Agricultural, Biosystems, and Biological Engineering Education

Global Perspectives and Current Practice

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First edition published 2024

ISBN: 978-1-032-48877-6 (hbk)
ISBN: 978-1-032-49607-8 (pbk)
ISBN: 978-0-429-15011-1 (ebk)

Chapter 4

Top 100 Questions of Importance to the Future of Agricultural Engineering Education, Research, and Practice in Africa

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DOI: 10.1201/9780429150111-5

The funder of the Open Access version of this chapter is National Research Foundation, South Africa.

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

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Umezuruike Linus Opara

Introduction

The African continent's strategic plan for socioeconomic development, titled "Agenda 2063 – The Africa We Want" (African Union, 2022), was approved by the African Union in 2013. Agenda 2063's objectives, aspirations, and focus areas stress the necessity of modernising agriculture for higher output and productivity to create an Africa that is wealthy due to an equitable growth and sustainable development. At the African Union Summit in Malabo, Equatorial Guinea, in June 2014, heads of state and government established a remarkable set of realistic concrete targets for agriculture to advance Agenda 2063. The Malabo Declaration on "Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods" outlines a fresh set of goals that display a more focused strategy for achieving the agricultural transformation agenda for the African continent, which is shared prosperity and enhanced livelihoods. The Malabo Summit reiterated the significance of prioritising agriculture on the African continent's development agenda. It emphasised that fostering agriculture is a vital policy endeavour for driving economic growth and eliminating poverty in the region. Africa's development partners, private sector, investors, and other stakeholders are expected to key into this policy initiative as the guiding principle for collaboration and cooperation.

It is widely recognised among policy makers, researchers, and development practitioners that agriculture has remained the mainstay of most African economies, accounting for nearly 80% of employment and remaining a major source of livelihood, particularly in rural areas. Accordingly, most pundits argue that transforming and modernising African agriculture is a *sine qua non* to its economic growth and best strategy for widespread poverty reduction. In this context, African leaders reached a consensus on the importance of achieving an annual agricultural GDP growth rate of at least 6% and generating employment opportunities for at least 30% of the youth within agricultural value chains in order to fulfil their "Commitment to Halving Poverty by the year 2025, through Inclusive Agricultural Growth and Transformation ". In a similar vein, African leaders pledged to end hunger in their continent by the year 2025. Additionally, they pledged to support various initiatives, including but not limited to promoting sustainable and dependable production methods, offering relevant knowledge, information, and skills to beneficiaries, improving water management systems with a focus on irrigation, ensuring accessible, dependable, and affordable mechanisation and energy resources, and reducing current postharvest losses by half.

To accomplish the ambitious goals set by African leaders in transforming and modernising the continent's agriculture and food systems for inclusive growth and sustainable development, Africa needs agricultural engineers and other technical experts. No other academic discipline or occupation is better equipped to lead the mechanisation, digitisation, commercialisation, and industrialisation of African agriculture, fostering a knowledge-intensive, profitable, and sustainable sector. To drive Africa's Green Revolution, there is a need for a significant number of exceptional young male and female agricultural engineers, along with their professional associations. To achieve this, it is essential to widen the pool of skilled individuals, reduce the loss of talent to other regions, and actively encourage the return of talented individuals who can contribute their expertise. Harnessing the finest talents from Africa and leveraging access to the most advanced engineering technologies globally is indispensable for the advancement and modernization of African agriculture and food systems.

The agricultural engineering discipline and profession has never been more important in the pursuit of widespread socioeconomic development, sustainable food systems transformation, and as part of efforts to mitigate climate change and environmental degradation. As the human population continues to expand and improve its standard of living, there is an escalating demand for plentiful and dependable access to safe, nutritious food, housing, clothing, fibre, and renewable energy sources. In the same vein, agriculture has important roles to play in addressing the problem of climate change, while preserving bioresources and protecting the environment. Currently, Africa stands as the most food insecure region globally, marked by a surging youth population and a significant poverty rate. Given the pivotal and fundamental role of agriculture in the economies of most Sub-Saharan African nations, addressing these global challenges necessitates a

DOI: 10.1201/9780429150111-5

robust comprehension of engineering applications in agriculture, and the translation of this knowledge into impactful technological and policy solutions.

In this Chapter, we discuss top-ranking questions facing agricultural engineering education and research in Africa in response to growing agricultural engineering for Agenda 2063, with particular relevance to the Agriculture We Want. This effort must be considered as a starting point because both educational and research priorities evolve continuously and unpredictably due to emerging concerns, evolving needs, and the discovery of new knowledge.

Agricultural Engineering Responds to the Grand Challenges and Big Questions Facing Africa

Agricultural Engineering is in a position to tackle the significant challenges confronting Africa. However, it remains uncertain whether the full scope of pressing and crucial issues concerning agricultural engineering education and research in Africa (and indeed globally) have been identified or thoroughly evaluated. What questions should the next generation of agricultural engineers in Africa be addressing to contribute to transforming Africa's agri-food systems into an engine for widespread socioeconomic development, wealth creation, and poverty reduction? What questions should agricultural engineering education in Africa be addressing to ensure that Africa's human capacity and skills are developed for both designing and implementing the needed policies and technological interventions across the value chain? What leading research topics should agricultural engineers in Africa be tackling in order to spearhead the required reduction of current massive yield gaps of crops (plant and animal), reduce losses and waste, and increase total factor productivity through sustainable intensification of agri-food systems?

To crystallise its role on the way to actualising Agenda 2063, the Pan African Society for Agricultural Engineering (PASAE), in partnership with and financial support of the Royal Academy of Engineering (RAEng, UK), implemented a project on "Growing Agricultural Engineering in Africa" (Taylor et al., 2021). To start to answer the questions raised above, we set out to compile a list of the top 100 questions facing agricultural engineering education and research in Africa, based on an extensive review of the literature covering agricultural engineering, agricultural development, and related topics, including policies related to agricultural modernisation in Africa. The literature search resulted in a list of 192 questions which were roughly organised into two main groups: (A1-A5) education, and (B1-B11) research and practice.

Within each group, the questions raised were further organised into sub-groups according to topic. During the process, similar questions were either reframed, merged or one of them discarded, and the process was continued until the top-ranking 100 questions emerged. These questions are expected to inspire the development of more region-specific variations that align closely with the priorities of education, research, and society. Overall, AE education accounted for 24 and AE research and practice accounted for 76 of the top-ranking questions identified.

The Future of Agricultural Engineering Education in Africa

The questions identified in relation to agricultural engineering education were categorised into four broad areas that reflect the breadth and depth of issues gleaned from the literature survey – curriculum, pedagogy, quality assurance, and the low public image of agricultural engineering. In this regard, one question stands out:

"How do we attract the best young minds to AE so that they can be best equipped to address the grand challenges facing Africa and humanity at large such as climate change, food security, water security, renewable energy, environmental degradation, and rising youth unemployment?"

Here, we consider the type and quality of education needed to produce, retain, and grow the pipeline of future agricultural engineers that are better equipped to transform Africa's agri-food systems through policy, practice, entrepreneurship, and thought leadership. Making the best possible progress in modernising and transforming Africa's agriculture will require exceptional people and globally competitive skills and talent. We need to radically change our culture and the way we train the future generation of agricultural engineers so that 'agri cultural/biosystems/biological/bioresource engineer' can join 'doctor', 'pharmacist', 'lawyer', 'computer engineer', 'biomedical engineer', and 'vet' in the list of top professions to which our most talented and capable young people aspire.

A1: What curriculum design and content do we need?

Curriculum design, structure and content are essential for organising knowledge for effective teaching and learning. These allow both the teacher and learner to have a clear understanding of what materials will be covered during the course, including the scope, thereby facilitating co-learning and the preparation for learning sessions by both participants. The curriculum will also address issues such as finding the appropriate balance between theory and practical sessions, basic sciences, engineering, and the humanities, etc.

1. What curriculum will prepare agricultural engineers for life-long learning and future work?
2. What is the balance between technical, soft, and entrepreneurial skills?
3. What are the new and emerging knowledge frontiers/topics relevant to AE education?
4. Agriculture vs Biology vs Engineering: what is the foundation of AE?
5. What are the desirable graduate quality attributes of future agricultural engineers?
6. What are the roles of agricultural experiment stations in AE education and training?

7. What is the relevance of smallholder agricultural practices and related hand tools in modern AE curricula?

A2: Pedagogy and epistemology

Questions related to pedagogy and epistemology concern how we train future agricultural engineers for life-long learning. Pedagogy refers to both the theoretical and practical approach employed by teachers to instruct, encompassing the interaction between culture and various learning methods. On the other hand, epistemology concerns the theory of knowledge, exploring the connection between the mind and reality. It is concerned with the mind's relation to reality. What is it for this relation to be one of knowledge? Do we know things? And if we do, how and when do we know things?

8. To what extent are new and modern teaching and learning methods, including online methods, incorporated in AE education?
9. What are the roles of information and communication technologies in future AE education?
10. How do we harness social media to promote effective learning?
11. How do we make Capstone/Design Project courses relevant to smallholder agriculture?
12. How do we improve and increase the ‘practical’ component of AE education?
13. Does the students’ industrial work experience scheme (SIWES) expose AE students to experiential learning relevant to commercial agribusiness?

A3: How do we assure quality and equivalence in agricultural engineering education?

Similar to any other field, the education sector is regulated and administered through particular policies, practices, and guidelines that define the minimum standards of quality and achievement expected from students, teachers, administrators, parents, and the general public. Quality assurance is necessary for programme accreditation (Opara, 2004; Opara et al., 2004a,b; Opara et al., 2006; Opara & Cuello, 2006a, b; Comparetti et al., 2006; Cuello, & Opara, 2007), and most importantly, it provides the blueprint for quality improvement and benchmarking. Both internal and external quality assurance are necessary to achieve the desired objectives.

14. What are the mechanisms and procedures for accreditation of AE degree programmes?
15. What are the internal and external mechanisms for quality assurance in AE education?
16. What benchmarks are required to standardise AE curricula?
17. How do we achieve a Pan African standard for AE curricula, mobility, and cross border recognition of qualifications?
18. How do we ensure that future researchers have the most suitable background knowledge and skill sets to address the research challenges that they are likely to face?

A4: How do we attract and retain the brightest and best young minds to careers in agricultural engineering?

During the past three decades, one of the major challenges facing the agricultural engineering discipline and related academic programmes in tertiary institutions is low enrolment (Opara, 2012, 2003a,b; Opara et al., 2004a,b). As a result, many programmes have been closed or merged into other related disciplines. Attracting, retaining, and graduating students majoring in agricultural and related bio-inspired engineering programmes remains a challenge and these raise critical questions which need to be addressed to assure the future of the discipline and skills needed to achieve the “Agriculture We Want”.

19. What actions (and by whom) are required to improve the low public image and perceptions of AE?
20. What’s in a name? – Agricultural, Biosystems, Bioresources, or Biological Engineering?
21. How do we ensure that society appreciates the full importance of AE?
22. How do we make AE attractive to top quality students, their guardians, and advisors?
23. How do we grow and retain the pipeline of AE graduates?
24. What are the current destinations of graduates trained in agricultural engineering in the workforce?

Future of Agricultural Engineering Research and Practice in Africa

Research and innovation are critical for socioeconomic development. Sub-Saharan Africa is still largely an agrarian economy, and the successful industrialisation of Africa, like in other developed economies, will be led by the modernisation and transformation of its predominant smallholders into agribusiness value chains. This transformation will require enhancing agribusiness productivity and growth, developing and advancing new knowledge, and developing novel agricultural engineering solutions to address the persistent technological and structural challenges facing subsistent and smallholder agriculture. These challenges include protecting the environment, sustainable conservation, and utilisation of bioresources, and responding to climate change and other emerging global challenges. Agricultural engineering research must also address the challenges that currently limit both intra-Africa and global trade and market access of agri-food products and services. In particular, the African Continental Free Trade Area (AfCFTA) is one of the 13 flagship projects of Agenda 2063: The Africa We Want, of the African Union. With the potential of creating a single market worth US$6.7 trillion by 2030, the objective of the AfCFTA is to significantly boost intra-Africa trade, particularly trade in value-added production and trade across all sectors of Africa’s economy (WEF, 2024). The achieve the goals of creating one Africa market, agricultural engineering education and research has important roles to play in developing the required workforce, conducting research and applying relevant technologies (novel products and processes) which contribute to eliminating barriers to trade in Africa and with the rest of the world.

Regarding the future of agricultural engineering research and practice, the leading questions identified were categorised into eleven broad areas:

(i) sustainable production and intensification;
(ii) banishing the hand-hoe to the museum;
(iii) finding best ways to maintain soil quality and health;
(iv) finding best ways to maintain plant and animal health;
(v) investigating how irrigation can contribute to sustainable agricultural intensification;
(vi) how we feed our children's children;
(vii) ensuring energy security for agriculture and rural development;
(viii) finding cost-effective ways to reduce preharvest and postharvest losses and food waste;
(ix) supporting trade and market access towards agricultural transformation and regional integration;
(x) mitigating the impacts of climate change on agriculture and the environment; and
(xi) Harnessing the power of new and emerging technologies to transform African agriculture and food systems for socioeconomic development.

The limited applications of modern agricultural engineering technologies and other improved inputs and services in African agriculture, which contribute to the deep yield gaps, limited value addition, and lack of competitiveness, can be illustrated by the huge deficits in mechanisation intensity, low levels of irrigation, and high degradation of agricultural soils.

Low Levels of Mechanisation

Sustainable intensification of agriculture, including agricultural mechanisation, is energy dependent (Pimental, 1976). The near-linear positive relationship between the degree of mechanisation (power input and use of improved machinery) and agricultural productivity is well documented in the global scientific literature. Correspondingly, there is overwhelming agreement and a renewed call for action on sustainable agricultural mechanisation as a key input in the modernisation and transformation of the agricultural sector in Africa (Sims et al., 2016). Today, human muscle still accounts for over 80% of the power input across much of Sub-Saharan Africa, while the hand-hoe and cutlass remain the primary tools used in cultivation and other on-farm operations. Similarly, the number and use of modern and improved power sources such as tractors and pumps in Africa is the lowest compared with other regions of the world. Current estimates show that Africa has approximately 5 tractors available for every 1,000 farmers, whereas the USA boasts a significantly higher ratio of 1,600 tractors for every 1,000 farmers (Jones, 2016). The mechanisation of smallholder agriculture remains an intractable problem. Overall, it can be said that Africa lacks the (mechanical) power to modernise and transform its agri-food systems. This deplorable state of modern power and machinery in agriculture has been recognised at the highest levels of leadership in Africa, resulting in the symbolic call to relegate the hand-hoe to the confines of a museum.

Irrigation Deficit and Related Water Harvesting and Water Saving Technologies

Africa's agriculture is thirsty. At the same time, there is rising competition for water between urban demand and agriculture. Approximately 63% of urban regions in sub-Saharan Africa lack access to fundamental water and sanitation services. Although irrigation has the potential to enhance agricultural productivity by at least 50%, the majority of food, feed, and fibre production on the continent relies heavily on rainfall. Currently, the area equipped for irrigation covers just over 13 million hectares, constituting only 6% of the total cultivated area, in stark contrast to Asia's 37%, Latin America's 14%, and the global average of 18%. Numerous governments and development organisations have proposed significant investments in irrigation across Africa. However, the success of these projects relies heavily on geographical, hydrological, agronomic, and economic factors that must be taken into account to assess their long-term viability and sustainability. The lack of sufficient irrigation contributes to Africa's low agricultural productivity. The current very limited application of irrigation in African agriculture underscores the need for research and innovation to optimise crop performance under the difference agro-ecological zones.

Poor Soil Quality and Health

Sub-Saharan Africa (SSA) covers an extensive region of 24.6 million km^2, encompassing a wide variety of soil and land management types. The predominant soil types include Arenosols (21.5%), Cambisols (10.8%), Ferralsols (10.4%), and Leptosols (17.5%). The extent and nature of soil constraints on agricultural productivity vary significantly. Approximately 40% of soils in SSA have low nutrient capital reserves (<10 weatherable minerals), 25% are affected by aluminium toxicity, and 18% have a high leaching potential with low buffering capacity. Soil degradation manifests at various scales, including individual farm fields, farming communities, and landscapes. For instance, gullies present on farms often indicate changes in land use upstream (at the head of the watershed), such as intensive grazing or excessive mechanised agriculture, which can lead to erosion or contamination downstream. Soil degradation, characterised by soil erosion, nutrient depletion, loss of biological diversity, and a decline in water quality and quantity, poses a significant challenge for many countries in sub-Saharan Africa.

Approximately 65% of the agricultural land in SSA suffers from degradation due to inadequate management practices, resulting in a decline in the biological, chemical, and physical quality of the soil. This degradation reduces the soil's ability to support crop production and provide essential ecosystem services. Soil degradation presents a significant challenge for agricultural systems in sub-Saharan Africa. While there is substantial knowledge about the consequences of degraded soils, the evidence base for farm management practices that could prevent and mitigate soil degradation is still developing, and farmers' adoption of such practices remains limited. Despite the low quality and poor health of Africa's agricultural soils, the use of fertilisers in crop production is notably lower compared to other parts of the world. Novel sources of sustainable and environmentally friendly and non-synthetic fertiliser are needed, and agricultural engineers play a crucial role in designing and deploying more effective methods for their application.

B1: How Do We Ensure Sustainable Production and Intensification?

Agricultural production has witnessed significant growth over the last fifty years, fostering economic development in rural and urban areas globally (Pretty et al., 2011). However, the result has been poor in Africa due to a wide range of factors, leading to widespread poverty among farmers, particularly the rural poor. From the early 1960s to the 1970s, Sub-Saharan Africa (SSA) experienced a moderate increase in agricultural production per capita, with intermittent brief periods of growth in the mid-1970s and 1980s. However, in contrast with other developing regions of the world, the overall trend in agricultural productivity growth has been one of decline (Hazell & Wood, 2008). As a result, food insecurity has been a continuing problem in SSA, affecting over 30% of the population (Pfister et al., 2011). In response, many governments in Africa and their external development partners (mainly government-funded donor agencies and philanthropic organisations) have promoted and focused their policies on smallholder/subsistence farming for food security. To date, it is clear that this decades-long approach to sustainable agri-food systems transformation has not yielded the expected results for sustainable economic development and widespread poverty reduction, particularly among the rural population who are responsible for the majority of the food produced and consumed in Africa. Evidence from both developed, developing and emerging regions have shown that sustainable intensification of agriculture can be a major driving force for widespread economic development and poverty reduction. For example, in China, Wang (2013) contended that maintaining agricultural growth over the past few decades played a pivotal role in reducing poverty as a significant portion of the impoverished population resides in rural regions and relies heavily on agriculture for their sustenance.

Many researchers have attributed the low agricultural productivity in Africa to factors intrinsic to the continent and its people, such as climate, soil quality, slavery, and disease. However, Bjornlund et al. (2020) argued that these are not the primary reasons behind the persistently poor performance of African agri-food systems. Instead, the authors traced the historical role of agriculture and asserted that complex agricultural systems once thrived in Africa, supporting food security, manufacturing, and trade before European traders arrived. External interference disrupted these systems in favour of export crops, and even after achieving political independence, the fundamental issues remain unchanged, with resource and wealth extraction continuing to hinder economic development in Africa.

The reported successes of many external development agricultural intensification projects and programmes in Africa have not been sustained nor replicated through domestic agricultural and rural development initiatives. For example, the UK Government's Foresight Global Food and Farming project commissioned analyses on sustainable intensification in 40 projects and programmes across 20 countries during the 1990s–2000s. By early 2010, these initiatives had demonstrated significant benefits for 10.39 million farmers and their families, leading to improvements on approximately 12.75 million hectares of land (Pretty et al., 2011). The research revealed that sustainable intensification had a multiplicative effect on food outputs, as it combined the use of new and improved crop varieties with enhanced agro-ecological management practices, resulting in average crop yields increasing by 2.13-fold. Additionally, sustainable intensification had an additive impact by promoting diversification, leading to the introduction of new crops, livestock, or fish alongside existing staples and vegetables cultivated on the land.

Africa still relies largely on subsistent smallholder agri-food systems, including the slash and burn of grasslands and woodlands for crop and livestock cultivation. Low levels of mechanisation mean that most farmers still rely on human muscle with associated ancient tools (hand-hoe and cutlass) for manual bush clearing, cultivation, weeding, harvesting (Figure 4.1), processing, and transport of food and other agricultural raw materials. Together, these contribute to the very low yield of crops and livestock. The modernisation of agri-food systems using agricultural technologies is crucial to close productivity gaps and reduce the negative impacts of agriculture on the environment.

25. How can AE technologies close the huge yield gaps in Africa?
26. What are the technological bottlenecks facing the adoption of protected cultivation of food, feed, and fibre, especially among smallholders and emerging commercial farmers in Africa?
27. What are the prospects for conservation agriculture among smallholders and emerging commercial farmers in Africa?
28. How do we make precision agriculture work for smallholders and emerging commercial farmers in Africa?
29. Given the increasing popularity and expansion of urban agriculture, including practices like roof-top farming, vertical farming, and basement farming, etc, what are the most effective management strategies to protect human and environmental health from potential risks such as pollution, soil compaction, runoff, erosion, and nutrient losses in urban settings?
30. What role for AE in intensifying the sustainable production, trade, and utilisation of Africa's indigenous plants and livestock for food, feed, fibre, and pharma?

FIGURE 4.1 Front (left) and side (right) views of a typical hand-hoe used for cultivation and harvesting root and tuber crops in Southeastern Nigeria. The handle is traditionally made from trunk and branch of small trees (giving the V shape) but increasing replaced by metal/iron. Notice the wrapping of the handle with discarded cloth materials to reduce bruising of the palms. Photo taken by author in Umubachi Kindred, Umunam Village, Imerienwe, Imo State, in Southeastern Nigeria during the 2023 farming season.

31. What are the technological and socioeconomic models to transit from nomadic herding to ranching and other methods of sustainable livestock intensification?
32. What is the scientific evidence on the impacts of slash-and-burn agriculture on sustainable food systems, habitat loss, environmental degradation, and pollution?

B2: How Do We Banish the Hand-Hoe to the Museum?

The predominance of the hand-hoe and cutlass as primary tools for food production has become a symbol of the primitive status of agriculture in Africa relative to the rest of the world. With the pervasive deployment of modern technologies across other economic sectors in Africa, from communication to transport, health care, fashion, housing, entertainment, etc., it is mind-blowing to imagine that the key technologies used to produce food in most parts of Africa have remained unchanged over millenia. This factor alone is arguably one of the largest contributors to the high level of drudgery and low interest in agriculture among the youth. With the rapidly declining adult population engaged in farming, the widespread use of modern power sources (especially the tractor) and associated implements has become an urgent necessity, including automation and other artificial intelligence enabled technologies.

Women and girls, who cultivate (Figure 4.2) and process (Figure 4.3) most of the food consumed in Africa, and who suffer the most from the associated ill-health of using the hand-hoe over their lifetime, have rejected it and called for the introduction of modern and productivity-enhancing

FIGURE 4.2 Teenage girl on her way home with her peers from farm demonstrating the use of the hand doe. Photo taken by author in Umubachi Kindred, Umunam Village, Imerienwe, Imo State, in Southeastern Nigeria during the 2023 farming season.

FIGURE 4.3 The last steps during cassava processing into garri. Left (pulverising by Mrs Onyewuonyeoma Ogazi) and right (frying by Ms Celicia, nee Ogazi). Photo taken by author in Umubachi Kindred, Umunam Village, Imerienwe, Imo State, in Southeastern Nigeria during the 2023 farming season.

technologies in agriculture. The African Union has called for the banishing of the hand-hoe. How do we achieve this? What is the role of agricultural, biosystems, bioresources, and biological engineering?

33. What is the degree of diversity in hand-hoe designs across the different agro-ecological zones in Africa?
34. To what extent has the ergonomics of past and present hand-hoe designs and their utilisation affected the health of farmers, especially women, in rural Africa?
35. What if agricultural production in Africa relied entirely on the hand-hoe and cutlass?
36. What is the level of agricultural mechanisation intensity across the different agro-ecological zones in Africa?
37. Are there optimal models for selection, cost-effective access and utilisation of improved agricultural mechanisation and automation technologies in Africa?
38. What are the cost-effective pathways for the introduction and utilisation of drones and robots to improve the productivity of smallholder agriculture?
39. How can the African agricultural engineering community better engage and share information with the public and broader scientific communities about the urgent and critical need to mechanise and modernise agriculture?
40. How can renewable energies such as solar accelerate electrification and industrialisation of rural communities in Africa?

B3: What Are the Best Ways to Maintain Soil Quality and Health?

Soils in most parts of Sub-Saharan Africa (SSA) have been reported to be notoriously fragile and degraded (Tully et al., 2015). Researchers have linked soil fertility and overall state of soil health to hunger in Africa (Sanchez, 2002, 2005). Due to the absence of reliable data and only approximate estimates, the true extent and pace of soil degradation in SSA remain largely uncertain. However, it is evident that soil fertility depletion stands as the primary factor leading to the decline in the ability of certain soils to support food production and essential ecosystem services. The main driver behind soil degradation is the expansion and intensification of agriculture aimed at catering to the growing population in the region. To achieve effective solutions to support resilient and sustainable food systems, the integration of agricultural, environmental, and socioeconomic objectives is paramount.

41. What critical soil functional properties and biological diversity are affected by mechanisation operations?

42. To what extent is soil compaction limiting agricultural productivity in Africa, and how can AE reverse this?
43. To what extent is soil erosion limiting agricultural land use and productivity in Africa, and how can AE reverse this?
44. What 'green technologies' and novel production practices can heal and restore damaged soils and ecosystems?
45. What is the economic cost of the soil degradation that may result from mechanisation (e.g., erosion, tillage, and compaction) relative to the value of crop production?
46. Drawing from both historical and recent remotely and closely sensed data, how can geospatial modelling or simulation methods offer enhanced insights into the connections between soil quality, soil management, climate, and agricultural production?
47. How can we enhance soil tillage techniques, residue management, and nutrient applications to foster the sustainability of natural resources, and minimise adverse environmental impacts while ensuring continued food production?
48. How do we raise productivity of marginal lands?
49. In what ways can the worldwide agricultural engineering community improve its communication and interaction with the public and broader scientific communities, encompassing fields like soil and earth sciences, hydrology, and environmental engineering?

B4: What Are the Best Ways to Maintain Plant and Animal Health?

African crops and animals are generally not in good health or highly vulnerable to ill-health due to high incidence of pests and diseases to reduce productivity and contribute to huge preharvest food losses. Due to ineffective cross border policies and practice, the borders of most Africa countries and indeed Africa's borders are highly porous to the movement of goods and people, making them predisposed to the entry of disastrous pests and diseases.

50. What 'green technologies' can be developed from bioresources for better plant and animal health?
51. How can we use knowledge of plants and soil to stop weeds from growing on farms?
52. What traceability systems are required to monitor the disease and contamination of plant and animal foods?
53. What are the prospects of on-farm and postharvest remote sensing of plant diseases and stress?

B5: How Can Irrigation Contribute to Sustainable Agricultural Intensification?

Irrigation is recognised as part of the suite of Green Revolution technologies, in addition to high-yielding crop varieties, fertiliser, the use of agri-chemicals, and mechanisation, which contributed to reported widespread increases in yield and productivity of farmers in Asia and Latin America during the past half century. It is widely acknowledged that the very limited application of these technologies across Africa has contributed to the delayed arrival of Africa's Green Revolution, and it is hoped that the Alliance for Green Revolution in Africa will lead the charge to change this narrative. Questions remain which needs answers to realise this goal.

54. What is the impact of deficit irrigation on crops that feed Africa, especially in water-scarce areas?
55. With the unique climatic conditions in most parts of Sub-Saharan Africa characterised by long periods of hot high temperatures and low relative humidity, what novel techniques can reduce the evaporation of water?
56. What is the evidence that novel water harvesting and storage technologies contribute to improved crop yield and overall agricultural productivity?
57. What are the latest techniques to reduce drainage and enhance water retention of agricultural soils?
58. What is the status of skills capacity, institutions and supply chains for pumps and spare parts necessary for successful irrigation sub-sector?
59. How can we reduce water use in agriculture without reducing yield and crop health?

B6: How Do We Feed Present and Future Generations?

Sub-Saharan Africa remains the hot spot and flash point for food and nutrition insecurity, and very limited resilience among farmers and their households. Both crop yield, productivity, and total production remain low, leading to high food deficits which make smallholder farmers vulnerable to food and nutrition insecurity, malnutrition, and stunting among children. Food deficit is further exacerbated during natural disasters, conflicts, and pandemics such as the recent COVID-19. To address the deficit, many countries rely on food aid donations and imports. Food imports have continued to rise during the past several decades, amounting to over US$ 48 billion per annum. The modernisation of Africa's agriculture and food systems is an imperative to improve productivity and total production through sustainable intensification. To achieve these, some big questions remain while new ones arise.

60. Can Africa feed itself by 2063?
61. How can agricultural engineering improve food availability?
62. How can agricultural engineering enhance access to food?
63. How can agricultural engineering improve food utilisation?
64. Can we use agricultural engineering to prevent malnutrition?
65. In what ways can agricultural engineering promote sustainable consumption?

66. Can we use agricultural engineering to reduce poverty, especially among farmers and rural communities?
67. How can agricultural engineering contribute to the domestication, commercialisation, and sustainable use of wild and under-utilised bioresources for food, feed, fibre, and pharma?
68. What are the best sustainable ways to commercially produce, handle, process, and market alternative new sources of food such as insects, without negatively altering the natural habitats and the environment?
69. Can the local (traditional) crops and animals that feed Africa be transformed into regional and global food value chains?

B7: How Do We Ensure Energy Security for Agriculture and Rural Development?

There is a near-linear relationship between energy input and crop yield. Africa has the lowest level of agricultural mechanisation intensity compared with other regions in the world, as measured by energy input from all sources – human, animals, tractors, and other engine-powered machinery. Human muscle is the largest contributor to agricultural power in Sub-Saharan Africa, which limits productivity and increases labour challenges. Agriculture is recognised as a major contributor to the emission of greenhouse gases (GHGs), contributing to rising temperatures and climate change. While advocating for an energy mix to propel Africa's development, there is tremendous opportunity for renewable energy generation and use in Africa, including autonomous power stations/units for remote rural communities.

70. What roles can agricultural engineering play in developing alternative, clean, and sustainable non-fossil energy sources, such as solar?
71. Which best candidate plants can be commercially grown and processed into biofuels with the least effects on biodiversity, carbon footprints, and food security?
72. How can agricultural engineering enhance the commercial production of "second-generation biofuels" – produced by algae, plant cellulose, etc?
73. Can we develop more efficient and long-term storage systems for solar energy?
74. How can we improve the collection, storage, and conversion of biomaterial wastes into bio-fuel?

B8: What Cost-Effective Ways Exist to Reduce Preharvest (On-Farm) and Postharvest Losses and Food Waste?

The incidence of preharvest and postharvest food losses is very high in Africa, thereby contributing to low crop yields and reduced food availability. While infestation by pests and diseases and inadequate farm management practices contribute to on-farm losses, harvesting and postharvest losses arise from improper harvest management practices, lack of improved postharvest knowledge, and limited application of novel postharvest technologies and agro-processing, among others. While preharvest and postharvest losses contribute to most incidence of food wastage, food waste is increasing becoming a problem among the middle class and in public institutions such as schools and hospitals. Africa's losses amount to over US$40 billion dollars in food produced per annum that does not reach the consumer, excluding the impacts of these losses on the environment, bioresources, and climate change. Investing in education and research efforts for sustainable production as well as sustainable consumption must be part of solution for sustainable agriculture for a sustainable Africa and the world.

75. What are the magnitudes and causes of preharvest (on-farm) losses of food crops and animals at subsistent/smallholder and commercial farms?
76. What the magnitudes and causes of postharvest losses of food crops and livestock products along the value chains of subsistent/smallholders and commercial agribusinesses?
77. Is food waste a problem in Africa?
78. What policies and incentives will promote the reduction of food losses and waste?
79. How can agricultural engineering contribute to reducing preharvest and postharvest food losses?
80. How can agricultural engineering contribute to reducing food waste?
81. Wealth from food waste: what effective processing methods and techniques can valorise food waste into safe food and high-value industrial raw materials?

B9: How Can We Ensure That Trade and Market Access Promote Agricultural Transformation and Regional Integration?

Africa has the lowest levels of intra-regional trade compared to other parts of the world. Trade within Africa has hovered at around 13% during the past decade and has recently increased to about 20% following the adoption of the African Continental Free Commerce Area, compared to about 70% in Europe and Asia. There are technological and policy dimensions to this problem, which can be adequately addressed to promote regional integration, economic development, and improvement in food security through enhanced availability. Developing and setting market standards for trade and exchange is important, including effective monitoring and surveillance systems for movement of people, goods, and services.

82. What are the quality attributes and marketing standards of fresh and processed foods in Africa?
83. How can agricultural engineering research contribute to market access and trade (intra- and global) in agri-food products?
84. What are the best ways to control pests, diseases, and disorders in Africa that are threats to the quality,

safety, marketing, and utilisation of plant and animal food products?

85. What research and new knowledge is required to transform selected local African foods into highly sought after regional and global brands?

B10: How Can We Mitigate the Impacts of Climate Change on Agriculture and the Environment?

Agricultural practices significantly contribute to climate change by negatively affecting the environment, bioresources, greenhouse gas emissions, pollution, and causing temperature rises. Simultaneously, agriculture also faces the consequences of climate change, experiencing shifts in weather patterns, heightened variability, unpredictability, more frequent natural disasters, and increased occurrences of pests and diseases. These climate-related challenges collectively result in reduced crop yields and compromised crop quality. Thus, agriculture is both a contributor and victim of climate change. While we recognise that these impacts of climate change are real in both directions, more evidence-based data is needed for specific agri-food systems and value chain to guide and support policies and investments to mitigate the impacts.

86. What are impacts of climate change on agriculture and food systems in Africa?
87. What are the impacts of climate change on bioresources and environment?
88. What current prediction models best simulate the possible climate change scenarios and impacts on agri-food systems in Africa?
89. Do we know the possible impacts of climate change on incidence of extreme and hazardous events such flooding of agricultural lands, drying of rivers, wildfires, etc?
90. Do we understand the potential impacts of climate change on plant/animal production cycles/seasons vis-à-vis the timeliness of agricultural operations?

B11: How Do We Harness the Power of New and Emerging Technologies to Transform African Agriculture for Socioeconomic Development?

Historically, advancements in agricultural and biosystems engineering education, and related technological advancements for application in agribusiness, have benefited from innovations emanating from other sectors of the economy. While agricultural mechanisation has been recognised as one of the greatest engineering and technological contributions to society during the past century, the benefits have not been realised in many parts of the world due to very low adoption in areas such as in Sub-Saharan Africa. Meanwhile, many new, novel, and emerging technologies have shown remarkable impacts in improving agricultural productivity through sustainable practices. Biotechnology and related technologies such as CRISPR genome editing provide opportunities to dramatically increase crop yield, reduce losses, and incorporate desired quality and safety attributes. Applications of nanotechnology and digitisation in agriculture offer new frontiers for a new agriculture that is more sustainable and delivers novel products and services demanded by consumers. The ongoing explosion in new knowledge and novel technological applications such as artificial intelligence (AI) (Waoo et al., 2023), Machine Learning (ML) (Nturambirwe & Opara, 2020; Nturambirwe et al., 2023), Digital Twins (DTs) (Pylianidis et al., 2021; Shoji et al., 2022), virtual prototyping (Ambaw et al., 2022; Mukama et al., 2020; Mukama et al., 2019), and virtual cold chain (Wu et al., 2018) offer new frontiers for agricultural engineering education and research which can contribute to a sustainable agriculture and a sustainable world.

91. How can agricultural engineers leverage the remarkable advances in biotechnology for sustainable intensification of Africa's agri-food systems?
92. How can agricultural engineers harness the developments in nanotechnology and miniaturisation to radically transform smallholder agriculture into commercial and profitable value chains?
93. Can we utilise the ubiquitous and rising power of information and communication technologies (ICTs) to digitise and connect African agri-food systems into regional and global value chains?
94. How can the integration of data science (DS), artificial intelligence (AI), machine learning (ML), and digital twins (DTs) be mainstreamed to agricultural engineering research?
95. What new scientific approaches will be central to agricultural engineering in the 21st Century?
96. How do we ensure that sound science and best engineering practice inform policy decisions on agricultural development?
97. What is the role of agricultural engineering in preventing and mitigating the impacts of current pandemics and future pandemics on agri-food systems?
98. How do we mainstream agricultural engineering extension services into agricultural development practice?
99. How can we provide effective extension services to farmers and agribusiness operators via smart and non-smart phones?
100. How can we promote and facilitate interdisciplinary collaboration in agricultural engineering research and practice to effectively work towards achieving the AU's Agenda 2063 and the UN's Sustainable Development Goals (SDGs) which address poverty, agricultural modernisation, climate change, the environment, and sustainable development?

Conclusions and Future Prospects

The Green Revolution that has propelled many countries in Asia and Latin America into new trajectories of economic development, through improved food security and widespread poverty reduction, has not had a similar influence in Africa. Sustainable intensification, mechanisation, irrigation, fertiliser application, the use of improved plant and animal genetic resources, soil management, and other recent agricultural technologies have all remained very low in most of Africa. Agricultural engineering education, research, and practice have critical roles to play in modernising and transforming agri-food systems in Africa. Africa needs its own agile and skilled workforce that can embrace and apply modern agricultural engineering technologies across the agri-food value chain, from production to postharvest handling, processing, storage, transport, logistics, and marketing. As the former President of the Federal Republic of Nigeria, His Excellency Olusegun Obasanjo (2016), aptly put it: "But one thing is clear to me as I return to farming: to achieve its potential, African agriculture needs a fresh infusion of innovation and talent".

Future agricultural engineering education must produce lifelong learners who possess the requisite engineering knowledge and understanding of the biological, environmental, and resource dimensions that are necessary for sustainable intensification of the agri-food system. This requires a rethink of agricultural and biosystems engineering education that is aligned with the future of agriculture and food systems that Africa wants – modern, knowledge-driven, technology-enabled, productive, resilient, sustainable, climate-smart, competitive, and profitable. Future agricultural engineering research must contribute to finding sustainable and cost-effective answers to the wide productivity gaps and efficiency challenges facing agriculture (and the environment). Africa's agri-food systems remain largely at the subsistence level, with farm sizes often less than 1 ha and smallholder farmers (mainly women and children) producing over 70% of food consumed. The call to banish the hand-hoe to the Museum in Africa is now urgent more than ever before, not only so as to replace it with tractors and other modern agricultural power sources and types of machinery such as the tractor, but also as a befitting symbol of the modernisation and transformation of African agriculture.

In consideration of these challenges (and opportunities!) facing agricultural engineering education and research in Africa, as well as the complexity of internal and external drivers affecting agriculture such as climate change, the emergence of transformative technologies (e.g., biotechnology, nanotechnology, information and communication technologies, robotics, artificial intelligence, etc.), and the globalisation of education and trade, a set of 100 top-ranking questions of importance to the future of agricultural engineering in Africa have been presented in this chapter. These questions do not address all the challenges facing agricultural and biosystems engineering education, research, and practices in Africa; however, they provide the needed foundation for future efforts to grow agricultural engineering education and research in Africa (and other developing regions) towards achieving both the SDGs and Agenda 2063 – The Africa We Want. Providing answers to these top-ranking questions must begin with Africans – especially agricultural and biosystems engineers – while recognising the importance of partnerships, cooperation, collaboration, and networks. As the former Board Chair of the Alliance for a Green Revolution in Africa put it while announcing the new Africa Food Prize (Masiyawa, 2016), Africa needs its own superheroes to respond to challenges: "But what Africa needs, each and every day, are heroes of a different sort – 'action heroes' with ideas and vision, ready to respond to challenges that could determine the fate of a continent with a land mass larger than the United States, Western Europe, China and India combined. This is a lot of land, with a lot of potential".

Acknowledgement

Prof. UL Opara gratefully acknowledges the Royal Academy of Engineering (RAEng), UK, for funding the project titled "Growing Agricultural Engineering in Africa: Supporting the Operations and Implementation of the Strategic Plan for AfroAgEng" through which the author carried out the study reported in this book chapter on top priority questions facing agricultural engineering education and research in Africa.

REFERENCE LIST

African Union. (2022). Agenda 2063: The Africa we want, overview. https://au.int/agenda2063/overview (Accessed on 10 April 2022).

Ambaw, A., Mukama, M., Fadiji, T. & Opara, U.L. (2022). Fresh fruit packaging design verification through virtual prototyping technique. *Food Packaging and Shelf Life (IF: 8.749, 15/12/2022)*, 32, 100858. https://doi.org/10.1016/j.fpsl.2022.100858

Bjornlund, V., Bjornlund, H. & Van Rooyen, A.F. (2020). Why agricultural production in sub-Saharan Africa remains low compared to the rest of the world – A historical perspective. *International Journal of Water Resources Development*, 36(sup1), S20–S53. https://doi.org/10.1080/07900627.2020.1739512

Comparetti, A, Febo, P., Orlando, S. & Mugnozza, G.S. (2006). Tools for quality assurance and assessment of agricultural engineering programmes, tuning subject-area lines and disappearing / rare knowledge in Italy. *Proceedings of Workshop on University Studies of Agricultural Engineering in Europe, Bonn*, September 7–8. https://www.researchgate.net/publication/266137701_Tools_for_quality_assurance_and_assessment_of_Agricultural_Engineering_programmes_TUNING_subject-area_lines_and_disappearing_rare_knowledge_in_Italy (Accessed on 25 April 2023).

Cuello, J. & Opara, L.U. (Guest Editors). (2007). Special issue series: Trends in agricultural, biosystems, and biological engineering education. *International Journal of Engineering Education*, 23(4 Part III). http://www.ijee.ie/contents/c230407.html

Hazell, P. & Wood, S. (2008). Drivers of change in global agriculture. *Philosophical Transactions of the Royal Society*, 363(1491), 495–515. https://doi.org/10.1098/rstb.2007.2166

Jones, R. (2016). Banishing the hoe to the Museum. Impact. Towards Africa's Agricultural Transformation, September–October, pp. 16–18. Nairobi: Alliance for a Green Revolution in Africa.

Masiyiwa, S. (2016). Africa needs its own superheroes to respond to challenges. Impact. Towards Africa's Agricultural Transformation, September–October, pp. 32–33. Nairobi: Alliance for a Green Revolution in Africa.

Mukama, M., Ambaw, A. & Opara, U.L. (2019). A virtual prototyping approach for redesigning the vent-holes of packaging for handling pomegranate fruit. *Journal of Food*

Engineering, 270. https://doi.org/10.1016/j.jfoodeng.2019.109762

Mukama, M., Ambaw, A. & Opara, U.L. (2020). A virtual prototyping approach for redesigning the vent-holes of packaging for handling pomegranate fruit–A short communication. *Journal of Food Engineering*, 270, 109762. https://doi.org/10.1016/j.jfoodeng.2019.109762

Nturambirwe, J.F.I., Hussein, E.A., Vaccari, M., Thron, C., Perold, W.J. & Opara, U.L. (2023). Feature reduction for the classification of bruise damage to apple fruit using a contactless FT-NIR spectroscopy with machine learning. *Foods*, 12(1), 210. https://doi.org/10.3390/foods12010210

Nturambirwe, J.F.I. & Opara, U.L. (2020). Machine learning applications to non-destructive defect detection in horticultural products. *Biosystems Engineering*, 189, 60–83. https://doi.org/10.1016/j.biosystemseng.2019.11.011

Obasanjo, O. (2016). Achieving Africa's agricultural potential. Impact. Towards Africa's Agricultural Transformation, September–October, pp. 28–29. Nairobi: Alliance for a Green Revolution in Africa.

Opara, L.U. (2003a). Image is everything: Undergraduate students' contributions towards better understanding and improvement of public attitudes and perceptions of agricultural engineering. *World Transactions on Engineering and Technology Education*, 2(3), 457±460.

Opara, L.U. (2003b). From farmers to blue-collar professionals: Agricultural Engineering students' perspectives on their career prospects, critical skills, and discipline name change. *World Transactions on Engineering and Technology Education*, 2(3), 399±402.

Opara, L.U. (2004). Outlook on Agricultural Engineering education and research and prospects for developing countries. *Outlook on Agriculture*, 33(2), 101–112.

Opara, U.L. (2012). The need for a professional network of agricultural and biosystems engineers in Africa. *International Journal of Postharvest Technology and Innovation*, 2(4), 426–432.

Opara, L.U., Al-Adawi, S.S. & Al-Shukeili, T.Y. (2004a). Students' perceptions of agricultural engineering education at Sultan Qaboos University in Oman, Part 1: Academic program selection. *World Transactions on Engineering and Technology Education*, 3(1), 139±142.

Opara, L.U., Al-Adawi, S.S. & Al-Shukeili, T.Y. (2004b). Students' perceptions of Agricultural Engineering education at Sultan Qaboos University in Oman, Part 2: Curriculum content and career preferences. *World Transactions on Engineering and Technology Education*, 3(1), 143–146.

Opara, L.U., Perret, J.S. & Ampratwum, D.B. (2006). The evolution of agricultural engineering education at Sultan Qaboos University. *International Journal of Engineering Education*, 22(6), 1139–1148.

Opara, U.L. & Cuello, J. (Guest Editors). (2006a). Special issue series: Trends in agricultural, biosystems, and biological engineering education. *International Journal of Engineering Education*, 22(1 Part I), Agricultural Engineering and the Emergence of Biological Engineering. http://www.ijee.ie/contents/c220106.html

Opara, U.L. & Cuello, J. (Guest Editors). (2006b). Special issue series: Agricultural/ biosystems/ biological engineering education. *International Journal of Engineering Education*, 22(6 Part II). Curriculum Reform, Assessment and Accreditation. http://www.ijee.ie/contents/c220606.html

Pfister, S., Bayer, P., Koehler, A. & Hellweg, S. (2011). Projected water consumption in future global agriculture: Scenarios and related impacts. *Science of the Total Environment*, 409(20), 4206–4216. https://doi.org/10.1016/j.scitotenv.2011.07.019

Pimental, D. (1976). World food crises: Energy and pests. *Bulletin of the Entomological Society of America*, 22(1), 20–26.

Pretty, J., Toulmin, C. & Williams, S. (2011). Sustainable intensification in African agriculture. *International Journal of Agricultural Sustainability*, 9(1), 5–24. https://doi.org/10.3763/ijas.2010.0583

Pylianidis, C., Osinga, S. & Athanasiadis, I.N. (2021). Introducing digital twins to agriculture. *Computers and Electronics in Agriculture*, 184, 105942. https://doi.org/10.1016/j.compag.2020.105942

Sanchez, P.A. (2002). Soil fertility and hunger in Africa. *Science*, 295, 2019–2020.

Sanchez, P.A. & Swaminathan, M.S. (2005).Hunger in Africa: The link between unhealthy people and unhealthy soils. *Lancet*, 365, 442–444. 2.

Shoji, K., Schudel, S., Shrivastava, C., Onwude, D. & Defraeye, T. (2022). Optimizing the postharvest supply chain of imported fresh produce with physics-based digital twins. *Journal of Food Engineering*, 329, 111077. https://doi.org/10.1016/j.jfoodeng.2022.111077

Sims, B., Hilmi, M. & Kienzle, J. (2016). Agricultural mechanization. A key input for sub-Saharan African smallholders. *Integrated Crop Management*, 23. Rome: Food and Agriculture Organization of the United Nations.

Taylor, A.J., Opara, U.L. & Smithers, J.C. (2021). *Agricultural Engineering in Africa: A Key Driver for Transforming Agriculture to Deliver Food Security and to Support Economic Prosperity*. Pretoria: Pan African society for Agricultural Engineering (PASAE/AfroAgEng).

Tully, K., Sullivan, C., Weil, R. & Sanchez, P. (2015). The state of soil degradation in Sub-Saharan Africa: Baselines, trajectories, and solutions. *Sustainability*, 7, 6523–6552. https://doi.org/10.3390/su7066523

Wang, S. (2013). Reducing poverty through agricultural development in China. *IDS Bulletin*, 44(5–6). https://doi.org/10.1111/1759-5436.12057

Waoo, A.A., Pandey, J. & Waoo, A.A. (2023). Chapter 5: Artificial intelligence in agricultural engineering. In A. Ahirwar, P.K. Shukla, M. Shrivastava, P. Maheshwary & B. Gour (Editors), *Innovative Engineering with AI Applications*. Wiley. https://doi.org/10.1002/9781119792161.ch5

WEF, 2024. An Action Plan to Accelerate Global Business and Investment in Africa. White Paper. 36 pages. World Economic Forum, In collaboration withAfrican Continental Free Trade Area Secretariat: Geneva.

Wu, W., Cronjé, P., Nicolai, B., Verboven, P., Opara, U.L. & Defraeye, T. (2018). Virtual cold chain method to model the postharvest temperature history and quality evolution of fresh fruit – A case study for citrus fruit packed in a single carton. Computers and Electronics in Agriculture, 144, 199–208. https://doi.org/10.1016/j.compag.2017.11.034