National Research Foundation

SCIENCE MATTERS

Vol:7 | ISSUE:4

BEANS' GENETIC RESPONSE TO RUST INFECTIONS

Sweet potatoes respond to early drought stress

Agricultural wastewater governance in Japan and South Africa

Drought response in cassava

REAL-TIME WEB SECURITY DETECTIONS

POPPER'S QUANTUM TEST—Testing Popper's conjecture using twisted light

OPEN CALLS

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The Research Development Grant for NRF Y-Rated Researchers is an instrument to support ring-fenced, once-off grants that is competitive and discipline-based in nature.

Chief Eligibility Criteria:

- A valid NRF Y-rating of the principal applicant;
- Scientific merit and quality of the research proposal; and
- Project management and feasibility of the proposed study

Maximum Duration of Support: 3 years

Application Deadline: 15 April 2026

Queries:
Mr Sello Moloi at
SP.Moloi@risa.nrf.ac.za

NRF Thuthuka Funding 2027

The NRF Thuthuka funding instrument is open to applicants who are employed at NRF-recognised public universities, research institutions and science councils in South Africa.

Support is available for emerging/ early career researchers and scholars under the following tracks:

- PhD Track: for applicants intending to obtain a doctoral degree within the funding period;
- Post-PhD Track: for applicants transitioning to become established researchers; and
- NRF Rating Track: for applicants intending to apply for an NRF rating within the funding period.

Application Deadline: 15 April 2026

Queries:
T.Mthethwa@risa.nrf.ac.za
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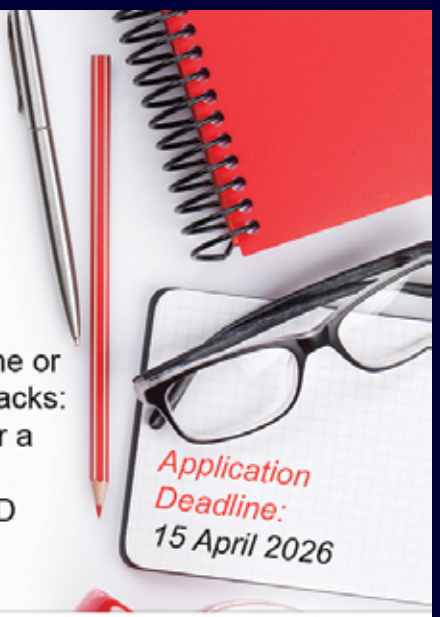
NRF-FREF Black Academics Advancement Programme 2027

The NRF-FREF Black Academics Advancement Programme is aimed at promoting the development of Black academics, specifically, Black South African citizens and academic staff with disabilities.

It is open to academics who are employed (permanent, full-time or fixed-term) at a public SA university and under the following tracks:

- **PhD Track**: for applicants registered/ intending to register for a PhD degree;
- **Post-PhD Track**: for applicants intending to pursue Post-PhD research training

Queries: Ms Nthabeleng Makhetha at N.makhetha@risa.nrf.ac.za



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SCiENCE MaTTERS

Welcome to the fourth issue of the seventh volume of the National Research Foundation (NRF) Science Matters magazine.

This edition brings together a collection of research articles that address pressing challenges across agriculture, sustainability, digital systems, and fundamental science. This issue explores: how science strengthens resilience across food systems; digital infrastructure; and emerging quantum technologies.

Featured research examines how crops such as common bean, sweet potato, and cassava are being studied at the genetic and biochemical level so as to make them able to withstand drought and disease. Research featured also explores the sustainability of South Africa's agricultural trade and agricultural wastewater governance using integrated resource frameworks. This issue also highlights advances in intelligent sensing, machine learning, and real-time cyber security designed to protect modern digital systems. In addition, we feature research that ventures into the quantum frontier, where researchers are testing the limits of uncertainty and reveal hidden topological structures in entangled light. Together, these studies demonstrate how research shapes a more resilient, secure, and sustainable futures.

The NRF would like to thank all the researchers who generously shared their research for this issue of Science Matters, allowing us to showcase the unique perspective of South African scientists and how they make a difference every day.

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HOW COMMON BEAN PLANTS respond to rust infection at the genetic level

Common bean (Phaseolus vulgaris) is a vital food crop in many parts of Africa and other developing regions. It provides an important source of protein, vitamins, and minerals, while supporting household food security and local economies.

However, common bean production is severely affected by plant diseases, particularly rust caused by the fungal pathogen *Uromyces appendiculatus*. This disease spreads rapidly under humid conditions and leads to leaf damage, premature leaf loss, and significant yield reductions. Developing rust-resistant bean varieties is therefore a key priority for sustainable agriculture.

Although several rust-resistance genes have been identified in common bean, resistance often breaks down as the pathogen evolves new virulent strains. Most existing studies focus on single resistance genes or early stages of infection, which offers only limited insight into how plants maintain resistance over time. There is also a lack of comprehensive understanding of how multiple genes interact during infection, particularly at later growth stages when yield losses become most severe. This gap limits the effectiveness of breeding programmes aimed at the development of durable, long-lasting resistance.

A recent research study funded by the NRF investigated how resistant and susceptible common bean varieties respond at the gene expression level

when infected by a virulent strain of Uromyces appendiculatus (race 31 1). The study focused on the identification of differentially expressed genes and potential genetic biomarkers associated with rust resistance at two critical stages of infection, namely 14 and 21 days after infection.

Two common bean varieties were examined, Golden Gate Wax, which is susceptible to rust, and Teebus RR 1, which is resistant. Plants were infected under controlled greenhouse conditions, and leaf samples were collected at 14 and 21 days after infection. Ribonucleic acid sequencing was used to analyse changes in gene expression. Bioinformatics tools were applied to identify differentially expressed genes, functional pathways, and potential biomarkers associated with resistance. Selected genes were further validated using quantitative real-time polymerase chain reaction.

The study revealed clear genetic differences between the susceptible and resistant varieties. The susceptible variety expressed a much higher number of stress-related genes, indicating a broad but largely ineffective response to infection. In contrast, the resistant variety displayed fewer but more targeted gene expression changes, which suggested a controlled and efficient defence strategy. At 14 days after infection, genes related to heat shock proteins, receptor-like kinases, cytochrome P450 enzymes, and terpene synthases were activated in both varieties, but were more tightly regulated in the resistant plants. By 21 days after infection, resistant plants showed enrichment of pathways associated with hormone signalling, photosynthesis, and stress regulation, while susceptible plants exhibited signs of tissue damage and secondary infection. Several potential resistance-associated biomarkers were identified, including genes linked to disease-resistance proteins, deoxyribonucleic acid repair, and stress signalling. Importantly, resistance was not linked to a single gene, but rather to coordinated activity across multiple genes and chromosomes.

> The susceptible variety showed extensive metabolite fluctuations, particularly during early infection stages, suggesting an uncoordinated stress response.

These findings, referred to as ‘Study A’, indicate that effective rust resistance depends on timely and coordinated gene regulation rather than high levels of gene activity alone. Breeding programmes should, therefore, focus on the identification and selection of combinations of resistance-related genes and biomarkers. The use of transcriptomics as a screening tool can help predict resistance performance before field deployment.

Shortly after this work, a follow-up study was conducted to further investigate common bean responses to rust infection by integrating metabolomic and transcriptomic analyses. This study aimed to identify key metabolites, genes, and

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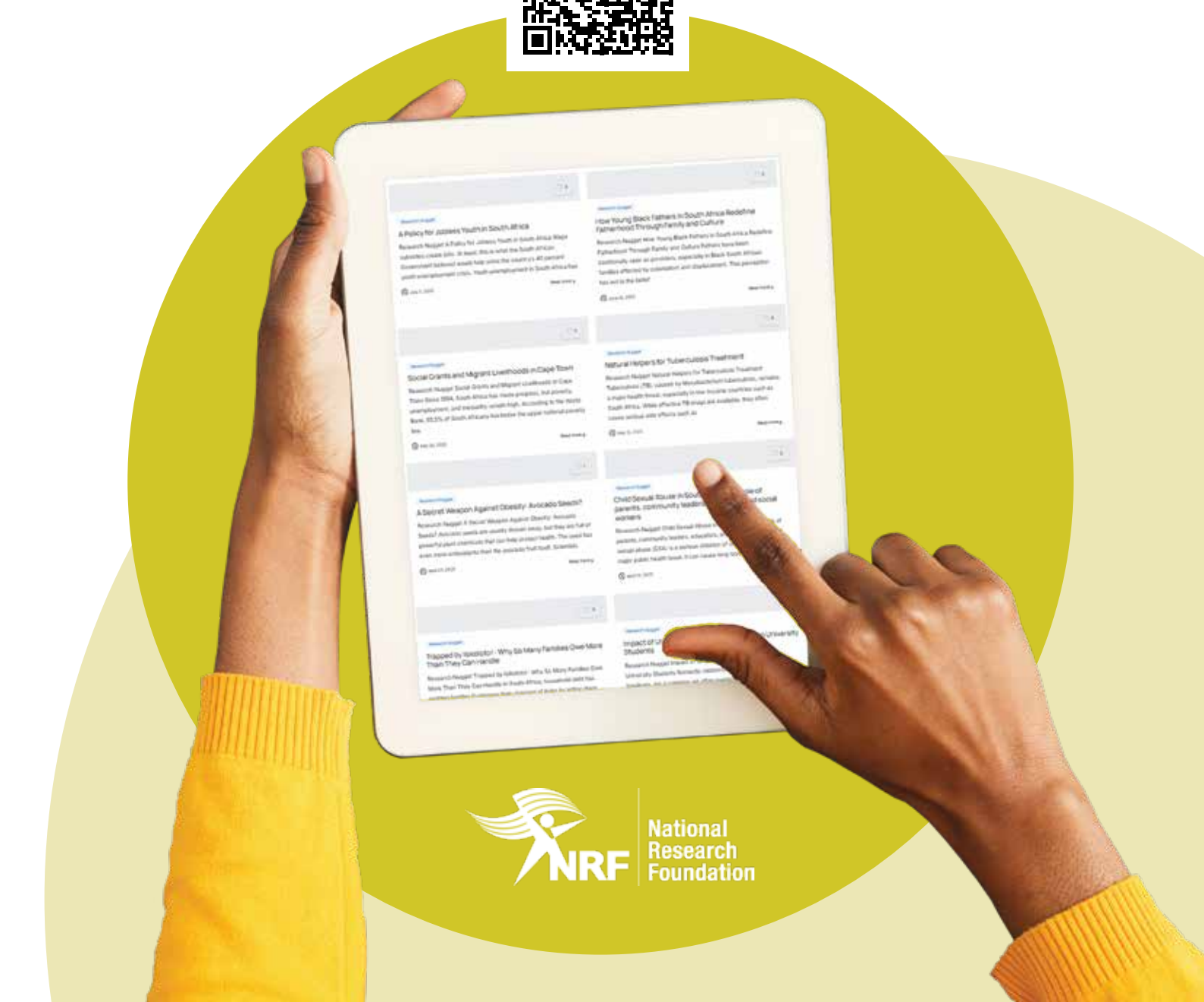

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biological pathways involved in defence responses in resistant and susceptible bean varieties at 14 and 21 days after infection with *Uromyces appendiculatus* (race 31 1).

The same two common bean varieties were used—Golden Gate Wax and Teebus RR 1. Plants were grown under controlled greenhouse conditions and infected with the rust pathogen. Leaf samples were collected at 14 and 21 days after infection. Metabolomic profiling was performed using liquid chromatography mass spectrometry to detect changes in metabolite abundance, while transcriptomic analysis was carried out using ribonucleic acid sequencing. Bioinformatics tools were then used to integrate metabolite and gene expression data and to identify enriched biological pathways associated with rust response.

The study revealed marked differences between the susceptible and resistant varieties. Rust infection altered the levels of more than 30 known metabolites, including flavonoids, phenylpropanoids, lipids, and nucleosides. The susceptible variety showed extensive metabolite fluctuations, particularly during early infection stages, suggesting an uncoordinated stress response. In contrast, the resistant variety exhibited more targeted regulation of metabolites, including compounds associated with antimicrobial activity and defence signalling. More than 3 000 genes were differentially expressed following infection, with the susceptible variety showing substantially higher numbers of gene expression changes than the resistant variety. Key gene families involved in stress and defence, such as heat shock proteins, cytochrome P450 enzymes, terpene synthases, and WRKY transcription factors, were identified. Integrated analysis revealed strong links between specific metabolites and genes, which highlighted coordinated defence mechanisms in the resistant plants. Several biological pathways were enriched, including secondary metabolite biosynthesis, protein processing in the endoplasmic reticulum, carbon metabolism, and purine metabolism.

Overall, the findings demonstrated that effective rust resistance relies on coordinated regulation of genes and metabolites rather than the activation of individual resistance genes. The Integration of metabolomic and transcriptomic data provides a powerful approach for the identification of biomarkers that can be used in breeding programmes to predict resistance performance.

The study further highlights that susceptible plants tend to activate broad stress responses that may inadvertently support pathogen progression. In contrast, resistant plants regulate specific defence-related pathways more precisely, enabling them to limit infection while maintaining normal growth. Notably, resistance mechanisms became more pronounced at later stages of infection, reinforcing the importance of evaluating plant responses beyond early time points. SM

Full research references

Study 4a: DOI 10.3389/fpls.2025.1557954
Study 4b: Makhumbila et al., 2025a

AUTHOR
Dr Penny Makhumbila

HOW SWEET POTATOES RESPOND TO EARLY DROUGHT STRESS

Drought is one of the biggest threats to crop production, particularly in regions already affected by climate change and water scarcity.

Sweet potato is a nutrient-rich crop with strong potential to support food security in South Africa and across the continent. However, its productivity is often limited by water stress. While much is known about the nutritional value of sweet potato, far less is understood about how different cultivars respond at a biochemical level when water becomes scarce.

A recent research study investigated how two sweet potato cultivars respond to early drought stress by analysing changes in their metabolic profiles. The research focused on Atacama, a drought-tolerant cultivar, and Blesbok, a commonly grown South African cultivar that is more susceptible to drought. The aim was to identify biochemical changes that occur during the early stages of drought and to explore whether these changes could serve as indicators of drought tolerance.

To achieve the research aim, the study was conducted during the 2024 growing season under controlled conditions at the Agricultural Research Council's Vegetable, Industrial and Medicinal Plants facility in Pretoria. Plants were grown under three water regimes which represented normal watering and increasing levels of drought stress. Leaf samples were collected two weeks after drought conditions were imposed in order to capture the plant response at an early stage before visible damage occurred.

To analyse the biochemical responses, the researchers used untargeted metabolomics, a technique that allows for the detection of a wide range of metabolites without prior assumptions. Advanced liquid chromatography–mass spectrometry was combined with statistical analysis to compare metabolite patterns between the two cultivars and across drought levels.

While much is known about the nutritional value of sweet potato, far less is understood about how different cultivars respond at a biochemical level when water becomes scarce.

The research findings demonstrated clear metabolic differences between Atacama and Blesbok. Even under normal watering conditions, the two cultivars displayed distinct biochemical profiles. Under drought stress, these differences became more pronounced. Ten key metabolites were significantly regulated in response to drought, including compounds involved in flavonoid biosynthesis, phenylpropanoid metabolism, and sugar and starch pathways.

Several metabolites showed strong increases under drought stress, particularly in the drought-tolerant Atacama cultivar. These included chlorogenic acid, kaempferol derivatives, and apigenin-based flavonoids, which are known to play roles in protecting plants from oxidative stress. Pathway analysis revealed that flavonoid biosynthesis, zeatin biosynthesis, and starch and sucrose metabolism were among the most affected metabolic pathways during early drought exposure.

Interestingly, although Blesbok showed more dramatic changes in metabolite levels, this was interpreted as a stress response linked to susceptibility rather than tolerance. In contrast, Atacama displayed a more stable metabolic response, which suggested that drought-tolerant cultivars may rely on inherent biochemical preparedness rather than large metabolic shifts when stress occurs.

Importantly, no visible differences in plant growth were observed at this early stage, highlighting that biochemical changes precede physical symptoms of drought stress. This finding underscores the value of metabolomics in the detection of early stress responses that are not apparent through visual assessment alone.

Overall, the study demonstrates that early drought stress triggers distinct biochemical responses in sweet potato cultivars. The identified metabolites have potential as early biomarkers for drought tolerance and could support breeding programmes aimed at developing climate-resilient sweet potato varieties. SM

Full study:
https://doi.org/10.3390/plants14223532

NITheCS

National Institute for
Theoretical and Computational Sciences

National Institute for Theoretical and Computational Sciences (NITheCS) is a South African national research institute dedicated to advancing theoretical and computational sciences across multiple disciplines.

It operates as a consortium of all public universities in South Africa together with the African Institute for Mathematical Sciences (AIMS) and brings researchers and students together in the spirit of open science to address major societal challenges.

FOCUS AREAS

NITheCS supports research and collaboration in fields such as:

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- *Data science*
- *Earth systems modelling & climate change modelling*
- *Mathematics*
- *Bioinformatics and quantitative biology*
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- *Supports cutting-edge research*
- *Provides postgraduate training and capacity development*
- *Hosts workshops, seminars, coding schools, and research programmes*
- *Promotes national collaboration and open science*

By strengthening theoretical foundations and computational expertise, NITheCS drives innovation in areas such as quantum science, artificial intelligence, climate modelling, and complex systems.

As a hub for scientific excellence, NITheCS is helping build the next generation of African scientists equipped to solve tomorrow's challenges.

PROGRESS AND IMPACTS OF omics technologies in understanding the drought response in cassava

Cassava is a crucial staple crop in Africa. It contributes to food security and is a major source of carbohydrates after rice and maize. However, its productivity is increasingly threatened by the worsening impacts of drought caused by climate change.

Despite cassava being relatively tolerant to dry conditions, drought continues to cause major reductions in cassava yield, and the biological mechanisms that control cassava's drought response are not yet fully understood, particularly at the molecular level.

To address this challenge, a research study co-funded by the NRF reviewed and brought together existing evidence from genomics, transcriptomics, proteomics, and metabolomics studies related to cassava drought stress. The review focused on progress, impacts, and challenges in an African context and included studies conducted on both African and non-African cassava germplasm, with attention to their relevance for African breeding programmes.

The research study showed that:

- Omics technologies have identified genes, proteins, and metabolites linked to cassava responses to drought stress.
- Genomics and transcriptomics have been used most extensively and have revealed drought-related genes, genomic regions, and changes in gene expression across cassava tissues.
- Proteomic and metabolomic studies showed that drought affects proteins and metabolites involved in energy use, stress defence, and metabolic regulation, although these approaches are less widely applied.
- Drought responses in cassava were shown to be genetically controlled, tissue-specific, and dependent on developmental stage.

Findings from both African and non-African cassava genotypes indicated that many drought response pathways are conserved across cassava diversity.

Drought responses in cassava were shown to be genetically controlled, tissue-specific, and dependent on developmental stage.

The research conclusion states that omics technologies have substantially improved our understanding of how cassava responds to drought by identifying genes, proteins, and metabolites involved in stress tolerance. However, these technologies have not yet been fully applied or integrated into cassava breeding programmes in Africa. SM

Full research study:
https://doi.org/10.1002/pei3.70100

Assessing the Sustainability of **SOUTH AFRICA'S AGRICULTURAL TRADE**

Agricultural trade plays an important role in feeding populations and responding to global food insecurity, especially in countries facing constraints in water, energy, and land.

Through trade, countries can effectively shift where food is produced, allowing the resources used in production to be transferred across borders. This process is often referred to as virtual resource transfer.

For a resource-scarce country such as South Africa, agricultural trade has the potential to support food security, reduce pressure on limited domestic resources, and generate economic value. At the same time, agricultural production places significant demands on water, energy, and land, while contributing to greenhouse gas emissions and other environmental impacts. Understanding whether agricultural trade supports or undermines sustainability, therefore, requires careful and comprehensive assessment.

A research study funded by the National Research Foundation (NRF) examined the sustainability of South Africa's agricultural trade using a newly developed analytical framework. The study addressed a key gap in existing research by moving beyond single-sector analyses and considering multiple resource, environmental, and economic dimensions together.

In the study, the researchers introduced the Water-Energy-Food-Land-Economy-Climate (WEF-LEC) framework, which builds on the widely used Water-Energy-Food nexus approach. In addition to water, energy, and food, the framework explicitly includes land use, economic value, and climatic impacts.

This broader perspective allows for a more holistic assessment of sustainability, particularly in developing and resource-constrained countries where economic outcomes are closely linked to development goals. By integrating multiple dimensions into a single framework, the approach

GETTY IMAGES

provides a clearer picture of the trade-offs and benefits associated with agricultural trade.

The framework was applied using life-cycle analysis to assess South Africa's agricultural imports and exports in 2020. The analysis considered resource use and environmental impacts linked to production, processing, storage, and domestic transport. International shipping was excluded due to data limitations, but sensitivity analyses were conducted to test the robustness of the results.

Key findings from South Africa's trade profile show that in 2020 the country exported approximately 11.01 million tonnes of agricultural products and imported about 8.8 million tonnes, resulting in a trade surplus of 2.21 million tonnes. Although South Africa exported around 25% more agricultural products than it imported, the study found that imports were considerably more resource-intensive.

Producing agricultural imports required 65% more water than exports, with green water accounting for most of this difference. Imports also required 3% more energy and 44% more land than exports. From an environmental perspective, imports generated 98% more carbon dioxide emissions and 103% more eutrophication-related emissions than exports.

In contrast, agricultural exports generated substantially greater economic value. South Africa earned 64% more economic value from its agricultural exports than the cost of its imports, resulting in an economic surplus of approximately USD 3.36 billion.

From an environmental perspective, imports generated 98% more carbon dioxide emissions and 103% more eutrophication-related emissions than exports.

The findings suggest that South Africa's agricultural trade mix aligns well with its domestic resource constraints. The country primarily exports products such as fruit, which generally require lower amounts of water, energy, and land; produce fewer environmental impacts; and generate high economic value.

More resource- and emission-intensive products, including grains and animal-based products, are largely imported. According to the WEF-LEC framework, this trade pattern supports sustainability by conserving scarce domestic resources, limiting environmental impacts, and strengthening economic returns.

Sensitivity analyses using different years and alternative assumptions confirmed that these overall trends remain consistent.

Full research study:
https://doi.org/10.1016/j.clpl.2025.100092

AUTHOR
Dr Thomas van Huyssteen

GOVERNANCE OF AGRICULTURAL WASTEWATER MANAGEMENT in Japan and South Africa

Agriculture is the world's largest user of freshwater and one of the major sources of water pollution. It accounts for about 70% of global freshwater withdrawals and produces wastewater that can carry nutrients, pathogens, pesticides, salts, and other contaminants into rivers, dams, and groundwater.

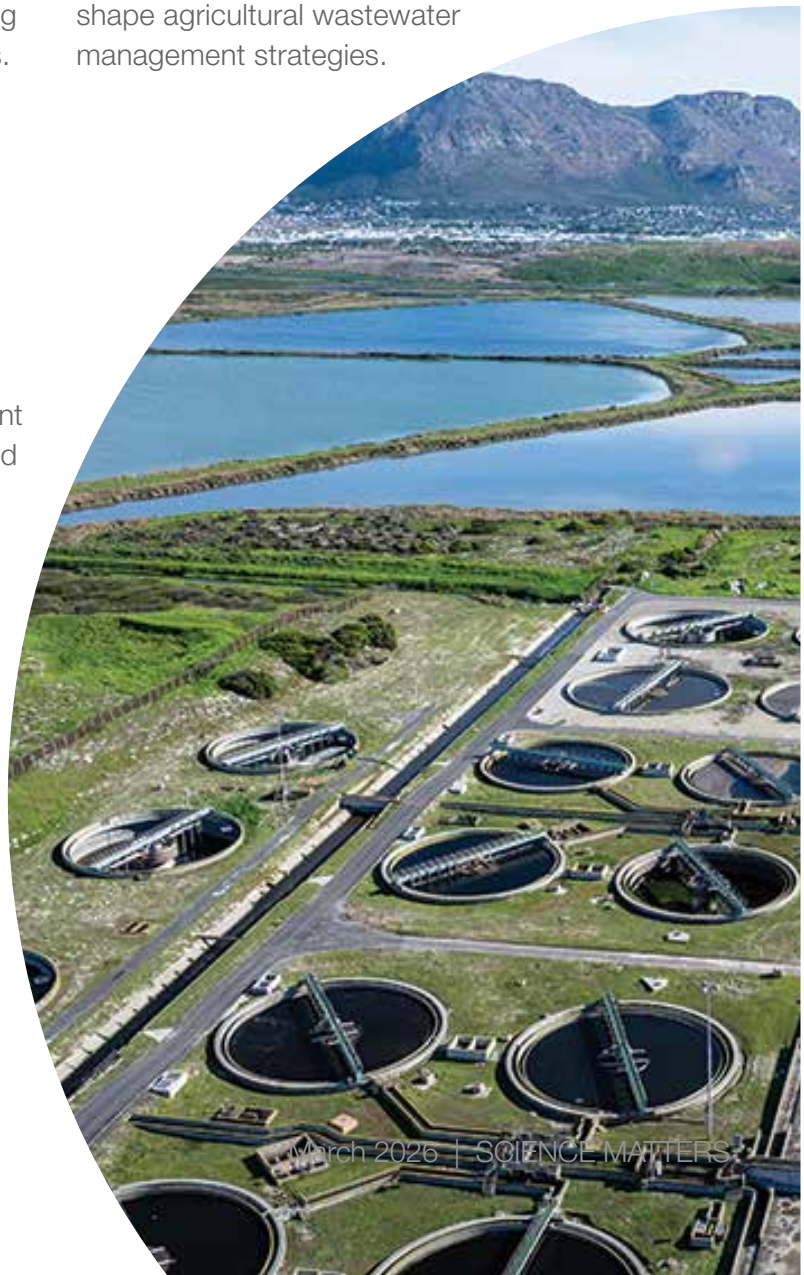
As agricultural production expands to meet rising food demand, pressure on water quality continues to increase. Effective management of agricultural wastewater is therefore essential for protecting water resources, supporting food security, and maintaining healthy ecosystems.

Managing agricultural wastewater, however, remains challenging. Unlike sewage or industrial waste, most agricultural pollution comes from nonpoint sources, meaning it is spread across the landscape through runoff rather than discharged from a single pipe.

This makes monitoring, regulation, and enforcement complex and costly. Farmers also face financial and technical barriers when adopting safer practices, with smallholder farmers often receiving the least support despite being among the most exposed to water and sanitation risks.

Many countries struggle to meet agricultural wastewater policy goals due to institutional, regulatory, and technological limitations. These challenges include unclear mandates across government departments, weak enforcement mechanisms, limited treatment and monitoring infrastructure, and incentive systems that do not always encourage sustainable practices. As a result, water pollution often persists even where environmental laws and standards are in place.

A study funded by the NRF examined how governance and infrastructure contexts shape agricultural wastewater management strategies.



Using a New Institutional Economics (NIE) framework, the researchers compared Japan and South Africa. Both countries face serious challenges related to agricultural wastewater, but they differ significantly in water availability, agrochemical use, infrastructure capacity, and socio-economic conditions. These contrasts provide a useful basis for understanding what works, what does not, and what lessons can be shared across contexts.

The study used a comparative case study approach supported by document-based analysis. It drew on peer-reviewed research, government policy documents, legal frameworks, and reports from established institutions. The analysis was guided by the NIE framework, which examines how formal rules, incentives, social norms, and individual behaviour influence policy outcomes.

Clear legislation and well-defined roles across government bodies support effective regulation and enforcement.

The framework considered four institutional pillars:

- The State, including laws, regulations, enforcement, and coordination
- Markets, such as incentives, investment mechanisms, and certification schemes
- Informal institutions, including community norms, social networks, and customary systems
- Individual actions, focusing on farmer decisions and behaviour

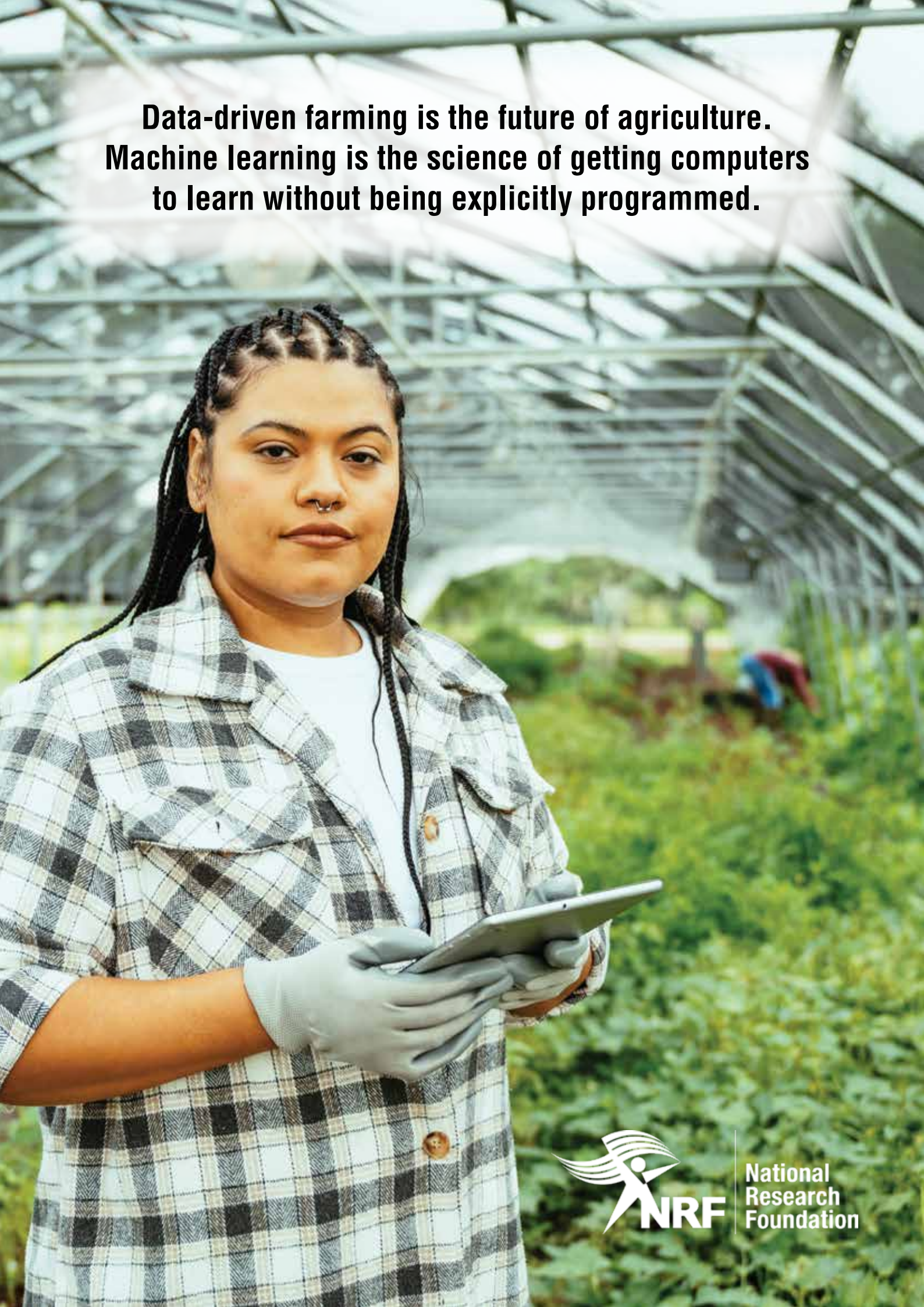
It also highlighted three enabling conditions that influence performance:

- Technological innovation
- Infrastructure development
- Stakeholder participation

The study found that while both countries aim to improve water quality, their governance pathways and implementation outcomes differ markedly.

In Japan, agricultural wastewater management is shaped by strong institutional coordination and long-term investment in infrastructure and technology. Clear legislation and well-defined roles across government bodies support effective regulation and enforcement. Advanced treatment and monitoring systems enable large-scale implementation, while market-based tools such as eco-certification and technology investment encourage sustainable farming practices.

Community participation structures, including water user organisations and legally supported local institutions, further strengthen implementation through shared responsibility and cost-sharing.


Data-driven farming is the future of agriculture.
Machine learning is the science of getting computers
to learn without being explicitly programmed.
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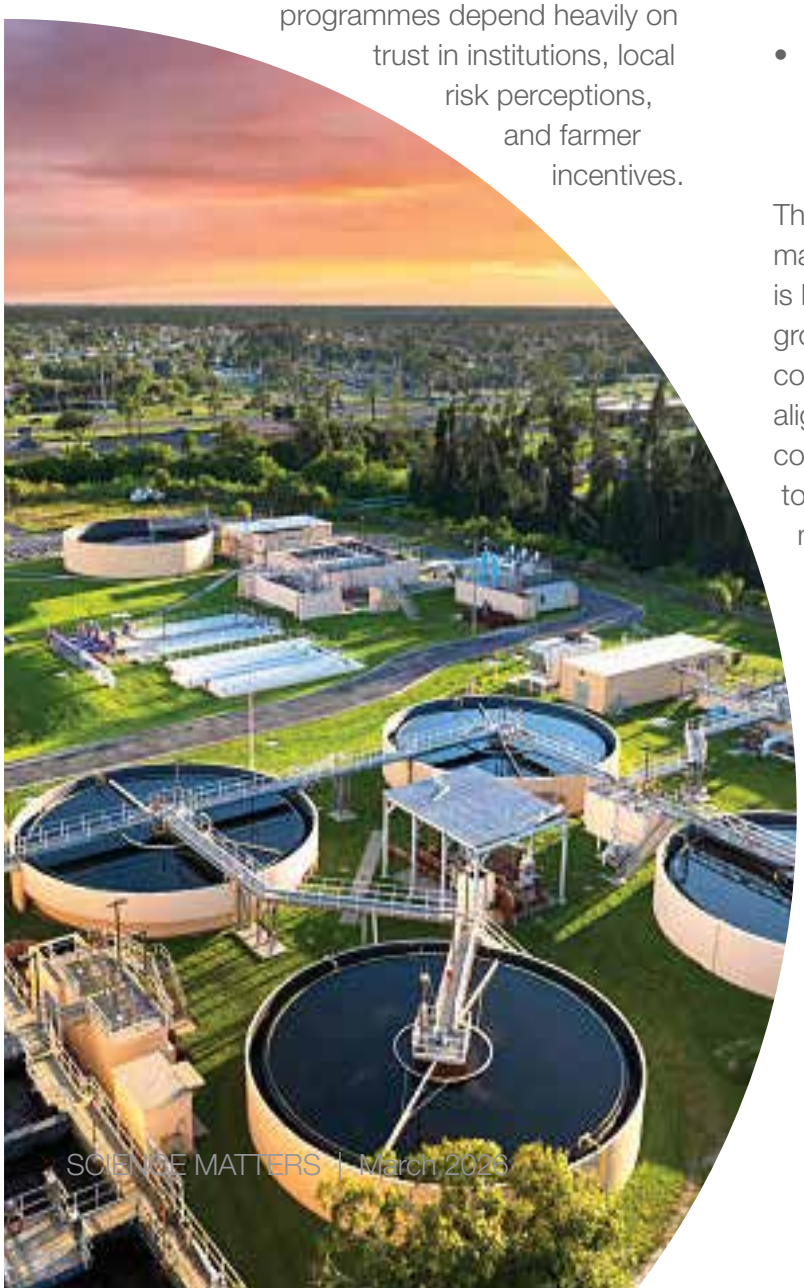
In South Africa, agricultural wastewater management operates under conditions of water scarcity, climate vulnerability, and persistent inequality in access to infrastructure. Although legislation exists, fewer than half of assessed wastewater treatment systems meet national and international standards, leading to untreated discharges in many areas. Institutional fragmentation, overlapping responsibilities, funding constraints, and weak coordination reduce policy effectiveness. Despite these challenges, South Africa demonstrates notable examples of low-cost, community-driven innovation. Practices such as constructed wetlands, conservation tillage, and grassroots water monitoring show how adaptation is possible under resource-constrained conditions, even though scaling these solutions remains difficult.

Across both countries, nonpoint source pollution increases transaction and information costs, particularly where institutions and infrastructure are weak. The study also highlights that voluntary programmes depend heavily on trust in institutions, local risk perceptions, and farmer incentives.



Policies and practices that succeed in one context may fail in another if they are transferred without adapting to local social, economic, and institutional conditions.

The study argued that improving agricultural wastewater policy outcomes requires governance systems that are collaborative, decentralised, and realistic about local capacity.

Priority actions included:

- Strengthening collaboration among government agencies, farmers, local communities, businesses, and researchers
- Clarifying institutional roles and mandates to improve accountability and coordination
- Investing in infrastructure and technology suited to local conditions, including decentralised systems where large-scale infrastructure is not feasible
- Designing incentives that support the adoption of safer practices, particularly for smallholder farmers
- Supporting participation mechanisms that build trust and encourage compliance through shared responsibility

The study concluded that agricultural wastewater management is most effective when governance is both institutionally coordinated and locally grounded. Overall, the researchers argued that collaborative and decentralised governance, aligned with local realities and supported by cross-country learning, offers a cost-effective pathway toward more sustainable agricultural wastewater management. SM

Full research study:
https://doi.org/10.1007/s40899-025-01297-2

Pyemo Afego

MAPPING RESEARCH ON SPECTRUM SENSING IN WIRELESS NETWORKS

What recent studies show about detecting unused frequency bands

Wireless networks rely on radio spectrum, which refers to the frequency bands used to transmit signals.

Spectrum scarcity has become an increasing challenge because regulatory bodies allocate most frequency bands to licensed operators, while unlicensed users are required to avoid interference when licensed users are active. Despite this, many allocated frequency bands remain underutilised for significant periods of time, which limits the overall efficiency of spectrum use.

A study funded by the **National Research Foundation** reviewed existing research on spectrum sensing, a key process used in cognitive radio systems to address spectrum scarcity. The aim of the study was to conduct a bibliometric analysis of research focused on the optimisation of spectrum sensing in wireless networks.

The review was guided by two main research questions:

1. Which traditional spectrum sensing techniques are most commonly used in cognitive radio networks?
2. What is the extent to which machine learning techniques are being applied to improve spectrum sensing performance?

The study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology to identify, screen, and filter relevant literature. Cognitive radio systems help reduce spectrum scarcity through the detection of unoccupied frequency bands and by allowing unlicensed users to access them when licensed users are not transmitting.

Spectrum sensing, also referred to as spectrum detection, is used to determine whether a licensed user signal is present within a specific frequency band. This decision is typically made by a comparison of the output of a detector to a predefined threshold. System performance is commonly evaluated using two key indicators: the probability of detection, which measures how often the system correctly identifies the presence of a licensed user, and the probability of false alarm, which measures how often the system incorrectly signals that a licensed user is present.

Several traditional spectrum sensing techniques are widely discussed in the literature and each method has distinct advantages and limitations:

- **Energy detection** – This is widely used due to its simplicity, but it performs poorly at low signal to noise ratio levels.
- **Matched filtering** – This technique can be highly efficient, but it requires prior knowledge of the licensed user signal.

- **Wavelet-based detection** – This method is more effective under low signal conditions but is often computationally complex and resource intensive.
- **Cyclostationary feature detection** – As with wavelet-based detection, this method more effective under low signal conditions, but also shares the same disadvantages of computational complexity and resource intensiveness.

To conduct the bibliometric analysis, the researchers searched two major academic databases: Web of Science and Scopus. Using the search terms “spectrum sensing” and “cognitive radio networks,” they initially identified 3 151 articles. After applying filtering criteria related to publication year (2017 to 2022), document type, language, and open access availability, 102 records were retained for detailed analysis.

The selected records were analysed using Bibliometrix, an R-based tool for bibliometric analysis and visualised using Biblioshiny. The final dataset included contributions from 334 authors across 49 publication sources. Most of the documents were journal articles, and the majority were co-authored, indicating a strong level of research collaboration in this field.

The analysis showed that IEEE Access was the most influential and most frequently cited publication source in the dataset, based on indicators such as h-index and source relevance.

The study highlights low signal to noise ratio performance as a persistent challenge that continues to drive research interest in machine learning based solutions.

China recorded the highest number of citations by country, followed by Korea, while South Africa had fewer citations compared to several other countries included in the analysis.

Keyword analysis revealed that frequently occurring terms included access, optimisation, allocation, algorithms, and energy detection. Thematic analysis indicated that optimisation and spectrum allocation remain central research themes. In contrast, machine learning techniques emerged as rapidly developing topics within the field.

Across the reviewed studies, machine learning and hybrid approaches were frequently reported to outperform traditional spectrum sensing methods, particularly under low signal to noise ratio conditions. The study highlights low signal to noise ratio performance as a persistent challenge that continues to drive research interest in machine learning based solutions.

The authors noted several limitations related to database coverage, analysis scope, and the selected time range. They recommended that future reviews include additional databases and broader bibliometric indicators to provide a more comprehensive overview of the field.

Overall, the findings point to growing research interest in machine learning and hybrid methods for improving spectrum sensing performance. This trend is especially evident in scenarios where traditional techniques struggle, such as low signal to noise ratio environments. SM

Full research study:
https://arxiv.org/pdf/2310.00278

AUTHOR
Dr. Nyashadzashe Tamuka

Are Chemicals in Sanitary Pads A **HIDDEN HEALTH RISK?**

Sanitary pads and pantyliners are widely used menstrual hygiene products and come into direct contact with the skin and mucosal tissues during use.

Recent international studies have reported the presence of endocrine-disrupting chemicals in feminine hygiene products. However, limited data are available from countries in the Southern Hemisphere, including South Africa.

Endocrine-disrupting chemicals are substances that interfere with the body's hormone system. Hormones control important functions such as growth, reproduction and metabolism. These chemicals can mimic hormones, block them or change how they work in the body. This disruption can affect normal body processes and health. Long-term exposure has been linked to problems such as infertility issues, reproductive disorders and hormone-related diseases.

A research study funded by the NRF evaluated the occurrence and concentration profiles of endocrine-disrupting chemicals, namely the phthalates, parabens, and bisphenols in sanitary pads and pantyliners sold in South Africa. It also estimated dermal exposure during product use and assessed the significance of menstrual products as a potential source of exposure.

To achieve the research objectives, a total of 20 endocrine-disrupting chemicals were analysed. These included nine phthalates, five parabens, and six bisphenols. Sixteen commercially available sanitary pads and seven pantyliners were purchased from a large retail store in South Africa.

Only the top sheet of each product, which comes into direct contact with the skin, was analysed. Samples were extracted using methanol.

Parabens and bisphenols were analysed using high-performance liquid chromatography coupled with tandem mass spectrometry. Phthalates were analysed using gas chromatography coupled with mass spectrometry. Calibration curves, quality control samples, and procedural blanks were included to ensure analytical reliability.

Endocrine-disrupting chemicals were detected in all tested products. Each product contained at least two of the targeted chemicals.

Phthalates were detected in 100% of pantyliners and 50% of sanitary pads. Bisphenols were

detected in 75% of pantyliners and 100% of sanitary pads. Parabens were detected in 75% of pantyliners and 85% of sanitary pads.

Pantyliners contained higher total concentrations of phthalates. Sanitary pads contained higher total concentrations of bisphenols. Methylparaben was the dominant paraben detected. Bisphenol A was the major bisphenol identified. Dibutyl phthalate and benzyl butyl phthalate were the major contributors among the detected phthalates.

Estimated daily exposure doses under normal dermal absorption ranged from 29.66 ng/kg body weight per day for sanitary pads to 32.31 ng/kg body weight per day for pantyliners.

For parabens and individual phthalates, estimated exposure levels were below established acceptable daily intake values. Cumulative exposure to phthalates approached a proportion of the group tolerable daily intake.

For parabens and individual phthalates, estimated exposure levels were below established acceptable daily intake values.

For bisphenol A, estimated daily exposure doses exceeded the European Food Safety Authority tolerable daily intake of 0.2 ng/kg body weight per day by 32-fold for pantyliners and 60-fold for sanitary pads under normal absorption assumptions. Total bisphenol exposure exceeded this reference value by 65-fold for pantyliners and 100-fold for sanitary pads.

Higher dermal absorption scenarios resulted in higher estimated exposure doses.

The research findings indicate that sanitary pads and pantyliners sold in South Africa contain measurable levels of phthalates, parabens, and bisphenols. Given the widespread use of menstrual products and the limited understanding of transmucosal absorption of environmental chemicals, further research is essential to evaluate potential risks and to inform evidence-based policies that protect consumer health. SM

Full research study: https://doi.org/10.1016/j.scitotenv.2026.181510

STRENGTHENING WEB SECURITY THROUGH REAL-TIME INTRUSION DETECTION

Developing a proactive system to detect web-based attacks

The widespread use of web applications has transformed how organisations deliver services. Many businesses now rely entirely on web-based systems rather than traditional client server applications.

The widespread use of web applications has transformed how organisations deliver services. Many businesses now rely entirely on web-based systems rather than traditional client server applications. While this shift offers greater flexibility and accessibility, it has also increased exposure to cyber security threats. Web applications are frequent targets of attack due to software vulnerabilities, particularly those associated with scripting languages such as PHP and JavaScript.

A research study funded by the National Research Foundation investigated how real-time intrusion detection systems can be used to strengthen the security of web applications. The study aimed to develop and test a web-based Intrusion Detection System (IDS) capable of detecting attacks as they occur, including previously unseen threats known as zero-day attacks.

An intrusion is defined as any unauthorised activity that can cause harm to a system or software.

Intrusion Detection Systems are designed to monitor system activity and identify potential security violations. Traditional IDS approaches often rely on predefined rules or large datasets of known attack patterns. While effective for recognised threats, these methods can struggle to detect new or evolving attacks, particularly in dynamic web environments.

Web based attacks commonly exploit weaknesses in user input validation. Two widely reported attack types are Structured Query Language (SQL) injection and cross-site scripting (XSS). SQL injection allows attackers to manipulate database queries, potentially gaining unauthorised access to sensitive data. XSS attacks involve injecting malicious scripts into trusted websites, which are then executed by unsuspecting users.

To achieve the research objectives, the researchers adopted an agile development methodology, allowing the system to be developed and tested iteratively. The IDS was implemented using PHP and designed to monitor Hypertext Transfer Protocol (HTTP) requests in real time. Incoming data was analysed for patterns associated with common web attacks, including SQL injection and both stored and reflected XSS attacks. The system was tested on a live website created for experimental purposes, which enabled the researchers to assess performance under realistic conditions.

The developed IDS included a web-based dashboard that allowed administrators to monitor detected intrusions. When an attack was identified, the system recorded key details, including the type of attack; the Internet Protocol (IP) address involved; and the time of occurrence. Importantly, the system also sent immediate email notifications to administrators, which enabled rapid response and mitigation.

The results showed that the IDS successfully detected 23 out of 25 simulated attacks, an achievement of an overall detection accuracy of 92%.

System testing involved the deliberate simulation of common web attacks. These included injecting malicious SQL queries into login forms and inserting harmful JavaScript code into website comment sections. The IDS was also tested against attempts to gain unauthorised administrative access.

The results showed that the IDS successfully detected 23 out of 25 simulated attacks, an achievement of an overall detection accuracy of 92%. The system was able to identify attacks in real time and automatically blacklist IP addresses associated with repeated intrusion attempts.

Overall, the research highlights the potential of proactive intrusion detection systems in improving web application security. The findings indicate that a rule-based, real-time IDS can effectively detect web-based attacks without reliance on extensive training datasets. While the current system focused on common attack types such as SQL injection and XSS, the researchers note that future work could expand detection capabilities to include more complex threats. Further testing in large-scale, real world environments is also recommended. SM

Full paper:
https://www.researchgate.net/publication/388477503_A_Novel_Real-Time_Web_Based_Intrusion_Detection_System_IDS

Dr. Nyashadzashe Tamuka

USING MOBILE SENSORS TO UNDERSTAND HUMAN ACTIVITY

Analysing and classifying context data in Internet of Things systems

The rapid growth of digital technologies has led to an unprecedented increase in data generation. Two key contributors to this growth are Big Data and the Internet of Things (IoT).

IoT systems rely on connected devices equipped with sensors that continuously collect information about users and their environments. This data can be analysed to better understand human behaviour and activity patterns.

A research study funded by the **National Research Foundation** investigated how sensor data from mobile devices can be used to identify and classify daily human activities. The study focused on the application of machine learning techniques to analyse context data generated within IoT environments. Its aim was to develop a scalable, mobile sensor data driven framework for the analysis and classification of human activity context.

To achieve this, the researchers designed a platform that consisted of three main components:

1. A mobile application for sensor data collection;
2. A server for data storage and aggregation; and
3. Machine learning algorithms to classify user activities.

Context awareness refers to a system's ability to gather information about a user, their device, and their surrounding environment, and then adapt its behaviour accordingly. In IoT systems, context information is commonly obtained through sensors embedded in mobile or wearable devices. These sensors can capture data related to movement, location, proximity, and environmental conditions.

In the field of human activity recognition, context awareness is used to identify activities such as walking, running, sitting, or driving. Traditional approaches to activity recognition often rely on computer vision techniques. While effective in some settings, these methods can be limited by high computational demands, restricted mobility, and privacy concerns.

In this study, a mobile application was developed for the Android platform to collect data from selected sensors, including the accelerometer, light sensor, proximity sensor, and Global Positioning System (GPS). These sensors were chosen because they are strongly influenced by physical user activities. The application was used both to collect labelled training data and to capture real-time sensor data during normal device use.

Three machine learning classifiers were evaluated:
1. K Nearest Neighbours (KNN);
2. Decision Trees; and
3. Support Vector Machines (SVM).

These algorithms were selected due to their widespread use in human activity recognition research. The dataset consisted of 1 090 sensor data instances, which were divided into training and testing sets.

Initial testing showed that the KNN classifier achieved higher accuracy than the other two models. Further experiments involved tuning model parameters and applying cross-validation techniques, which improved the performance of all classifiers. Across these tests, KNN consistently demonstrated strong performance in classifying human activities.

The study found that the KNN classifier performed particularly well under these conditions.

The study also examined how changes in training set size affected classification accuracy. The results showed that increasing the amount of training data generally improved model performance, which highlighted the importance of sufficient data for reliable activity recognition.

Overall, the findings indicated that mobile sensor data can be effectively used to classify human activities, even in situations where activities overlap or change rapidly. The study found that the KNN classifier performed particularly well under these conditions.

The research demonstrates the potential of combining IoT technologies and machine learning to enhance context aware systems. Such systems could have practical applications in areas such as healthcare monitoring, smart homes, and behavioural analysis. SM

Full research: https://www.researchgate.net/publication/388474238_Towards_IoT_Context_Data_Analysis_and_Classification

Revealing the topological nature of **ENTANGLED ORBITAL ANGULAR MOMENTUM STATES OF LIGHT**

Light can carry information in many ways, including through a property known as orbital angular momentum.

This property allows light to exist in many distinct states, which makes it useful for high-dimensional quantum technologies. At the same time, topology, a branch of mathematics that studies properties that remain unchanged under smooth deformations, has become an important tool for understanding robustness in physical systems. In quantum science, topology is especially valuable because it can protect fragile quantum states from noise and disturbance.

Until now, most optical topological structures have been limited to low-dimensional systems and often rely on combining multiple properties of light, such as spatial structure and polarisation. This study shows that rich topological structures can exist directly within the spatial entanglement of light itself, through the use of only orbital angular momentum.

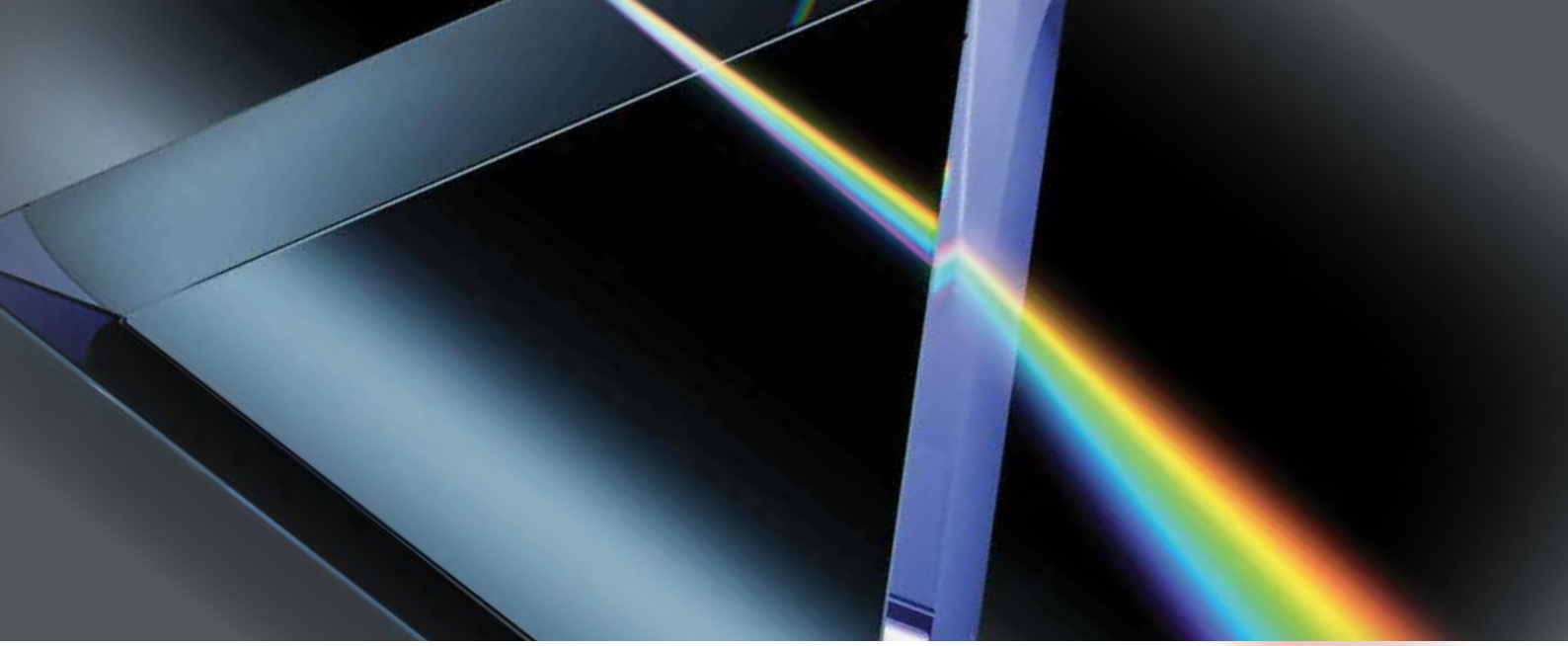
High-dimensional quantum states offer major advantages for quantum communication, sensing, and information processing, but they are highly sensitive to noise and loss. While topology is known to improve robustness, topological effects in light have largely been explored in low-dimensional systems or through multiple degrees of freedom. It has therefore remained unclear whether complex and scalable topological structures exist inherently within high-dimensional quantum entanglement.

A recent research study funded by the **National Research Foundation (NRF)** experimentally demonstrated the hidden topological structure of entangled states of light that carry orbital angular momentum. The research shows that topology can emerge directly from spatial entanglement, extend to high dimensions, and form a rich spectrum of topological signatures.

The researchers used pairs of entangled photons produced through spontaneous parametric down-conversion. These photons are entangled in orbital angular momentum, which allows access to quantum states of increasing dimensionality. Theoretical tools from topology and non-Abelian gauge theory were used to describe how these quantum states map onto higher-dimensional topological spaces.

Experimentally, the team reconstructed the quantum states using established measurement techniques and extracted topological features through analysis of how the spatial position of one photon maps onto the state space of the other.

This approach was first applied to two-dimensional states and then extended to higher



dimensions, reaching systems with up to seven dimensions.

The study found that even two-dimensional orbital angular momentum states can form topological structures known as skyrmions, using only a single degree of freedom. These structures are shown to be equivalent to well-known magnetic monopole solutions in high-energy physics, establishing a direct link between quantum light and fundamental field theories.

In higher dimensions, the researchers discovered that a single topological number is no longer sufficient. Instead, each quantum state is characterised by a spectrum of many topological invariants. Experiments confirmed this prediction, revealing thousands of topological signatures in high-dimensional states, including the highest-dimensional topological structures reported to date.

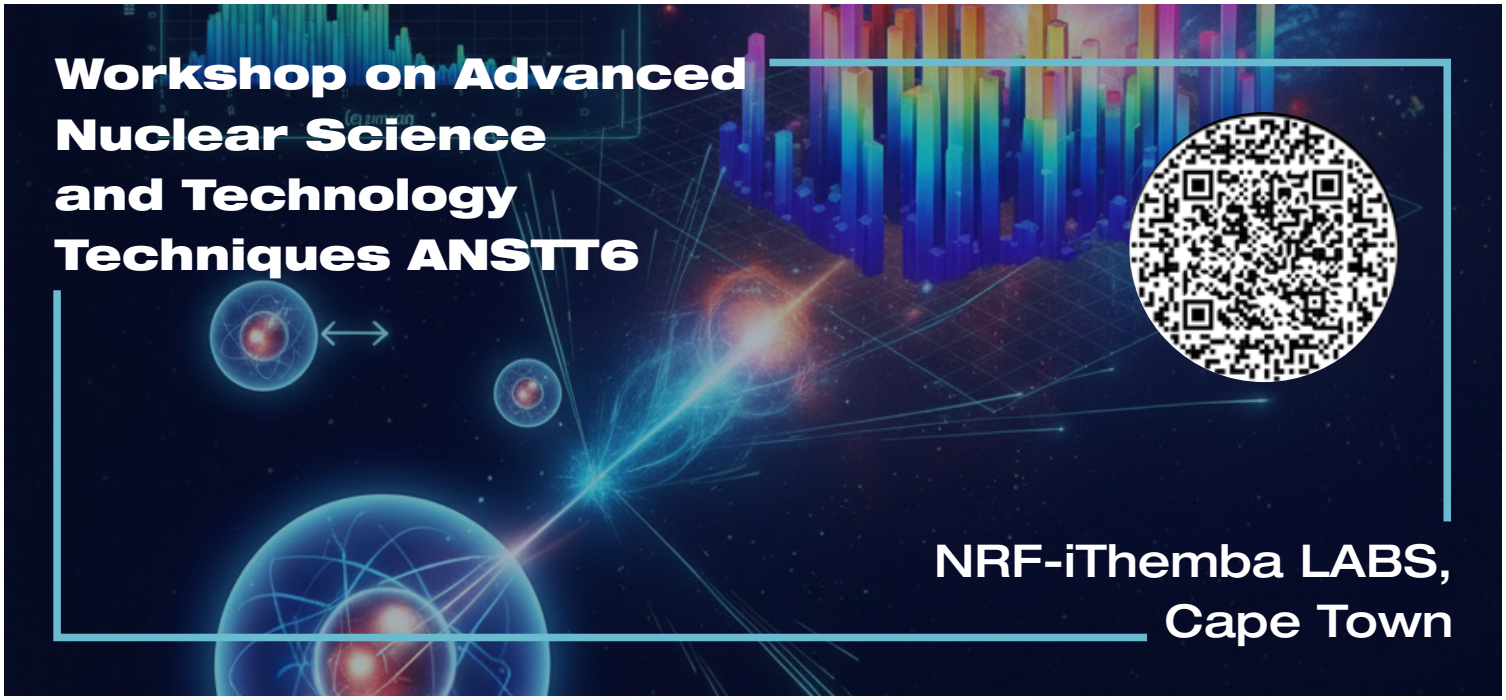
Experiments confirmed this prediction, revealing thousands of topological signatures in high-dimensional states, including the highest-dimensional topological structures reported to date.

The results also show that these topological spectra remain largely unchanged under noise, demonstrating strong robustness. At the same time, new topological features can emerge when entanglement spreads into previously unused regions of the quantum state.

Overall, the study demonstrates that high-dimensional entangled light carries an intrinsic topological structure that can be experimentally accessed and measured. By revealing a scalable topological spectrum rooted in orbital angular momentum, the research provides a new framework for understanding and harnessing robustness in quantum systems, with potential applications in future quantum technologies. SM

Full research study:
https://doi.org/10.1038/s41467-025-66066-3

Workshop on Advanced Nuclear Science and Technology Techniques ANSTT6



NRF-iThemba LABS, Cape Town

18-22 May 2026

The sixth workshop on Advanced Nuclear Science and Technology Techniques (ANSTT6) will be held at NRF-iThemba LABS, Cape Town, during 18-22 May 2026.

This workshop will focus on:

- Cosmic Ray and Muon Physics and Applications,
- Environmental Measurements,
- Future experimental programmes at NRF-iThemba LABS,
- Nuclear Energy,
- Nuclear Experimental Techniques and Data Analysis,
- Nuclear Safety and Security,
- Nuclear Structure Studies and
- Radiation and Health Physics.

Oral and poster presentations are subject to abstracts being accepted by an advisory panel.

Abstract submissions CLOSE on 3 APRIL 2026

The workshop will be structured for presentations, discussions and networking. Collaborations and networking will again be at the forefront of the workshop, including Memoranda of Understanding. The workshop offers a comprehensive programme of invited talks, accepted talks, poster presentations by students and round-table discussions. Lectures on specific topics will be presented in a hybrid format in the afternoons allowing for a wider audience at no cost for virtual attendance.

The workshop site can be found here: https://indico.tlabs.ac.za/event/139

Prior to the Workshop, 13-15 May, the Southern African Institute for Nuclear Technology and Sciences (SAINTS) at NRF-iThemba LABS will be hosting a satellite event, the SPAMs workshop on Spectrum, Presentation, Analysis, and Manipulations. This hands-on workshop will introduce students and researchers to a variety of data analysis techniques through lectures, presentations and demonstrations. Courses will introduce attendees to methods and techniques relevant to the ANSTT workshop.

Pete Jones (NRF-iThemba LABS) and Alison Bruce (University of Brighton)
on behalf of the organising committee.

We look forward to seeing you in Cape Town in May 2026!

NRF National Research Foundation | iThemba LABS Laboratory for Accelerator Based Sciences

UKRI Science and Technology Facilities Council

science, technology & innovation
Department: Science, Technology and Innovation
REPUBLIC OF SOUTH AFRICA

TESTING POPPER'S CONJECTURE using twisted light

Uncertainty is an important concept in physics. It means there are limits to how accurately we can know certain things at the same time, such as a particle's position and how fast it moves.

A long-standing question called Popper's conjecture asks whether measuring one particle that is connected to another can increase the uncertainty of the second particle more than what was already present when the particles were created.

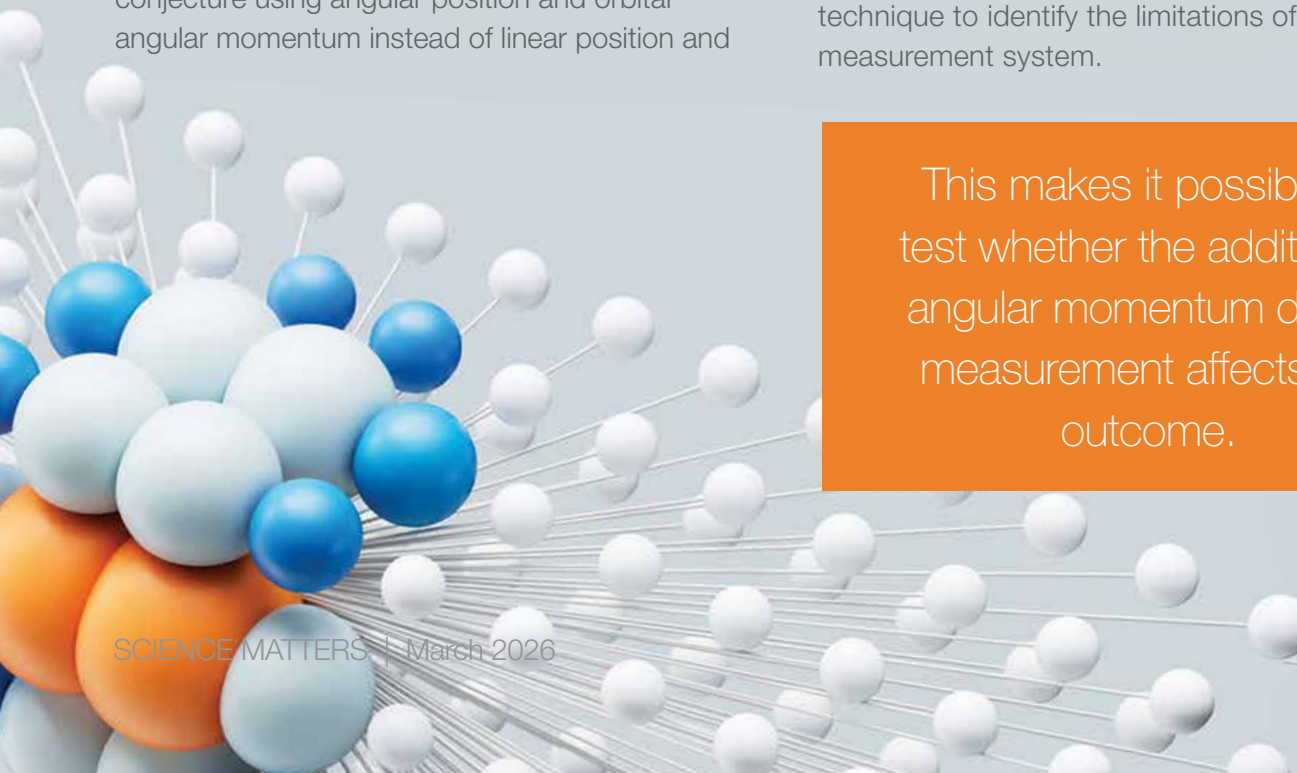
Scientists have started to use a special type of light called structured or twisted light, which can exist in many different states. Earlier experiments mainly focused on position and straight-line motion, but they faced problems such as limited control and interference from measurement tools. Because of this, it has been unclear whether the results were caused by the particles being connected or by limitations in the experiments themselves.

A recent research study funded by the National Research Foundation (NRF) tested Popper's conjecture using angular position and orbital angular momentum instead of linear position and momentum. By doing so, the researchers aimed to find out whether the spread in orbital angular momentum of one photon in an entangled pair is fundamentally limited by the source, even when the other photon is tightly confined.

To achieve this, the researchers generated pairs of entangled photons using spontaneous parametric down-conversion. These photons are entangled in orbital angular momentum. One photon passes through an angular slit created digitally using a spatial light modulator, which precisely controls its angular position. At the same time, the orbital angular momentum of the second photon is measured.

Using a digital slit allows the researchers to control both the slit width and the angular momentum encoded into the slit itself. This makes it possible to test whether the addition of angular momentum during measurement affects the outcome. The team also used a classical back-projection technique to identify the limitations of the measurement system.

This makes it possible to test whether the addition of angular momentum during measurement affects the outcome.



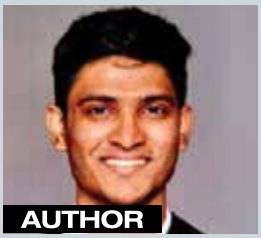
The results show that as the angular slit becomes narrower, the spread in orbital angular momentum of the entangled partner increases, as expected from uncertainty relations. However, this increase does not continue indefinitely. Instead, the spread reaches a fixed maximum determined by the original entangled state produced at the source.

Crucially, even when angular momentum is encoded into the slit, the width of the orbital angular momentum distribution remains unchanged. Only the position of the distribution shifts. This shows that the spread is not influenced by the measurement process or by the motion of the observer but is limited by the source itself.

The classical back-projection experiments further revealed that much of what is measured in such experiments is shaped by the measurement system. This highlighted the importance of separating the properties of the source from the effects of the detector.

Overall, the study shows that using orbital angular momentum and digital angular slits provides a more controlled and flexible way to test foundational questions in quantum physics. This approach overcomes many of the limitations associated with physical slits and linear momentum measurements. SM

Full research study:
https://doi.org/10.1038/s41598-023-48915-7



AUTHOR
Neelan Gounden

Ayabulela Binase Shines in National EDHE Absa Challenge

A proud moment for the Botany Department at Nelson Mandela University (NMU) as Ayabulela Binase, a second-year Master's student under the supervision of Prof Molemi Rauwane, an NRF-funded researcher, was named among the Top 20 finalists in the prestigious Entrepreneurship Development in Higher Education (EDHE) Absa Innovation Challenge 2025.

She designed a NanoLAMP Diagnostic Field Kit, which is linked to the NRF grant project led by Prof Rauwane. The kit is designed for the early detection of viral pathogens that affect common bean crops in South Africa. In her Master's research study, she sought to identify viral pathogens in common bean cultivars in South Africa using molecular techniques across six plots in the Free State and Mpumalanga provinces. This led to the development of a creative idea for an affordable NanoLAMP kit, similar to a home pregnancy test, which would support sustainable agriculture and empower farmers by detecting infections early.

The EDHE Absa Innovation Challenge serves as a national platform for 'studentpreneurs' to showcase solutions that contribute to sustainable development, economic growth, and social impact. By reaching this stage, NMU's finalists have demonstrated not only innovation but also the readiness to compete and lead at a national scale.

LEFT: Ayabulela Binase presents her innovative idea to panellists at the Absa Innovation Challenge.

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We look forward to seeing you on our podcast!