.	*Mycobacterium* sp. JLS	640069320
3.	*Mycobacterium smegmatis* MC2 155	639633041	14.	*Mycobacterium rhodesiae* NBB3	2508501106
4.	*Mycobacterium smegmatis* MC2 155	2518645537	15.	*Mycolicibacterium rhodesiae* JS60	2506783048
5.	*Mycobacterium smegmatis* LR222	651716594	16.	*Mycobacterium chubuense* NBB4	2506783014
6.	*Mycobacterium smegmatis* MC2 155	651716860	17.	*Mycobacterium neoaurum* VKM Ac-1815D	2551306466
7.	*Mycobacterium* sp. JS623	2506783060	18.	*Mycobacterium neoaurum* ATCC 25795	2582581012
8.	*Mycobacterium vanbaalenii* PYR-1	639633044	19.	*Mycobacterium* sp. VKM Ac-1816D	2551306546
9.	*Mycobacterium gilvum* Spyr1	649633070	20.	*Mycobacterium* sp. VKM Ac-1817D	2551306544
10.	*Mycolicibacterium gilvum* PYR-GCK	640427122	21.	*Mycobacterium fortuitum* subsp. *fortuitum*	2519899744

				DSM 46621	
11.	*Mycobacterium* sp. MCS	637000171			
***Mycobacterium chelonae-abscessus* Complex (MCAC)**					
1.	*Mycobacterium abscessus* 4S-0206	2526164587	32.	*Mycobacterium abscessus* M94	2516143052
2.	*Mycobacterium abscessus*V06705	2582580872	33.	*Mycobacterium abscessus* 6G-0728-R	2526164684
3.	*Mycobacterium abscessus* 5S-0921	2526164682	34.	*Mycobacterium abscessus* 5S-0422	2526164589
4.	*Mycobacterium abscessus* M148	2548877037	35.	*Mycobacterium abscessus* M152	2548877038
5.	*Mycobacterium abscessus* 3A-0122-S	2526164623	36.	*Mycobacterium abscessus* 3A-0930-S	2526164626
6.	*Mycobacterium abscessus bolletii* Timone LB	2531839070	37.	*Mycobacterium abscessus* MAB_091912_2455	2579779023
7.	*Mycobacterium abscessus* 5S-0708	2526164593	38.	*Mycobacterium abscessus* 6G-0125-S	2526164686
8.	*Mycobacterium abscessus* ATCC 19977	641522641	39.	*Mycobacterium abscessus* 5S-1215	2526164680

9.	*Mycobacterium abscessus* MAB_110811_1470	2579778595	40.	*Mycobacterium abscessus bolletii* INCQS 00594	2597489897
10.	*Mycobacterium abscessus* 1948	2565956814	41.	*Mycobacterium abscessus*M139	2548877041
11.	*Mycobacterium abscessus* 6G-1108	2526164679	42.	*Mycobacterium abscessus bolletii* Timone LB	2579778727
12.	*Mycobacterium abscessus* 4S-0116-R	2526164627	43.	*Mycobacterium abscessus* MAB_091912_2446	2574180273
13.	*Mycobacterium abscessus* M156	2548877034	44.	*Mycobacterium abscessus*159	2548876927
14.	*Mycobacterium abscessus*5S-0421	2526164590	45.	*Mycobacterium abscessus* 3A-0810-R	2531839203
15.	*Mycobacterium abscessus* 9808	2551306463	46.	*Mycobacterium abscessus* MAB_082312_2273	2585427958
16.	*Mycobacterium abscessus*MAB_082312_2258	2579779115	47.	*Mycobacteroides abscessus bolletii* 50594	2561511210
17.	*Mycobacterium abscessus* MAB_082312_2272	2582580860	48.	*Mycobacterium abscessus bolletii* CRM-0020	2582580873
18.	*Mycobacterium abscessus bolletii* BD	2529293190	49.	*Mycobacterium abscessus* 3A-0119-R	2526164622

19.	*Mycobacterium abscessus* 6G-0212	2526164687	50.	*Mycobacterium abscessus* 5S-1212	2526164683
20.	*Mycobacterium abscessus*4S-0116-S	2526164588	51.	*Mycobacterium abscessus* 47J26	2519899837
21.	*Mycobacterium abscessus*3A-0731	2526164624	52.	*Mycobacterium abscessus* MAB_020201_1075	2568526042
22.	*Mycobacterium abscessus* 6G-0728-S	2526164685	53.	*Mycobacterium abscessus bolletii* Timone LB	2526164611
23.	*Mycobacterium abscessus* 3A-0122-R	2531839202	54.	*Mycobacterium abscessus*3A-0930-R	2526164625
24.	*Mycobacterium abscessus*M172	2548876926	55.	*Mycobacterium abscessus* 4S-0303	2526164586
25.	*Mycobacteroides abscessus* 4S-0726-RB	2526164592	56.	*Mycobacterium abscessus* M24	2548877036
26.	*Mycobacterium abscessus* 6G-0125-R	2526164681	57.	*Mycobacterium abscessus* 103	2565956816
27.	*Mycobacterium abscessus*M154	2548877035	58.	*Mycobacterium abscessus*115	2548876928
28.	*Mycobacterium abscessus*4S-0726-RA	2526164585	59.	*Mycobacterium abscessus* CF	2551306647

29.	*Mycobacterium abscessus bolletii* M18	2551306144	60.	*Mycobacterium abscessus* 5S-0304	2526164591
30.	*Mycobacterium abscessus*5S-0817	2537561552	61.	*Mycobacterium abscessus* MAB_110811_2726	2568526391
31.	*Mycobacterium abscessus*M93	2516143102			
Mycobacterium avium complex (MAC)					
1.	*Mycobacterium avium* 2285 (R)	2565956782	30.	*Mycobacterium avium* 11-0986	2582580886
2.	*Mycobacterium avium paratuberculosis* JQ6	2548876687	31.	*Mycobacterium avium* MAV_120709_2344	2579779122
3.	*Mycobacterium avium paratuberculosis* Pt155	2547132383	32.	*Mycobacterium avium paratuberculosis* Pt146	2547132381
4.	*Mycobacterium avium paratuberculosis* S5	2541047521	33.	*Mycobacterium avium hominissuis* MAH 2721	2571042795
5.	*Mycobacterium avium avium* 10-9275	2576861178	34.	*Mycobacterium avium paratuberculosis* Pt139	2547132378
6.	*Mycobacterium avium paratuberculosis* 08-8281	2574179921	35.	*Mycobacterium avium paratuberculosis* DT 3	2548876683
7.	*Mycobacterium avium paratuberculosis* 1281	2548876681	36.	*Mycobacterium avium avium* 3388	2579778886

8.	*Mycobacterium avium paratuberculosis* 10-5864	2568526703	37.	*Mycobacterium avium avium* ATCC 25291	645058725
9.	*Mycobacterium avium paratuberculosis* 10-4404	2590828662	38.	Mycobacterium avium avium DT 78	2548876685
10.	*Mycobacterium avium paratuberculosis* Pt144	2547132379	39.	*Mycobacterium avium hominissuis* 10-4249	2579778680
11.	*Mycobacterium avium* 2151	651716619	40.	*Mycobacterium avium hominissuis* MAH 27-1	2579778818
12.	*Mycobacterium avium avium* 11-4751	2579778835	41.	*Mycobacterium avium* 09-5983	2571042704
13.	*Mycobacterium avium* 05-4293	2579779008	42.	*Mycobacterium avium paratuberculosis* Pt145	2547132380
14.	*Mycobacterium avium avium* Env 77	2548876686	43.	*Mycobacterium avium* MAV_120809_2495	2579778728
15.	*Mycobacterium avium paratuberculosis* Pt154	2547132382	44.	*Mycobacterium avium paratuberculosis* CLIJ623	2547132392
16.	*Mycobacterium avium* 2285 (S)	2565956783	45.	*Mycobacterium avium paratuberculosis* K-10	637000168
17.	*Mycobacterium avium paratuberculosis* 4B	2548877002	46.	*Mycobacterium avium hominissuis* 10-5606	2579779061

18.	*Mycobacterium avium paratuberculosis* 10-5975	2574180289	47.	*Mycobacterium avium hominissuis* 101	2579778556
19.	*Mycobacterium avium* subsp. *avium A5*	2579778738	48.	*Mycobacterium avium paratuberculosis* S397	2534681669
20.	*Mycobacterium avium* 10-5560	2574180263	49.	*Mycobacterium avium paratuberculosis* Env 210	2548876684
21.	*Mycobacterium avium silvaticum* ATCC 49884	2568526319	50.	*Mycobacterium avium paratuberculosis* Pt164	2547132384
22.	*Mycobacterium avium paratuberculosis* CLIJ644	2547132102	51.	*Mycobacterium avium* 104	639633039
23.	*Mycobacterium avium paratuberculosis* 10-8425	2590828661	52.	*Mycobacterium avium paratuberculosis* MAP4	2554235361
24.	*Mycobacterium avium paratuberculosis* JQ5	2548876680	53.	*Mycobacterium avium paratuberculosis* CLIJ361	2547132397
25.	*Mycobacterium avium hominissuis* 100	2579778785	54.	*Mycobacterium avium paratuberculosis* JTC 1285	2548876682
26.	*Mycobacterium avium* 10-5581	2571042511	55.	*Mycobacterium* sp. MAC_011194_8550	2579779081
27.	*Mycobacterium avium paratuberculosis* 11-1786	2590828660	56.	*Mycobacterium* sp. MAC_080597_8934	2576861029

28.	*Mycobacterium avium* MAV_061107_1842	2579779075	57.	*Mycobacterium* sp. UM_CSW	2554235286
29.	*Mycobacterium avium paratuberculosis* ATCC 19698	2548876531			
Non-tuberculosis Mycobacteria (NTM)					
1.	*Mycobacterium ulcerans* Harvey	2565956790	8.	*Mycobacterium liflandii* 128FXT	2563366549
2.	*Mycobacterium ulcerans* Agy99	642555140	9.	*Mycobacterium kansasii* 662	2565956794
3.	*Mycolicibacter sinense* JDM601	650716061	10.	*Mycobacterium kansasii* 824	2565956815
4.	*Mycobacterium marinum* Europe	2541047508	11.	*Mycobacterium kansasii* SMC1	2585427992
5.	*Mycobacterium marinum* M, ATCC BAA-535	641522642	12.	*Mycobacterium kansasii* 732	2565956793
6.	*Mycobacterium marinum* E11	2588253759	13.	*Mycobacterium kansasii* ATCC 12478	2563366550
7.	*Mycobacterium marinum* MB2	2545824679	14.	*Mycobacterium genavense* ATCC 51234	2545555864