



The Fourth Industrial Revolution: Can Emerging Technologies Address Rural Food Insecurity for Smallholder Farmers in Sub-Saharan Africa?

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Technological advances have the potential to increase agricultural production in Sub-Saharan Africa (SSA) and thereby respond to growing food insecurity. This paper, in light of what is being called “the fourth industrial revolution,” reviews the potential of emerging technologies, in particular artificial intelligence (AI) and satellite crop mapping, for increasing agricultural production and addressing food insecurity in Africa. It concludes that unequal global development, and unequal access to, distribution and control of emerging technologies by China and the United States, combined with the prevalence of smallholder farming, makes positive impacts unlikely in the near future.

Introduction

Since the COVID-19 pandemic, progress toward addressing food insecurity in SSA has faced differential setbacks, with some countries having stronger public health governance infrastructure.¹ Although the impacts of COVID-19 were uneven across countries and regions,² they negatively impacted value chains and food systems throughout SSA, contributing to a worsening of the existing food security crisis.³ The SSA's agricultural sector is critical in addressing food insecurity; it employs an average of 54 percent of the working population and accounts for 30 to 40 percent of GDP.⁴ Technological advancement is one lever available to reform agricultural production to address this growing challenge. The United Nations Food and Agriculture Organization (FAO) and International Telecommunication Union (ITU) found the pandemic demonstrated an "urgent need for digitalization" and that it had "accelerated the shift toward innovation and digital transformation to harness more digital economies."⁵ In technological sectors, however, there is a longstanding technological gap between Africa and the rest of the world.⁶ This paper reviews the progress, potential and challenges of the fourth industrial revolution⁷ to positively impact food security in Africa. Food security includes four established pillars: availability, access, utilization, and stability.⁸ Jennifer Clapp and colleagues argue for an explicit adoption of the six-dimensional food security framework, which also includes agency and sustainability.⁹

In the 2000s, we entered the fourth industrial revolution, also referred to as the era of emerging technologies, which includes AI, big data and smart sensor robotics.¹⁰ The fourth industrial revolution has gained considerable attention due to the exponential speed and impacts of emerging technologies (see Table 1).¹¹ By 2030, it is estimated that AI will contribute upwards of US\$15.7 trillion to the global economy, as well as an increase of 20 percent in GDP.¹² These technological advances, in particular those that facilitate crop mapping, provide data to producers that can help them increase agricultural output. However, these advances will most likely disproportionately benefit China and North America, and have uneven impacts for food security, especially for Africa's smallholder farmers.

Table 1: Selection of Emerging Technologies in Agriculture: Benefits and Limitations

Technology	Benefits	Limitations
Farm robotics	Farm robotics integrate AI and remote monitoring of environment of agricultural fields, which can be controlled by the individual or programmed to act autonomously with an expected increase in crop yield, revenue and net profit. ¹³	Requires continued Internet of Things development and suitable infrastructure for this technology. ¹⁴
Blockchain + AI for supply chain	Blockchain technology paired with AI has improved agricultural supply chains to allow for greater transparency and traceability of products. The expected outcomes are fair pricing, and sustainable and ethical practices. Smallholder farmers expected to benefit greatly with more trust in agricultural value chains. ¹⁵	Tracking supply and value chains faces unique challenges due to unpredictable weather patterns and limited access to the resources required to build blockchain- and AI-powered supply chains. Prediction models also require data labels to be created for input and output variables. ¹⁶

Technology	Benefits	Limitations
AI drones and precision agriculture	Satellite imagery combined with AI-powered drones enables precision agriculture by mapping crop and soil conditions as well digital mapping of disease to determine maintenance needed for increased crop production. ¹⁷	Data gathering from drones may not be useful to smallholder farmers, who use intercropping and thus maintenance suggestions pose challenges. The cost is a major barrier with the need to purchase the drone, sensors, mounting parts and other technology-based applications. ¹⁸
Weather-index insurance	Mobile AI-powered weather forecasting has become a conventional tool that allows predictive financial planning to purchase and or adjust credit exposure through weather-indexed insurance. This is most beneficial in risk-sensitive areas. ¹⁹	Requires widespread adoption, posing a challenge to traditional crop insurance models. Furthermore, the data relies on local weather stations. ²⁰ Local insurance companies may not have the experience to provide this insurance option. ²¹
AI pest & disease diagnosis (offline mobile)	Smartphones can scan images and use AI/machine learning to spot signs of pest infestation or disease in crops at various stages. ²²	Access to mobile phones is important, with urban individuals having greater access than rural, and men having greater access than women. Implementation may be positive, but disparities of who benefits occurs. ²³
Internet-of-Things (IoT) and climate-smart agriculture (CSA)	Provides remote control of agricultural equipment and devices, which is expected to reduce operating costs, as well as reduce carbon output of farm machinery. ²⁴	IoT with CSA is limited by two factors: high equipment and product costs; and technical knowledge required by farmers to use these technologies. ²⁵

Potential Benefits and Pitfalls to Addressing Food Insecurity with Emerging Technologies

Previous industrial revolutions excluded Africa or left the continent with unequal access to new technologies. A continued technology gap will perpetuate and worsen global inequalities. There is minimal indication that this pattern will change with the latest revolution and technologies. As H.E. Lerato D. Mataboge, African Union Commissioner for Infrastructure and Energy, points out, “Over 83% of AI startup funding in Q1 2025 went to Kenya, Nigeria, South Africa and Egypt. AI should help narrow the digital divide, not widen it.”²⁶ While technology may be developed within the African continent, access to funding and development is an ongoing challenge. Some scholars identify promise in technological transfers,²⁷ although technologies continue to be developed in advanced economies and transferred with “export-oriented colonial agricultural production systems,” prioritizing benefits for external actors rather than those of Africa’s most food-insecure.²⁸ Food security for rural households is highly dependent on agricultural productivity, through entitlements derived from both market income and subsistence.²⁹ Further, food security must be addressed through multiple levers, with attention to access and policy as well as increased output.

China and the United States are dominant players in Africa, developing, training and transferring technology and technocratic rationality to address food insecurity.³⁰ The United States has historically been involved in Africa through the United States Agency for International Development (USAID), which approached food security through an expansion of existing technologies.³¹ More specifically, its involvement in the design of technology for small farmers has been primarily through a food production lens,³² which is insufficient for addressing food access.³³ US Secretary of State Marco Rubio's pause of USAID funds has left the extent of US involvement in technology transfer going forward uncertain.³⁴ The Gates Foundation has also been a technology-driven innovator in Africa's food production through the advancement of its Alliance for a Green Revolution in Africa (AGRA). Since AGRA's launch in 2006, results for food security have been disappointing and some African states have withdrawn (from 18 states to 13). AGRA has undergone two evolutions since its inception, namely AGRA 2.0 (2017–2021) and AGRA 3.0 (2022–present), now focusing on “systemic change” to create sustainable food systems.³⁵ The Gates Foundation, in addition to others such as the Rockefeller and Ford Foundations, represents philanthrocapitalism or more specifically technophilanthropy, which is a market-based social investment mechanism that emphasizes commodification. Thus far there is minimal evidence that massive top-down investment is an effective mechanism to increase the agricultural production of smallholder farmers, with critics arguing that the majority of measurable benefits have accrued to the foundations themselves.³⁶

In contrast, China's increasing investment and collaboration in Africa is viewed by many as a partnership benefitting both China and Africa, with Chinese technological capability and expertise harnessing technologies to reduce poverty.³⁷ For example, at the third Summit of the Forum on China-Africa Cooperation in 2018, China pledged not only US\$60 billion in grants, but also training for African scientists to advance their fields in key areas, notably agriculture.³⁸ A key aspect of this initiative has been the transfer of technology in the agriculture sector, facilitated through 23 Agricultural Technology Demonstration Centers across Africa.³⁹ However, because China's investment and collaboration remain aligned with its own national political and economic interests, that being economic diversification and political allyship, China does not aim at alleviating food insecurity in the continent.⁴⁰

Should emerging technologies be integrated into Africa's agricultural sector, they will present a fundamental and necessary agricultural paradigm shift. Successful implementation could result in increased efficiency and food affordability, and provide infrastructure that can cope with the growing adverse effects from climate change. They have the potential to positively address food insecurity in Africa.⁴¹ Food security, as defined by the FAO, includes four pillars: availability, which seeks to expand food production; access, which concerns distribution and the ability of consumers to access food; utilization, which measures food's nutrition; and stability, which considers impacts on food availability and access due to political or economic shocks and disruptions.⁴² Technology transfers that increase production impacts are likely to emerge across intersections of all food security pillars, over different timelines, making the process challenging to predict, measure and assess.

More concerning is that these emerging technologies are being developed in the Global North and China, then exported to Africa as a form of techno-colonialism.⁴³ Techno-colonialism is not only the transfer of technology but also the transfer of norms from one locale to another; this can reinforce techno-

optimism and hierarchies of knowledge, with Indigenous knowledge systems being disregarded, reminiscent of the legacies of colonial extraction and exploitation.⁴⁴ The infrastructure and capabilities of African countries are ill-prepared for the fourth industrial revolution, and face disparities related to differential levels of profiting from data by technology actors, privacy, ownership, and the potential of causing technological disparities between smallholder farmers versus commercial farms.⁴⁵ While there are potential gains, emerging technologies in the fourth industrial revolution carry a high risk of accelerating disparities and increasing food insecurity.

New advances in technology provide opportunities for climate-smart solutions to address current and future food security concerns. AI offers a transformative approach. AI is “a computerized approximation of human comprehension and intelligence processes that do specific tasks with human-like judgment.”⁴⁶ AI applications, such as natural language processing computer vision, can convert raw data, including digital imagery, to stimulate judgment.⁴⁷ A critical application of AI combines industrialization technologies of the past, explicitly pairing AI with satellite Earth observations.⁴⁸ The use of this pair is becoming more accessible, enabling the analysis of data at global scales, with many sets available at no cost, making this an affordable option.⁴⁹ One by-product of the synergy of these two technologies is the creation of crop type maps, which provide yield estimation, and pest, disease and anomaly detection. This allows farmers to forecast food production surplus or deficits, but also supports external parties, government, states or non-governmental organizations to inform their trade relations and aid decisions.⁵⁰ Technological ability to predict food output is especially beneficial in predicting and planning for food stability disruptions and external shocks, however, the extent of this depends on commercial access, which is limited for smallholder farmers. Crop type mapping shows the exact configuration of where crops are growing and what crop types are in specific spatial units; this data can be used to map out vulnerabilities due to factors such as soil degradation, pests and droughts.⁵¹ Yield estimation can be derived from crop simulation and statistical regression models, which estimate crop yield per unit area and assist in determining the end-of-season yield to help farmers prepare for shocks in case of lower output.⁵² For instance, Earth Observation Satellite Data Analytics (EOSDA) Crop Monitoring is a satellite-driven platform for precision agriculture, and the assembly of various crop data, which can be paired with the EOSDA Application Programming Interface (API) and EOSDA API Connect for AI and decision-making.⁵³ These services are paid through a subscription model for EOSDA Crop Monitoring, with additional costs for API packages.⁵⁴ However, Nakalembe and Kerner find that crop production increases in Africa have usually resulted from an increase in the cultivated area rather than an increase in yield output (extensification rather than intensification).⁵⁵ Given Africa’s shrinking cropland, due to population growth, land degradation and desertification exacerbated by climate change,⁵⁶ extensification is not a viable option. Yet intensification is not a pathway that is readily available for smallholder farmers, as rural households lack sufficient land or economic means to invest in agriculture, and the fragmentation and subdivision of land creates a reduction of land productivity.⁵⁷ Considering historical factors, including colonization and its continued ramifications, Nyong’o (2013) highlights how British settler colonists in South Africa, Kenya and Zimbabwe deprived Africans of their land and forced them to work as cheap or free labour.⁵⁸ Legacies of land grabbing and political exploitation continue to be important factors when discussing land.

Crop type mapping can also be used to detect pests and diseases over the crop area during the growing season, enabling a response before there is damage to the whole crop.⁵⁹ For instance, in 2020, when desert locusts were causing widespread crop damage in Kenya, an emergency early warning system was created to provide better monitoring and response to the locusts.⁶⁰ Overall, the increased understanding of the crops with Earth observations, and the use of AI to complete the analysis of data to forecast changes, can enable the protection of crops, increasing food stability and output. This is important, as knowing whether crop production will be affected allows farmers to adapt prior to the external shocks, mitigating the full effect. Having crop data also provides farmers with individualized data sets and enables them to compare data on their crops over time. However, the extent of technological adaptation is still unknown, limiting the ability to predict the effectiveness of farmers' mitigation capabilities.

According to the latest statistics, SSA had a prevalence of undernourishment (PoU) indicator of 22.3% in 2024; however, this prevalence varies by region, with Middle Africa (MA) having the highest at 30.2%, and Southern Africa (SA) at 11.4% (see Table 2 for further data). This varied data demonstrates how food insecurity manifests differently across SSA, but also highlights a key factor: nutrition.⁶¹ Micronutrient deficiencies and associated ailments are important contributors to undernourishment.⁶²

Table 2: Prevalence of Undernourishment in Africa 2018-2024

Africa	Prevalence of Undernourishment (PoU) (%)						
	Year						
	2018	2019	2020	2021	2022	2023	2024
Sub-Saharan Africa	19.0	20.0	21.2	21.5	21.3	22.1	22.3
Eastern Africa	24.8	27.0	26.6	27.1	25.7	25.9	25.9
Middle Africa	24.9	25.4	28.3	28.2	28.7	29.7	30.2
Southern Africa	7.5	8.0	9.5	11.2	10.3	11.1	11.4
Western Africa	12.1	11.9	14.1	14.1	15.1	16.3	16.5

Source: FAO, "Suite of Food Security Indicators," FAOSTAT database, accessed August 13, 2025, <https://fao.org/faostat/en/#data/FS>.

Precision agriculture uses new technology to tackle nourishment. It measures and analyzes soil moisture, nutrients and irrigation using a combination of technologies such as global positioning systems, satellite imagery, monitoring control systems, soilless cultivation systems and unmanned aerial vehicles.⁶³ These are brought together using spatial information and on-the-ground data to analyze the condition of crops

and provide an irrigation schedule to maximize production.⁶⁴ Precision agriculture was shown to be effective by Omer Gulec and colleagues, where water conservation and reduced labour had a dual benefit.⁶⁵ In the Western Cape of South Africa, using FruitLook was found to be positive in water efficiency and carbon reduction. Among small-scale farmers in Mozambique, Tanzania and Zimbabwe, Chameleon Sensors and Wetting Front Detector Sensors were shown to cut irrigation frequency by 50 times.⁶⁶ In addition to this, there was an increase in per capita revenue.⁶⁷ As Vibeke Bjornlund and colleagues (among countless others) stress, increasing income and uplifting individuals and families from poverty are key to addressing food insecurity.⁶⁸ Precision agriculture has been shown to increase income and therefore is a mechanism to address, to some extent, food insecurity.

From a gendered lens, technology can act as a gender equalizer. In SSA, women have a productivity deficit or gap of 13 to 25 percent, compared to their male counterparts.⁶⁹ However, this deficit is in part due to the triple role that women have, with work outside their homes, in their communities, and with domestic care. Technologies that allow greater output for time spent on the farm may reduce the overall time burden.⁷⁰ Agricultural technologies for African women who farm should seek three improved outcomes: increased agricultural productivity, reduced postharvest losses, and a lower care burden. Combined, these will improve all four food pillars among families led by women farmers.⁷¹ Predictions of technological advances to relieve women's work are not new, and echo the unfulfilled Women in Development promises associated with development since the 1950s. Optimism on this front, in the absence of structural transformations in gendered roles and responsibilities, should therefore be cautious.⁷²

While these technological improvements offer the potential to address food insecurity in SSA, the limitations of addressing food security through the promotion of food availability need to be addressed alongside broader risks. Bjornlund and colleagues challenge the widespread assumption that food availability and food production are the central sources of food insecurity.⁷³ The World Bank estimates 464 million Africans are living in extreme poverty, with numbers increasing with population growth.⁷⁴ While the prevalence of poverty is not necessarily an indicator of food insecurity, it can reflect differential access and entitlements as marginalized communities such as women, minority groups or migrants are impacted by poverty differently. The governance mechanisms and policies in place by different African countries may or may not be inclusive for all. In Ethiopia, for instance, the Productive Safety Net Program responds not only to chronic food insecurity among Ethiopia's poor, but also to short-term shocks, most caused by drought.⁷⁵ Such programs emphasize the importance of governance addressing food insecurity, rather than relying solely on the incomes of individuals or households.

Increasing yield is one of many strategies to address food insecurity; however, in the case of SSA, it is not the only tool needed in the toolbox. Other important levers for smallholder farmers include improving access to markets and to income-generating activities to diversify income streams.⁷⁶ With growing urban populations, additional strategies for food access must respond to urban poverty; for example, through social protection and other policy approaches to address poverty and facilitate secure income-generating opportunities. A central driver of food insecurity is not only the quantity of food produced, but the nutritional quality and how that nutrition is accessed and utilized. Ensuring the production of diverse, nutrient-rich foods and equitable access to them is critical in ensuring nutrient-rich diets.⁷⁷ Emerging

technologies primarily encompass a productionist availability focus and, as such, their impact on food security is limited.

Past use of seed patenting technologies has contributed to structural inequalities for small-scale farmers. Seed sharing is a longstanding practice among smallholder farmers in Africa, necessary to ensure collective food security, but the patenting of seeds has prevented collective benefits.⁷⁸ Patenting removes control from farmers and undermines their food security.

Technology is not neutral, especially considering that the technological development of the West and China creates a threat of technological colonialism and exploitation.⁷⁹ A central question around intellectual property (IP) rights for these new technologies is who owns and controls the data generated by farmers in Africa?⁸⁰ IP rights were initially designed with access and benefit-sharing laws.⁸¹ However, with data gathered through AI, the intersection of AI and IP rights remains unclear.⁸² The scope, subject and standards are still being debated globally, with no international consensus.⁸³ As a result, the regulation is left to states, resulting in differential standards.⁸⁴

Many regions in Africa lack the necessary infrastructure for emerging technologies to operate.⁸⁵ A lack of electricity, internet connection and advanced machinery limits the ability of AI technologies and precision agriculture, making optimizing resources inaccessible.⁸⁶ Furthermore, the data that AI relies on and the processing that is integrated into the system is based on trained data sets generated outside of Africa, leading to data and capacity gaps when implemented in Africa.⁸⁷ Data quality is vital in many cases, but is even more critical in Africa due to the agricultural diversity and smallholder farmers producing the majority of agricultural output.⁸⁸ Successful application of AI will rely on quality and reliable data, and this remains a critical challenge in Africa.⁸⁹ The lack of quality and reliable data creates data scarcity, preventing the full utilization of emerging technologies to address food security concerns.⁹⁰

Data and infrastructure development is expensive, and governments have a primary role in enabling regulatory frameworks and funding for scientific research to enable technological innovation.⁹¹ This is a critical issue highlighted by the World Bank: global expenditures for research and development in agriculture are rising, but while developed countries spend 3.25 percent of their agricultural GDP in this area, SSA spends only 0.38 percent, with projected decreases in the future.⁹² In Africa another important gap is the need for more skilled workers proficient in AI.⁹³ The United National Development Programme states that about 33 percent of the Sub-Saharan population cannot read or write and of the 46 percent of the population with access to mobile internet, only 22 percent have access to 3G or 4G, and even less have such access in rural communities.⁹⁴ The lack of basic infrastructure is essential to note, as emerging technology through the fourth industrial revolution will be built upon access to earlier technology, thus capacity will decrease without addressing this gap.⁹⁵ This concern is exacerbated by the fact that agriculture is a vital sector of the economy, but it is the least digitized.⁹⁶ Africa's digital divide exacerbates existing socio-economic disparities, leading to ongoing unequal distribution and access to technological benefits.⁹⁷

Digital Divide Creating Technology Adoption Disparities

Despite the clear advantage of AI with Earth observations, the technology's limitations prevent its full utilization and benefit. This is partly due to crop-type mapping being restricted to classifying spatial units through pixels, which provide specific crop data in the aggregate form rather than detailed spatial insights.⁹⁸ The more detailed the data, the less accurately the pixel will represent the data, although technological advances are being made to address these gaps.⁹⁹ In addition, the available data sets have discrepancies, where the data is more accurate in developed regions, with lower accuracy in Africa, especially SSA.¹⁰⁰ Unlike other regions, SSA has many smallholder farmers who practice intercropping, making it difficult to differentiate the multiple crops without high-resolution satellite imaging, which is not freely available.¹⁰¹

This data limitation is especially a barrier for smallholder farmers who lack the capital to access high-resolution data, creating a disparity with commercial farmers who have greater means to practise data-driven agriculture. Pushes toward large farming practices and more monocropping may result in increased output and better use of new technologies, but this approach poses an existential threat to the livelihoods and food security of millions of smallholder farmers in Africa, and to the diverse, nutritious and culturally important crops they produce. Another limitation is the need for on-the-ground verification: the satellite's ability to determine pests or diseases, and surveillance of the crops, still needs to be improved, requiring cell phone imaging as a second step to determine the validity of the original data.¹⁰²

Overall, these limitations reflect broader structural issues in SSA countries, including brain drain — a “phenomenon of massive skilled migration from developing countries to developed and industrialized countries,” with specific skilled researchers in science, technology and innovation.¹⁰³ Due to significant outflows, individuals in these fields are leaving sectors domestically, which is a challenge to the development capacities of domestic technologies.¹⁰⁴

These concerns are notable as the benefits of the technology are not accessible to most small-scale farmers, making it less effective as a tool. However, the restriction of pixels and the ability to determine crops more efficiently from intercropping may be addressed with further research and development as new technology continues to advance rapidly. How new technologies will shape land-use practices, especially for small landholders, will have pronounced impacts for food access and nutrition among African farmers. African-led innovation continues to occur, aiming to address technological limitations; for instance, a Kenyan-created mobile app, AfriScout, addresses food security for pastoralists, co-designed with pastoralists. The app analyzes data on water and vegetation conditions, producing open-source, digitized, local community maps to be used.¹⁰⁵

Oxford Insights finds that SSA has the lowest AI Readiness Index among nine groups, with an 18-point difference between SSA and the Pacific, the second lowest, highlighting the limited ability to regulate AI and IP rights effectively.¹⁰⁶ Ownership concerns include the data collected and commercialized, with significant disparities between commercial and smallholder farmers. The commercialization of emerging technologies is a major roadblock for smallholder farmers, and to be able to access commercial data, they need to work with other communities of farmers or cross-institutions.¹⁰⁷ This technology is commercially

available but there are barriers for technology adoption at the smallholder farmer level.¹⁰⁸ Weak financial access is an important consideration as only commercial farmers can leverage this technology to increase their food output consistently. External shocks will continue to negatively impact smallholder farmers.

Food insecurity affects the most vulnerable, women in particular.¹⁰⁹ There is a digital divide between women and men; women, unlike men, face intra-household inequality that limits their ability to own or access basic technologies, including mobile phones.¹¹⁰ The gap between men and women engaging in AI is 78 percent to 22 percent, respectively, and is increasing.¹¹¹ Men have more financial capacity compared to women, who have historically had lower financial access due to gender discrimination.¹¹² The African Union's Pan-African Agenda 2063 action goals aim at alleviating these disparities, including ensuring expanded agricultural and technological systems for women, greater access to land and farming inputs for women, and ensuring that women access a minimum of 30 percent of agrarian financing.¹¹³ A risk when adopting new technology is a narrative of techno-optimism, where technology seen as modern and more valuable displaces knowledge systems and traditional practices of women who work on farms.¹¹⁴ Although it may assist food security, emerging technology often neglects the integration of cultural and traditional practices that different community groups, specifically women, make use of in crop production.

Conclusion

Emerging technologies, part of the fourth industrial revolution, are rapidly becoming central to the technology and infrastructure of the future. Currently, Africa does not have the technological infrastructure in place for this revolution. There is a lack of investment in the population and in the research and development needed to create technologies and data sets that are made in Africa and can address the specific needs of Africans. Better access to technology offers incredible potential to address food insecurity with its data-driven approach to agriculture. However, there are several limitations and concerns regarding data quality, including the generalization of data sets to country-specific or sub-region-specific agriculture, limited data accessibility due to data monetization and a lack of data sovereignty, and gender disparities in training and access to emerging technologies.

As emerging technologies are implemented, the disparity between smallholder and commercial farmers will only increase, with a continuing worsening of food insecurity for Africa's most vulnerable. These limitations can be addressed. This is a policy window that requires attention from regional organizations such as the African Union, which, as mentioned earlier, while investing in equitable technology integration, needs to avoid technological disparities within SSA through funding mechanisms.

Endnotes

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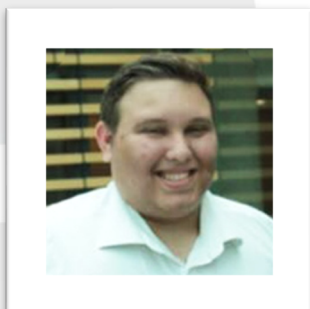
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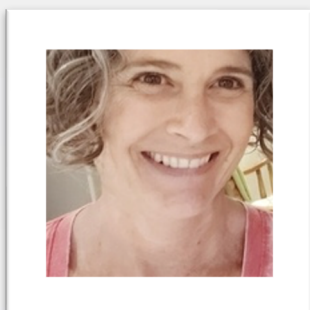
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