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Mapping underutilised and emerging food sources and technologies as solutions to food insecurity in South Africa

There are clear signs that the South African food system is failing as we experience increasing trends in hunger, rising food costs, lack of dietary diversity, child stunting, foodborne illnesses, food waste and an obesity epidemic coupled with malnutrition. A literature review was conducted to identify underutilised or emerging new food sources and technologies (UEFST). They were identified as indigenous African crops (IACs), insects, fermentation, cultured meat and seafood, food waste recovery and algae. Criteria were developed to assess these UEFST to evaluate their ability to provide affordable, nutritious, safe and relevant food for South Africans (ANSSA). A survey was conducted with food professionals from industry, academia and government to evaluate these UEFST against the ANSSA criteria. Findings indicate that the two most promising UEFSTs – IACs and food waste recovery – could be available to South Africans within three to five years. These sources were rated highest in their ability to meet the ANSSA criteria identified. The two underutilised or emerging food sources with the longest time frame to commercialisation were cultured meat and seafood and algae (5 to 10 years), with cultured meat and seafood scoring the lowest of all six UEFST against the ANSSA criteria.

Significance:

- Underutilised and emerging food sources offer South Africa new solutions to address food security.
- Indigenous African crops and recovery and valorisation of food waste are the most promising short-term options to address food security.
- South African stakeholders from academia, government and industry will need to invest in research, product development, capability-building, scale-up and an agile regulatory environment for these underutilised and emerging food sources to reach commercialisation.

Introduction

South Africa emerged from an oppressive apartheid system in 1994, and more than 30 years of democracy later, over half of the population still lives in poverty.[1] Levels of inequality have remained high, and South Africa remains one of the most unequal countries in the world.[1] Unemployment in 2024 was 32% and remains a pressing national challenge.[2]

One in five South African households (21%) in 2021 was affected by moderate to severe food insecurity.[3] Poorer households can spend more than 40% of their total expenditure on food compared to the national average of 13%.[4] Data from the Household Affordability Index indicate that a minimum nutritious food basket is unaffordable for most low-income South Africans.[5]

Food consumption patterns have changed and will continue to change dramatically over the coming decades in South Africa.[6] Ronquest-Ross et al.[7] concluded that food consumption shifts have been towards sugar-sweetened beverages, processed and packaged food, animal-source foods, added caloric sweeteners and away from vegetables.[7] These dietary shifts are concerning as they relate to public health.[7] Poor diet contributes to four of the top ten death and disability risk factors.[8] The prevalence of obesity is pervasive in South Africa, with 68% of women either overweight or obese.[9] In 2021, 11% of the adult South African population had diabetes.[10] Unfortunately, South Africa has made limited progress in reducing stunting in children under five years, with 21% stunted.[11] Even though the SANHANES-18 survey indicates that anaemia and iron status have improved, poor micronutrient status, especially vitamin A and iron, is still common among young children.[4]

South Africa's food system contributes 15–20% of greenhouse gas emissions.[12] Although 80% of South African land is suitable for livestock farming, overgrazing on erosion-prone soils has led to widespread land degradation, dramatically reducing soil carbon storage.[13] Food production and processing are energy intensive, especially in a country dependent on coal-fired energy sources, and thus substantially increase the system's carbon footprint.[13] South Africa is a water-scarce country with water security becoming a crisis.[14]

Tubb and Seba's[15] RethinkX report suggests we are on the edge of transformational food and agricultural production disruption. This results in uncoupling from land and sea resources to novel protein sources derived from bacteria, yeasts and fungi.[15-17] This will be achieved through rapid advances in synthetic biology and precision fermentation, enabling microorganisms to produce almost any complex organic molecule. A study by Ronquest-Ross et al.[18] indicated that, while South African food and beverage manufacturing appears to be keeping pace with the advances in food manufacturing in the areas of automation, process and quality control, material handling and centralised distribution centres with warehouse management systems, there is a low adoption and commercialisation of novel technologies. However, recently, foodtech start-ups focused on precision fermentation and cultured meat and seafood have been established in South Africa.[19] Several countries have put in place strategic food system transformation action plans to address climate change and food security. For example, Denmark launched the

Danish Action Plan for Plant-based Foods in 2023 to address climate, environmental and nutritional challenges.[20]

It is evident that the South African food system is failing as we experience increasing trends in hunger and malnutrition, rising food costs, a lack of dietary diversity, child stunting, foodborne illnesses, an obesity epidemic coupled with negative climate impacts and environmental degradation. There is a need to develop renewable and sustainable sources of food.[21] Underutilised or emerging food sources and technologies (UEFST) present potential solutions to South Africa's food security challenges and could deliver beneficial changes to its food system.

The objective of this study was to identify which UEFSTs have the potential to be able to address food security and environmental issues in South Africa and to provide recommendations to enable this transition. The findings of this study could help key stakeholders in government and academia and those along the food value chain to prepare for or enable acceleration in research, advance scale-up infrastructure, and enable regulatory and/or policy frameworks to support the commercialisation of these potential future food solutions for South Africa.

Materials and methods

Literature review

A literature review was conducted to identify UEFSTs that could potentially provide solutions to delivering safe, affordable and nutritious foods for vulnerable South Africans. These food sources and technologies were then evaluated based on their positive and negative inherent properties (such as nutritional value, food safety and organoleptic properties) as well as the drivers and barriers to reaching commercialisation related to achieving scale, consumer adoption, regulatory considerations and food system impact.

Quantitative expert survey

A quantitative study was conducted to gain insight from South African food science and technology professionals on the potential of these UEFSTs to provide affordable, nutritious, safe food products. The question was defined so that respondents could familiarise themselves with the six underutilised or emerging food sources. The survey (Table 1) was designed around criteria related to affordability, nutrition, safety, consumer acceptance and regulatory environment (referred to as ANSSA criteria – Affordable, Nutritious, Safe, relevant for South Africans). The ANSSA criteria (Table 2) were designed to evaluate those UEFSTs most likely to be produced locally at scale, to be accepted by South Africans, and to enable a sustainable and affordable diet while improving the population's health. A question was also included to understand the time horizon for commercialisation in South Africa. The survey consisted of 14 questions. The criteria were rated on a 4-point Likert scale, where 4 = strongly agree, 3 = agree, 2 = disagree and 1 = strongly disagree.

Recruitment of experts

We identified experts from government, industry and academia through our professional networks (Figure 1). They were selected for their experience and skills related to the South African food and beverage industry and food science and technology.

Ethical approval was obtained from Stellenbosch University's Ethics Council on 15 July 2021 with project number 22423 before the commencement of the research process. We extended an invitation

Table 1: Survey questions and definitions of underutilised or emerging food sources and technologies

Number	Question
1	Indicate the field you work in. Options: industry, academia, government
2	Area of expertise? Options: indigenous African crops, insects, biomass fermentation, genetic engineering, cellular agriculture, food waste, algae, other
3	These underutilised or emerging food sources are **affordable**, as they could reach **scale** quickly (Definition: Can reach the mass market at scale)
4	These underutilised or emerging food sources are **affordable**, as they can be **locally produced** and **processed** (Definition: This food source can be locally produced and processed in South Africa)
5	These underutilised or emerging food sources are **affordable,** as the **level of investment** required will be achievable (Definition: The capital and resources needed to set up production and processing facilities are available or can be easily sourced)
6	These underutilised or emerging food sources are **affordable**, as there are the necessary **stakeholders and capabilities** available (Definition: There is sufficient stakeholder alignment and support as well as capabilities and related skills available to be able to research and industrialise this food source)
7	These underutilised or emerging food sources are **nutritious** due to **their inherent nutritional profile** (Definition: The nutritional profile is favourable in terms of overall protein, fat, carbohydrate, fibre, vitamin and mineral content)
8	These underutilised or emerging food sources are **safe**, as they do not pose an insurmountable **allergen, toxicological or microbial risk** (Definition: These allergens, toxicological or microbial risks would be a concern for human health)
9	These underutilised or emerging food sources are **safe,** as **processing** has been proven to effectively reduce any **inherent food safety risks** in this food source (Definition: An inherent food safety risk like an allergen, toxicological or microbial risk)
10	These underutilised or emerging food sources are **safe**, as products utilising this food source **do not** require **special storage conditions**, with ambient conditions being the most favourable.
11	Consumers would accept these underutilised or emerging food source**s** as they are **culturally acceptable** (Definition: The food source is part of South African culture through local cuisines and traditional diets)
12	Consumers would accept these underutilised or emerging food source**s**, as their **organoleptic profile is desirable** (Definition: The food source is part of South African culture through local cuisines and traditional diets and is enjoyed)
13	These underutilised or emerging food sources would be able to **reach consumers**, as there is a **favourable regulatory environment** in regard to this food source (Definition: The South African regulatory environment permits or would not prohibit this food source from being produced and marketed to South African consumers)
14	Please indicate **(use an X in the appropriate box)** the time frame in which you expect these underutilised or emerging food sources to be commercially available in South Africa, where 1 = short term (3–5 years); 2 = medium term (5–10 years) and 3 = long term (10+ years).

via email to 53 experts identified to participate in the survey. of the 53 experts invited to participate, 40 agreed and signed the informed consent letter. They were told that they could withdraw their participation at any point during the survey.

Statistical analysis

The questionnaire (in Microsoft Word) was sent to all willing participants electronically via email to complete the survey (Figure 1). MS Excel was used to capture the response data and STATISTICA 14 (TIBCO Software Inc. Data Science Workbench, version 14, 2020) was used to analyse the data.

Constructs in the study were measured with items on a Likert scale, and the reliability of the items was investigated with Cronbach alpha analyses to indicate how well the set of items in the survey results related to each other. The mean of the reliable items was used to measure these constructs.

The relationships between two continuous variables were investigated using regression analysis, and the relationship's strength was measured with the Spearman correlation to determine whether there was a correlation between the variables. The agreement between repeated measures of the same variable was investigated through Bland-Altman plots. The relationships between continuous response variables and nominal input variables were analysed to determine if there were statistically significant differences using appropriate analyses of variance (ANOVA). A *p*-value of less than 0.05 represents statistical significance in hypothesis testing, and 95% confidence intervals were used to describe the estimation of unknown parameters.

The total scores of each underutilised or emerging new food source from this survey were plotted against the estimated time horizon indicated to determine the most promising future food sources.

Table 2: Definitions of ANSSA (Affordable, Nutritious, Safe, relevant for South Africans) criteria

Criteria	Definition
Affordable	• Scalable • Locally produced and manufactured/processed • Level of investment required • Stakeholders and capabilities available, e.g. research institutes, academia, industry
Nutritious	• Nutritional profile • Lack of anti-nutrients
Safe	• Allergens • Toxicity • Microorganisms • Pesticides • Storage conditions • Processing safety
South Africa	• Culturally relevant • Consumer acceptance • Favourable regulatory environment

Results and discussion

Summarised results of the literature review on UEFST

Indigenous African crops

Modern agricultural systems promote the cultivation of a limited number of crop species, such as wheat and maize, and have neglected the utilisation of indigenous African crops (IACs).[22] IACs originated in Africa or were introduced into Africa, and are now recognised as naturalised or traditional crops. Many indigenous African grains, pulses, vegetables and fruits remain essential for food security, nutrition and dietary diversity for vulnerable African communities. These grains are well adapted to semi-arid conditions with natural resistance to many pests, requiring fewer inputs.[22-24] However, these grains and vegetables remain limited to subsistence farming and remain underutilised due to a lack of commercial production and processing, new product development, distribution and marketing, and consumer awareness about their benefits or inclusion in diets, as well as negative cultural perceptions.[23-27] However, there is now a growing interest from the government and other stakeholders in the value of IACs to address food security and climate change.[28,29]

Insects

The consumption of insects, also called entomophagy, is practised by more than two billion people worldwide and is steadily increasing.[30-32] Over 1500 species of insects are eaten across Africa, including the mopane worm, termites, grasshoppers and crickets.[33] Compared with conventional livestock, insects have low space requirements, high reproductive rates and feed conversion ratios and emit low levels of greenhouse gases, making them ideal for farming purposes.[30,31,34] Some

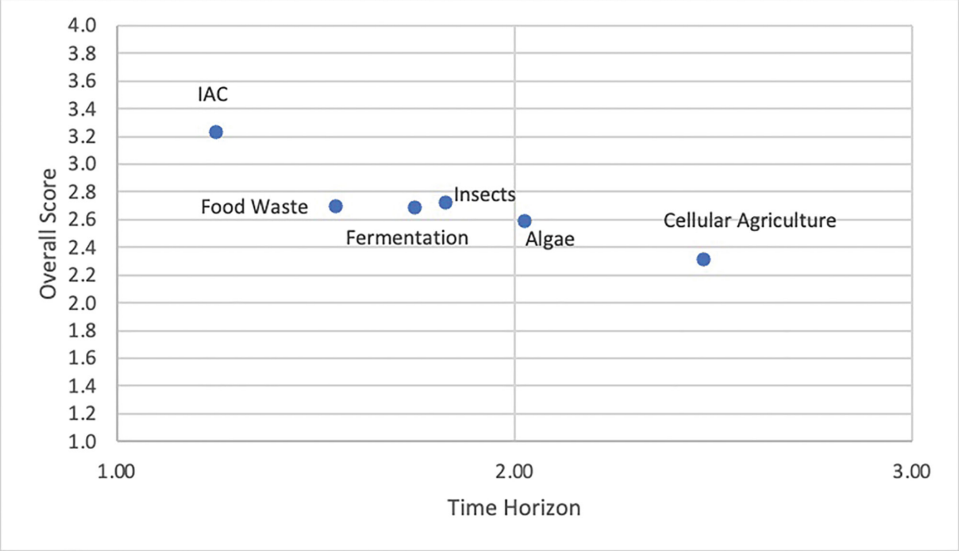

Figure 1: Time horizon and overall score analysis for the underutilised or emerging food sources and technologies.

insect species can be grown on organic side streams, thus transforming waste into high-value food or feed.[34] Furthermore, insects have a positive nutrition profile.[30,31]

Fermentation

Dating back 6000 years, fermentation is the oldest and most economical biotechnology process.[35,36] Traditional fermentation uses microorganisms to process raw materials into enhanced products with unique flavours, nutritional profiles or modified textures, such as kimchi or tempeh.[36]

Fungal mycoproteins are already widely consumed as meat alternatives through the brand Quorn, which is made from *Fusarium venenatum.*[16,17,36] This is known as biomass fermentation and leverages the fast growth of the fungal mycelium to produce large quantities of protein efficiently.[36]

Precision fermentation can also use microbial cells to produce specific functional ingredients or recombinant proteins such as dairy, egg or heme proteins that can enhance plant proteins, cultivated animal cells or other microbial biomass.[16,36] Research opportunities are related to strain development and target selection through biotechnology like gene editing, genetic engineering and breeding strategies.[36,37] Feedstock optimisation – including waste products or agro-industrial by-products to reduce costs and improve yields, bioreactor design and downstream processing – are all areas to be researched further.[36,37]

Cultured meat or seafood

Cultured meat or seafood is an emerging branch of biotechnology that encompasses culturing techniques to manufacture products typically obtained from animal production.[38,39] The cells are extracted, isolated and fed a nutrient-dense liquid, allowing them to proliferate in bioreactors.[39,40] The product replicates conventionally derived meat's structure, composition and nutritional value.[39] Cultured meat is promising but at an early stage and requires significant improvements and modifications for the process to be cost-efficient and robust enough to be produced at scale.[41] Key challenges include cell source, selection and development; culture media optimisation; mimicking the in-vivo myogenesis environment; bioreactor and bioprocess engineering; scaffold biomaterials; regulatory approvals; and consumer acceptance.[38,39,41] Cultured meat could deliver large reductions in water use, greenhouse gas emissions, eutrophication potential, land use, biodiversity loss, and zoonotic diseases compared to conventional meat production.[38,39,42]

Food waste

It is estimated that 30% of all food produced on the planet is lost before reaching a human stomach.[43] This is of great concern because a substantial portion of discarded food is still edible and because of the wasted resources and emissions related to its production.[43,44]

A staggering 10 million tonnes (about one-third) of food is wasted in South Africa.[44,45] The bulk of this loss (49%) arises from the processing and packaging stage and 18% from the consumption stage.[45]

The edible portion of currently wasted foods is an emerging source of new ingredients for the food-processing industry.[21] Valorisation opportunities exist for extracting protein from post-industrial streams, like spent brewer's yeast and rapeseed press cake.[16]

Algae

Algae have been exploited for centuries as food and feed.[46] Seaweed polysaccharides such as carrageenan are extensively used as a thickening agent, stabiliser and fat replacer in various food applications.[47] Japan started the first industrial-scale production of *Chlorella* microalgae for human consumption. Algae are abundant primary producers with multiple species having a high protein content, oils rich in polyunsaturated fatty acids (PUFAs), a high fibre content, vitamins, minerals, antioxidants and natural colourants.[46,48]

Algae use less land, are fast growing, can grow in areas unsuitable for plants, and more efficiently utilise energy from sunlight.[48,49] They have simple nutritional requirements and can produce specific compounds by manipulating cultivation conditions.[48] However, high production costs, high energy and water usage, and technical difficulties in including algal material in palatable food preparations remain the challenges.[50] Furthermore, safety assessments and restrictive regulatory requirements can delay commercialisation.[46]

Results of the quantitative expert survey

Descriptive statistics were used to describe the variables (Table 3). Of the 40 expert respondents, 50% were from industry and 50% were from academia or government (called academia for statistical analysis purposes). The power analysis result for the total group of 40 respondents was a 90% power with a small/medium effect size of $\delta = 0.53$. When comparing the two groups of 20 each, industry compared to academia, there was a 90% power and medium effect size of $\delta = 0.75$. The power analysis measures the likelihood that a researcher will find statistical significance in a sample if the effect exists.

Overall results

Indigenous African crops

IACs recorded the highest mean and highest scores out of the six UEFST for each criterion (Tables 3 and 4). This was consistent across both the industry and academic expert groups. IACs received the highest score for the 'Affordable' criteria due to their ability to be locally produced and processed. IACs are inherently suitable to the South African climate, especially given their drought tolerance, and are currently grown by subsistence farmers. The potential integration of subsistence farming with the formal market would create economic opportunities, employment and improved food security. The criterion of 'Safe' was the lowest score related to inherent allergens, toxicological and microbial risks. With such positive results across all criteria, the question remains: why are IACs not being utilised more to address food insecurity in South Africa? Some respondents (3 of 40) highlighted that the perception of these crops being linked to poverty requires a real public shift to enable the adoption of this underutilised food source.

Insects

Insects scored the second highest of the six UEFSTs for the criterion of 'Nutritious', which was the highest of all the criteria for insects (Table 4). The lowest overall result for insects was related to the 'South Africa' criterion. Challenges were related to cultural acceptability, organoleptic profile and favourable regulatory environment. These are significant

Table 3: Descriptive statistics of the expert survey data

Variable	Valid *N*	Mean	Median	Minimum	Maximum	Lower quartile	Upper quartile	Range	Quartile range	SD
Indigenous African crops	40	3.44	3.42	2.67	4.00	3.25	3.67	1.33	0.42	0.32
Insects	40	2.83	2.75	1.75	3.83	2.50	3.08	2.08	0.58	0.43
Fermentation	40	2.81	2.83	1.75	3.75	2.58	3.00	2.00	0.42	0.39
Cultured meat / seafood	40	2.31	2.25	1.50	3.08	2.04	2.60	1.58	0.56	0.38
Recovery of food waste	40	2.86	2.83	1.50	4.00	2.67	3.08	2.50	0.42	0.45
Algae	40	2.68	2.67	2.00	3.58	2.42	3.00	1.58	0.58	0.39

Table 4: Summary of sub-criteria scores for the underutilised or emerging food sources and technologies

	Indigenous African crops	Insects	Fermentation	Cultured meat or seafood	Recovery of food waste	Algae
Affordable – scale	3.35	2.75	2.86	2.00	3.15	2.61
Affordable – local production and process	3.70	3.18	2.82	2.05	3.33	2.58
Affordable – investment	3.48	2.90	2.67	1.92	3.08	2.49
Affordable – stakeholders and capabilities	3.28	2.73	2.59	1.97	3.05	2.54
Nutritious	3.54	3.46	3.18	2.95	3.00	3.24
Safe – allergens, toxicological, microbial	3.18	2.83	3.03	2.92	2.59	2.92
Safe – processing	3.35	2.88	2.97	2.68	2.62	2.92
Safe – storage conditions	3.08	2.36	2.18	1.95	2.20	2.49
South Africa – culturally acceptable	3.65	2.65	2.73	2.13	2.60	2.45
South Africa – organoleptic profile	3.53	2.53	2.82	2.55	2.78	2.44
South Africa – regulatory environment	3.38	2.55	2.79	2.16	2.48	2.61

barriers to insect protein gaining momentum globally, not only in South Africa. In many parts of rural South Africa, however, catching, cooking and eating insects whole is a common practice.[51] Adding insects as milled or ground has improved consumer acceptance, which respondents also suggested. It could be a way to provide nutrition and overcome the barriers of cultural acceptance and taste.[31] In addition, challenges to reach scale were identified as a result of the lack of stakeholders and capabilities and lack of local production and processing. A South African company, Maltento, is investing in insect growing and harvesting. However, insects as a food source will remain limited to animal feed if the challenges related to the 'South Africa' criterion are not addressed.

Fermentation

The criterion of 'Nutritious' was the highest score for this UEFST (Table 4). The lowest scores for fermentation were for the criteria of 'Safe', related to contamination of reactors and the requirement of chilled storage conditions and 'Affordable' associated with the lack of stakeholders and capabilities (respondents highlighted the need for specialised scientific support and research), as well as investment available for this technology. Furthermore, the 'South Africa' criterion scored lower for cultural acceptability, organoleptic profile and regulatory environment. Fermentation has been a culturally acceptable processing practice for dairy (e.g. amasi) and grains (e.g. mageu) for generations, and hence, an extension of this into meat/dairy alternatives or nutritional ingredients is a leap consumers could make if transparency and trust are maintained between industry, regulators and consumers.

Cultured meat or seafood

Cultured meat or seafood scored the lowest of the UEFSTs for the 'Affordability' criterion. This was related to the investment required, the availability of stakeholders and capabilities (respondents highlighted the need for specialised scientific support and research), and the ability to reach scale with local production and processes (Table 4). All these challenges identified by the respondents are aligned with an emerging and novel technology. Further barriers to meeting the criteria are related to cultured meat or seafood being culturally acceptable in a country where animal meat is extremely desirable from a cultural, heritage and status perspective. In addition, the regulatory environment is a barrier as no regulations exist for cultured meat and seafood from the Department of Agriculture, Land Reform and Rural Development. Furthermore, there were safety hurdles related to storage conditions, namely requiring a chilled/cold chain.

The Mann–Whitney test indicated a significant difference ($p = 0.04$) between industry and academia in their assessment of cultured meat or seafood. Academia scored higher at 2.43 than the 2.18 for industry, indicating that industry is challenged to engage with this new technology as multiple hurdles remain to be solved at the research and scale-up stage and, hence, is not yet ready for commercialisation. There are two cultured meat start-ups, Mzansi Meats Co. (now Newform Foods) and WildBio, and a cultured seafood start-up, Sea-Stematic, headquartered in South Africa.

Recovery of food waste

A few respondents (3 of 40) highlighted food waste avoidance as a critical first step to feeding hungry South Africans. They indicated that food manufacturers are working hard to integrate post-industrial food waste into their processes but suggested there is more value to be captured. In line with the United Nation's Sustainable Development Goals, food manufacturers and retail members of the Consumer Goods Council of South Africa launched the South African Food Loss and Waste Voluntary Agreement, committing to halving food waste by 2030.[52]

Food waste recovery scored highest in the 'Affordable' sub-criteria and the 'Nutritious' criterion (Table 4). However, it scored the lowest for safety of all the UEFSTs, with respondents highlighting storage as the primary concern (most likely after recovery and before processing), then inherent food safety risks (examples given by respondents were cross-contamination, pathogen growth, mycotoxins and microbial spoilage) and then safe processing. Furthermore, respondents highlighted the lack of a favourable regulatory environment for companies to redistribute food waste as a key barrier. Consumer acceptance was also highlighted as a challenge, with respondents suggesting the term 'food surplus' rather than 'food waste'.

Algae

The major hurdle for algae indicated by respondents was acceptance by the South African consumer, with cultural acceptance and organoleptic profile scoring the lowest (Table 4). Unlike in Asia, eating algae is not part of the South African diet. Furthermore, respondents indicated affordability with a lack of investment, stakeholder and capability (respondents highlighted the need for specialised scientific support and research) and local production and processes as challenges. The 'Nutritious' criterion was the highest score for algae, suggesting that using nutrients and bioactive extracts from algae to enhance products is an opportunity.

Time frames

Respondents indicated that the two most promising UEFSTs – IACs and food waste recovery – could be available to South Africans in the shortest time frame (within 3–5 years), with a score of > 2.8 for their ability to meet the criteria identified (Figure 1). According to the

Spearman correlation, acceptance by South Africans of recovered food waste as a food source is the reason for the longer time frame ($p = 0.04$) for this UEFST. Fermentation and insects are next in terms of time frames to commercialisation (< 5–10 years) and they scored > 2.8. The Spearman correlation indicated that the criterion of 'affordability' was the main reason for the longer time estimates provided for fermentation by the respondents ($p = 0.02$).

The two underutilised or emerging food sources and technologies with the most extended time frames to availability are algae and cultured meat or seafood (> 5–10 years). 'Affordability', 'safety' and 'acceptance' by South African consumers were all reasons for the longer time estimates provided by respondents for algae when analysing the Spearman correlation.

Conclusion

UEFSTs could be an essential solution in providing South Africans with affordable, nutritious, safe foods. These could be in the form of a nutritious ingredient enhancing the overall nutritional profile of a product with added macro- or micronutrients derived from insects, algae or food waste. Replacement of whole animal/fish proteins could be through biomass fermentation, cultured meat, seafood, or hybrids utilising plant proteins and precision fermentation. Enhancing dietary diversity could be achieved by incorporating IACs into our diets through innovative new products like baked goods, snacks or meat alternatives. Through product formulation and flavour science, food products utilising these new ingredients/food sources can be designed to be tasty, ensuring that consumers purchase them again.

Marketing these products to ensure consumers understand what they are, as well as their benefits, is essential to any new product adoption, especially to overcome food neophobia. Respondents in the survey highlighted that, as South Africa is so diverse, products made from UEFSTs will not necessarily appeal to all South Africans. However, they may be targeted to a niche-conscious consumer group and grow in mass adoption and acceptance over time.

Respondents indicated that, for any of these UEFSTs to reach the market, there needs to be investment from industry, governments, and academia into research, technical capability building and scale-up infrastructure through to commercialisation. According to the report conducted by Mouton et al.[53], South Africa invests too little in research and development. Gross Domestic Expenditure on R&D (GERD)/Gross Domestic Product (GDP) has remained unchanged at around 0.8% for the last 15 years, compared to an elusive national target of 1%. The number of full-time researchers in the broad field of agriculture has not increased between the early 1980s and 2014.[53] Fortunately, the academic pipeline has expanded through master's and doctoral graduates.[53] It is promising to see research projects like InnoFoodAfrica trying to increase the dietary diversity of affordable, nutrient-dense and healthy food products from IACs. There is also research across multiple academic institutions on insect techno-functional properties, allergenicity, microbial aspects, and new product development for human food (KaMshayisa V, 2022, Research and Lecturer at Cape Peninsula University of Technology, personal communication, 11 April). Research in South Africa is relatively cost-effective and significant research can be conducted at a fraction of the cost (Bessa L, 2022, Co-founder & CSO of De Novo Dairy, personal communication, 25 April). However, the lack of scale-up capabilities to bring new technologies to market results in complicated logistics and high costs for overseas trials (Bessa L, 2022, Co-founder & CSO of De Novo Dairy, personal communication, 25 April).

It is also evident from the research that for many of these UEFSTs to become available to South Africans, a progressive and agile regulatory environment needs to be in place, which is not the case today. For example, Singapore's Food Agency approved the sale of cultured meat in 2020, enabling start-ups like Eat Just to test and scale this technology in that country.[54] The South African government also needs to provide funding, tax incentives and an enabling environment for various stakeholders to collaborate and innovate to unlock new food production technologies. In 2022, the Netherlands government, for example, announced an initial USD60 million funding to expand and develop its domestic cultured meat and seafood ecosystem.[55]

Industry, too, needs to shift R&D investment and focus on supporting research and capability building. Food and beverage multinationals traditionally spend far less on R&D than other sectors like the healthcare, automotive and technology sectors.[56] Some overseas food and beverage companies have created venture capital divisions that are seen as an extension of their R&D departments and are far less risky than significant merger and acquisition deals.[56] This is an example for South African food and beverage manufacturers to follow. It is promising to see Tiger Brands utilising its recently launched venture capital fund to invest in the plant-based protein start-up Herbivore Earthfoods.

Recommendations

Future diets of South Africans could be far more diverse and nutritious and have less impact on the climate and environment if we invest in UEFST research and commercialisation. This requires a collaborative stakeholder effort from academia, government and industry to ensure UEFSTs reach everyday South Africans. Some recommendations from the research are for:

- government funding and incentives for research, development, infrastructure and commercialisation;
- an agile regulatory framework to assess safety and enable novel technologies to be commercialised; and
- industry venture capital appetite to assess and invest in start-ups and research looking to develop and commercialise UESFT.

Limitations

The experts identified for the survey to map underutilised and emerging food sources to provide safe, affordable, and nutritious foods for South Africans, were from the researchers' professional network. To reduce bias, a statistically significant sample size of respondents was recruited that represents the various role players of academia, government, and industry.

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Data availability

The data supporting the results of this study are available upon request to the corresponding author.

Declarations

We have no AI or LLM use to declare. L-C.R-R. worked in the South African food and beverage industry while conducting this research as part of her PhD. Ethical approval was obtained from Stellenbosch University's Ethics Council (project number 22423).

Authors' contributions

L-C.R-R.: Conceptualisation, methodology, project leadership, investigation, formal analysis, validation, data curation, writing – the original draft. G.O.S.: Conceptualisation, methodology, supervision, writing – review and editing. Both authors read and approved the final manuscript.

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