Structure Validation:

Automated MRR Library Building for Confident Molecular Identification

Introduction

Terpenes are a structurally diverse and commercially important class of natural products used in flavors & fragrances, pharmaceuticals, and botanical authentication. Subtle differences in stereochemistry or functional group orientation can significantly influence aroma, biological activity, and regulatory classification. Accurate structural characterization is essential for compound identification. Despite this significance, closely related terpenes remain difficult to distinguish using conventional analytical techniques. These methods often rely on chromatographic retention behavior or fragmentation-based spectral libraries that may fail to resolve stereoisomers or structurally similar compounds within complex mixtures. This application note presents an automated structure-validation workflow for generating experimentally confirmed MRR spectral libraries that enable unambiguous molecular identification in complex samples.

Figure 1. Terpene chemical space linking molecular structure to natural sources across hydrocarbons, alcohols, and sesquiterpenes. Closely related terpenes and stereoisomers cluster despite subtle differences in functional groups, highlighting the analytical challenge of terpene-rich mixtures and the need for structure-specific rotational spectroscopy.

MRR as a Structure-Specific Solution

Molecular rotational resonance (MRR) spectroscopy provides direct structural information by measuring gas-phase rotational transitions that are uniquely determined by a molecule's three-dimensional geometry. Each molecule produces a distinct rotational spectrum that functions as a structural fingerprint. This enables the differentiation of isomers (as well as other closely related species) without reliance on chromatographic separation or inference from fragmentation.

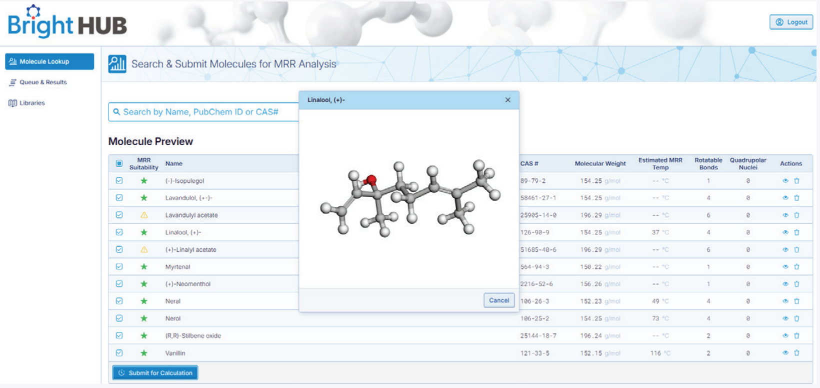
When combined with the simulated rotational spectra of proposed molecular structures, MRR enables a structure-validation workflow in which theoretical predictions are directly validated against experimental data. The agreement between predicted and measured spectra provides definitive confirmation of molecular identity.

Workflow for Structure Validation and Experimental Library Creation

The same validation process used for individual structure confirmation can be repeated across related molecules to generate experimentally confirmed spectral references. In this way, MRR enables scalable construction of spectral libraries that support rapid future identification within defined chemical classes. The practical operation of this workflow is illustrated here using an automated measurement of a representative terpene.

Step 1: Define the candidate structures

Candidate molecular structures are defined and submitted to BrightHub to generate predicted rotational spectra, which form the theoretical reference library used for subsequent spectral matching. These calculations also dictate the parameters to be used for experimental data collection.

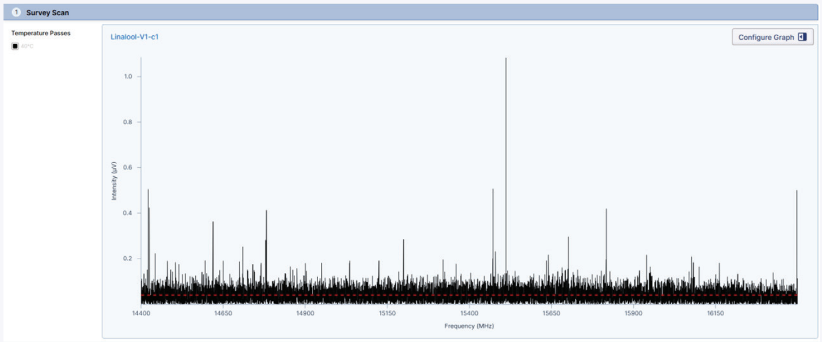


Molecule Preview

☑	MRR Suitability	Name	CAS #	Molecular Weight	Estimated MRR Temp	Rotatable Bonds	Quadrupolar Nuclei	Actions
☑	★	(-)-Isopulegol	89-79-2	154.25 g/mol	-- °C	1	0	👁 🗑
☑	★	Lavandulol, (+-)-	58461-27-1	154.25 g/mol	-- °C	4	0	👁 🗑
☑	⚠	Lavandulyl acetate	25905-14-0	196.29 g/mol	-- °C	6	0	👁 🗑
☑	★	Linalool, (+)-	126-90-9	154.25 g/mol	37 °C	4	0	👁 🗑
☑	⚠	(+)-Linalyl acetate	51685-40-6	196.29 g/mol	-- °C	6	0	👁 🗑
☑	★	Myrtenal	564-94-3	150.22 g/mol	-- °C	1	0	👁 🗑
☑	★	(+)-Neomenthol	2216-52-6	156.26 g/mol	-- °C	1	0	👁 🗑
☑	★	Neral	106-26-3	152.23 g/mol	49 °C	4	0	👁 🗑
☑	★	Nerol	106-25-2	154.25 g/mol	73 °C	4	0	👁 🗑
☑	★	(R,R)-Stilbene oxide	25144-18-7	196.24 g/mol	-- °C	2	0	👁 🗑
☑	★	Vanillin	121-33-5	152.15 g/mol	116 °C	2	0	👁 🗑

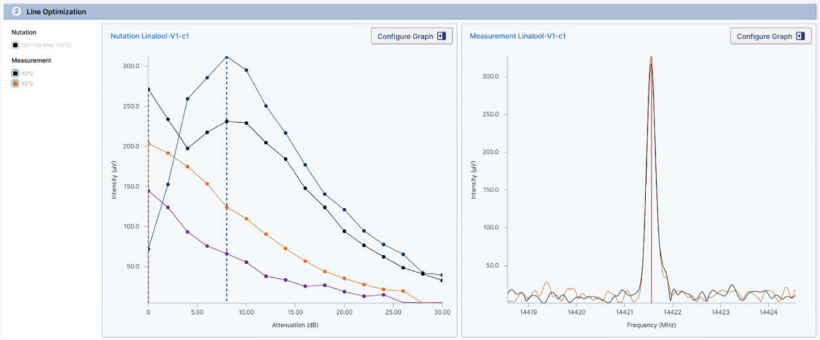
Step 2: Acquire the experimental spectrum

The sample is introduced for automated MRR measurement to acquire the experimental rotational spectrum for subsequent comparison with the predicted reference library.



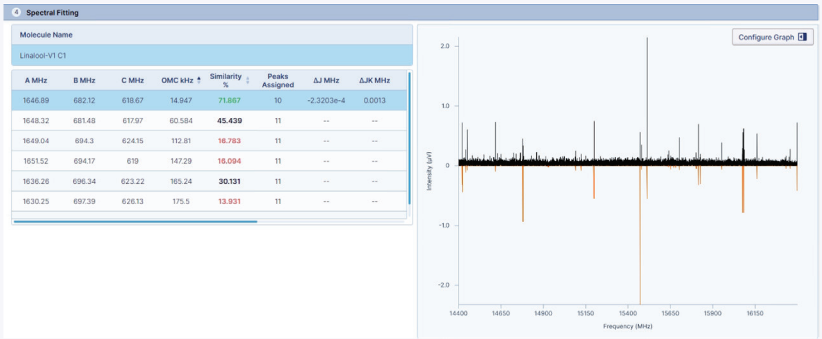
Step 3: Optimize and measure

Acquisition conditions are refined to obtain a high-quality experimental spectrum suitable for matching to the predicted spectrum.



Step 4: Match theory and experiment

The experimental rotational spectrum is compared with the predicted spectra for the candidate structures. Spectral agreement identifies a single matching structure and provides definitive confirmation of molecular identity.



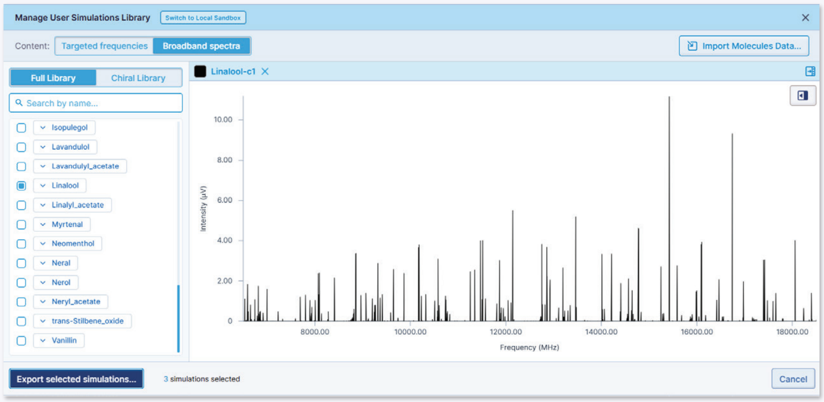
Molecule Name
Linalool-V1 C1

A MHz	B MHz	C MHz	OMC kHz	Similarity %	Peaks Assigned	ΔJ MHz	ΔJK MHz
1646.89	682.12	618.67	14.947	71.867	10	-2.3203e-4	0.0013
1648.32	681.48	617.97	60.584	45.439	11	--	--
1649.04	694.3	624.15	112.81	16.783	11	--	--
1651.52	694.17	619	147.29	16.094	11	--	--
1636.26	696.34	623.22	165.24	30.131	11	--	--
1630.25	697.39	626.13	175.5	13.931	11	--	--

Step 5: Capture the validated reference

The validated spectrum, confirmed through Edgar analysis, is established and incorporated into an experimental spectral library for confident future identification.

Because the spectra are a unique molecular-structure-dependent fingerprint, they can now be used for matching across all MRR instruments without the need for repeat calibration runs in the future.



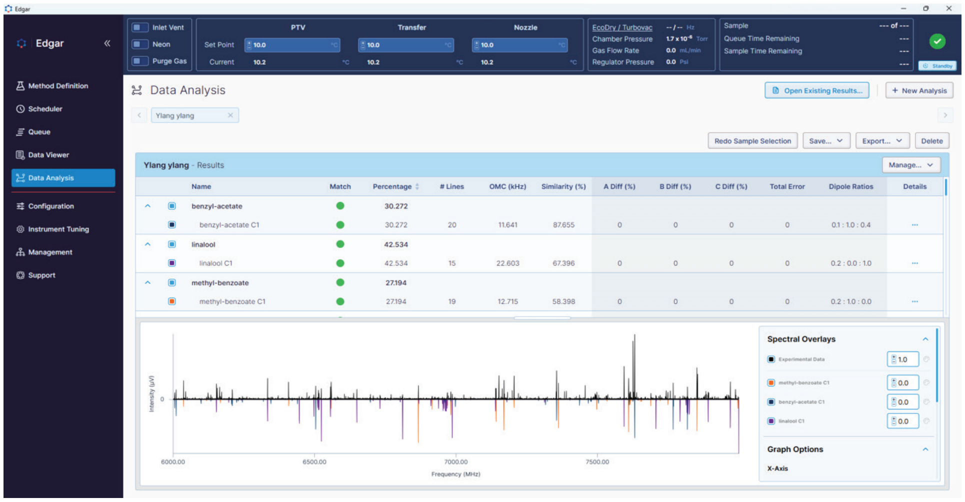
Content: Targeted frequencies | Broadband spectra

- ☐ Isopulegol
- ☐ Lavandulol
- ☐ Lavandulyl_acetate
- ☑ Linalool
- ☐ Linalyl_acetate
- ☐ Myrtenal
- ☐ Neomenthol
- ☐ Neral
- ☐ Nerol
- ☐ Neryl_acetate
- ☐ trans-Stilbene_oxide
- ☐ Vanillin

3 simulations selected

From Single Confirmation to Scalable Libraries

Repeating this automated structure validation workflow across multiple terpenes enables systematic accumulation of experimentally confirmed spectra, producing a class-specific library for confident future identification. Because each entry is grounded in direct experimental structural confirmation, these libraries support high-confidence screening, authentication, and quality control for terpene-containing samples.



Data Analysis

Ylang ylang

Ylang ylang - Results

Name	Match	Percentage	# Lines	OMC (kHz)	Similarity (%)	A Diff (%)	B Diff (%)	C Diff (%)	Total Error	Dipole Ratios	Details
benzyl-acetate	●	30.272									
benzyl-acetate C1	●	30.272	20	11.641	87.655	0	0	0	0	0.1 : 1.0 : 0.4	···
linalool	●	42.534									
linalool C1	●	42.534	15	22.603	67.396	0	0	0	0	0.2 : 0.0 : 1.0	···
methyl-benzoate	●	27.194									
methyl-benzoate C1	●	27.194	19	12.715	58.398	0	0	0	0	0.2 : 1.0 : 0.0	···

Experimental Data 1.0
methyl-benzoate C1 0.0
benzyl-acetate C1 0.0
linalool C1 0.0

Figure 2. Direct identification of linalool and related terpenes in ylang-ylang oil. Identification is enabled by a structurally specific, experimentally confirmed spectral library that supports confident screening, authentication, and quality control.

Conclusion

MRR enables a direct path from proposed molecular structure to definitive experimental confirmation. When combined with automated spectral acquisition and repeated across related molecules, this workflow extends beyond single-compound validation to create scalable spectral libraries that support confident molecular identification across diverse chemical classes and analytical applications.