Stakeholders prioritization of climate-smart agriculture (CSA) in the rice-based production systems of Mali

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Contents

1. Introduction

Agriculture, food and nutrition security, and the livelihoods of millions of people are affected by climate change (Connolly-Boutin and Barry Smit, 2016). Due to the overall dry arid nature of much of West Africa and the multiple interacting biophysical, political, and socioeconomic stresses, the climate change impacts are expected to be particularly severe in the region (IPCC, 2013). Aside from temperature rises, climate change in West Africa is expected to result in changes in rainfall intensity, an increase in the frequency of extreme events such as droughts and floods, desertification, and changes in disease vectors, all of which will affect the spatial and temporal transmissions of infectious diseases (Zougmore et al., 2016). In many parts of West Africa, the expected effects include shortened or disrupted growing seasons, flooding, reductions in the area suitable for agriculture, and decreases in agricultural yields (Serdeczny et al., 2016). Besides, emerging research indicates that vulnerabilities related to climate change and its impacts on communities are gendered. Women have access to limited finance and agricultural inputs, such as (better-quality) land and agricultural assets leaving them more exposed to climate change impacts (Dillon et al., 2014). Agriculture production systems require adaptation to these changes to ensure the food and livelihood security of farming communities.

Climate-smart agriculture has been proposed to adapt and reorient agricultural systems to promote food and nutrition security in the face of climate change. Climate-smart agriculture (CSA) can be defined as innovations, practices, or services that increase or sustain productivity over time, boost farmers' climate resilience, and reduce greenhouse gas emissions (Andrieu et al., 2017). Some categories of CSA practices include improved agronomic practices, integrated nutrient management, improved seeds, conservation tillage, water management, and crop diversification options.

Despite the numerous advantages of CSA technologies, farmers are currently adopting them at a slow pace. Some of the factors that influence the adoption of those technologies include the cost-benefits, implementation feasibility, adoption barriers, and incentive mechanisms provided by governments and development agencies to farmers and farming communities. Such factors largely influence the farmers, resource managers, and policy decision-makers at the local level who make most of the resource endowment and decisions to adapt to climatic risks in agriculture. Given the scarce resources of the West African countries, there is a need to prioritize the technologies that need to be taken at scale based on an impact assessment (Thornton et al., 2018).

Several tools and approaches were used for setting priorities among agricultural technologies including simulation modeling, mathematic programming, cost-benefit analysis, economic surpluses, econometrics, participatory ranking, meta-analysis, systematic review, spatial analysis, geographic information systems, remote sensing, and integrated assessment modeling (Thornton et al., 2018). Even though there has been a significant increase in attention to the prioritization of CSA practices in recent years, there has been a lack of better integration of stakeholders' inputs into the CSA prioritization framework (Khatri-Chhetri et al., 2019). Incorporating the perspectives and knowledge of a variety of stakeholders can aid in the development of a portfolio of locally viable and feasible practices for specific contexts.

This study used a participatory stakeholder prioritization framework, widely employed in the development sector that integrates CSA indicators with technology implementation feasibility to facilitate an equitable scaling out of the technologies (Herforth et al., 2012; Jomehpour, 2017; Khatri-Chhetri et al., 2019). The objectives of the study were to prioritize CSA interventions based on climatic risks, productivity, resilience, mitigation potentials as well as technical feasibility, investment requirement, gender inclusivity, demand by market, and alignment with the social and cultural contexts. We applied this framework to the rice-based systems of Mali, the second-biggest rice producer in West Africa, but a country highly vulnerable to climate change with a 10 – 80% projected yield decrease as a consequence of climate change (van Oort and Zwart, 2018). Major climatic risks in the rice-based systems in Mali include drought, flooding, water scarcity, and cold. The study translates local stakeholders' knowledge and strategy to mitigate climate risks in rice-based systems into the portfolio of CSA interventions suitable for the local context.

2. Data, method, and analysis

This study used a participatory approach of technology evaluation and prioritization at the local level. Stakeholder consultation workshops were organized to identify and evaluate a range of technologies, practices, and services in the four major rice production systems in Mali: irrigated lowland, rainfed lowland, rainfed upland, and submergence system. The region of Mopti was selected for submergence rice, Niono, Segou, Baguineda, and Selingue for irrigated lowland, and Sikasso for rainfed lowland and rainfed upland. These regions were selected by the National Agricultural Research and Extension Systems (NARES) as priority intervention regions for rice research and development and are characterized by different climatic conditions (Fig. 1).

A total of 73 technologies relevant for addressing the climatic risks in the different production systems were chosen by agriculture and climate change adaptation experts. These include 29 technologies in the irrigated system, 23 in the rainfed lowland, 9 in the rainfed upland, and 12 in the submergence system. The stakeholders involved in the prioritization comprise officers from the agriculture and extension departments, agricultural research institutions, development organizations, private sector, and farmers organizations of the selected sites. A total of 69 participants were involved: 30% from the private sector, 22% local farmers, 22% development organizations, 17% agricultural research institutions, and 9% agriculture department extension offices. The representatives were selected based on their knowledge of climate change adaptation and mitigation in the rice-based systems and their working experience with farming communities. The farmers' representatives were randomly chosen, but in a way to ensure that at least 40% are women. Women and youth organizations of the selected regions also participated in the workshop. The initial list of technologies proposed by the experts was submitted to the stakeholders for review and a final list was made. The invited stakeholders evaluated the final list of technologies in each production system based on CSA performance and implementation feasibility.

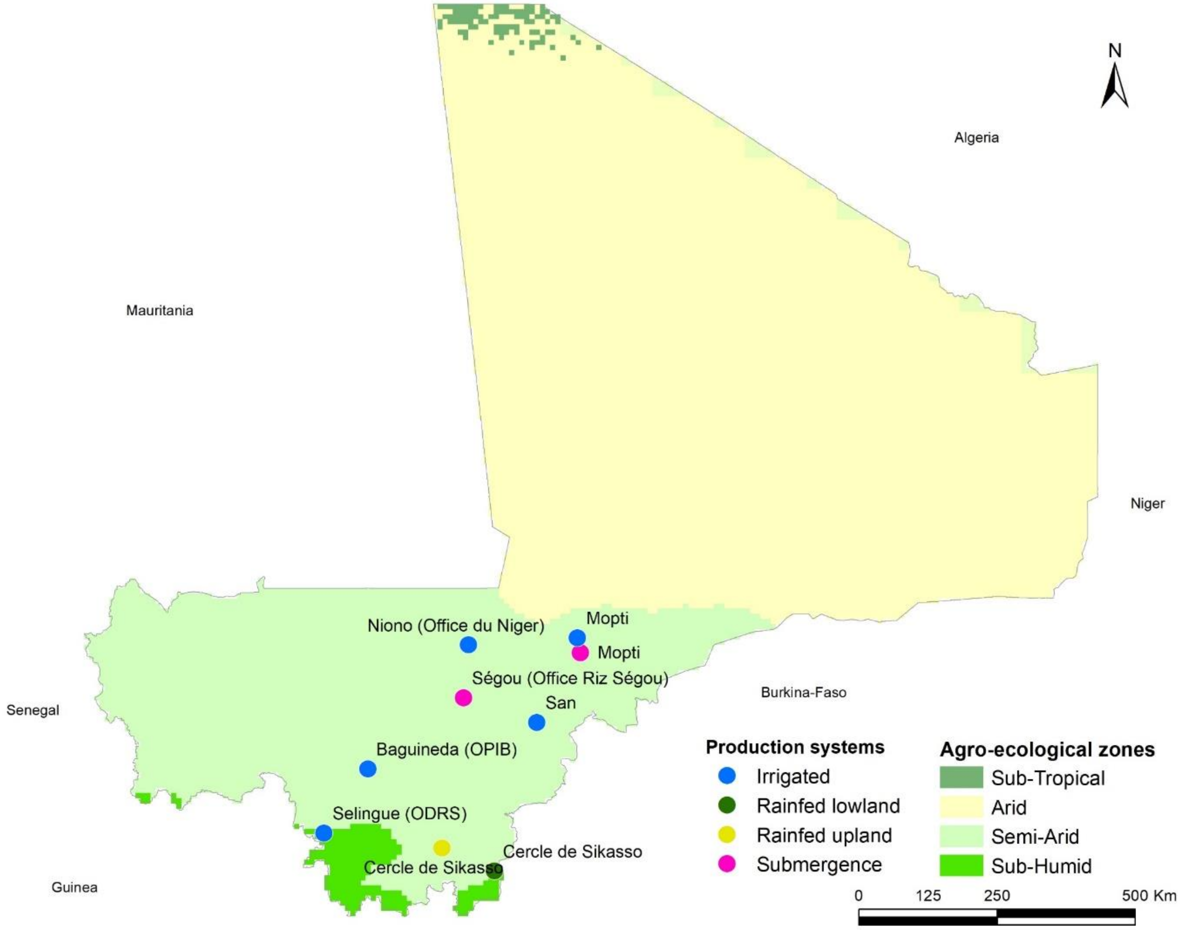


Fig. 1. Location of study sites per rice production system overlaid in the agro-ecological zones map.

2.1 Evaluation of climate-smart agriculture performance indicators

The potential CSA technologies were compiled into a 'long list' based on an extensive literature survey of technologies evaluated in rice-based systems in Mali (supplementary information). The evaluation was made based on four indicators: productivity, income, resilience, and emission (Table 1). The ability of technology to reduce loss in yield and income due to climatic stresses such as drought, flooding, water scarcity, heat, cold, pest, and diseases outbreaks was considered as proxy indicators for resilience. Reduction in the amount of water and fertilizer use was considered as proxy indicators for greenhouse gas emission mitigation. It is well established that an increase in the amount of water use is associated with a higher emission of methane (Jiang et al., 2019), while an increase in the quantity of nitrogen fertilizer is associated with a higher emission of nitrous oxide (Shcherbak et al., 2014). Each stakeholder was asked to give a weight to each of the four pillars using a scale of 0 to 5, where each unit represented an improvement in the productivity, income, resilience, and mitigation of a given technology. An overall CSA performance index (CSA-PI) was constructed using a weighted sum of the four CSA indicators (Eq. 1).

$$CSA - PI = \alpha_1 * Productivity\ (\%) + \alpha_2 * Income\ (\%) + \alpha_3 * Resilience\ (\%) - \alpha_4 * Emission\ (\%) \qquad \text{(Eq. 1)}$$

where, CSA-PI=CSA Performance Index, α1=0.40, α2=0.30, α3=0.20 and α4=0.10 are weight for each indicator of CSA estimated based on stakeholders' response.

Table 1. Pillars, indicators, and variables used in the evaluation of technologies and practices in the rice-based production systems in Mali by the stakeholders

Pillar	Indicator	Variable	Rationale
CSA	Productivity		
		Yield	Increase yield
		Net income	Increase income
	Adaptation		
		Variability in yield	Reduce yield variability
		Reduction in yield loss	Reduce yield loss due to climatic stress
	Mitigation		
		Greenhouse gas emission	Reduce greenhouse gas emission
Implementation feasibility	Technical feasibility		
		Knowledge and skill	Require limited knowledge and skill for use
		Investment	Require low investment
	Gender inclusivity		
		Gendered impact	Reduce a specific constraint faced by women
	Acceptability		
		Social and cultural norms	Respect the social and cultural environment
	Market		
		Market demand	Demanded by the market

2.2 Assessment of implementation feasibility

The proposed CSA technologies by the stakeholders were assessed on their overall implementation feasibility, which was based on their technical feasibility, cost, gender inclusivity, respect to the social and cultural environment, and demand by the market (Table 2). The technical feasibility represents stakeholders' current knowledge and skills to implement/use technology in their farming activities and was estimated based on how easy it is for the stakeholders to implement the technology. The cost of the technology was apprehended based on the investment capacity required to adopt it.

Despite proven economic benefits of technologies to farmers, their uptake among smallholder farmers in Mali remains low because of the failure to properly understand, and respond to gender relations as they relate to decision-making in the rice-based systems (Wooten, 2003; Efisue et al, 2008; Beaman et al., 2013). The adoption of CSA is influenced by complex interactions between natural factors, including climatic and agroecological conditions, and socioeconomic factors, including interactions between gender, market demand, ownership of resources, and information. In the rice-based systems, where there is a clear separation between the roles of men and women, as well as their capacity as household heads and households members to respond to incentives for behavioral change (Kinkingninhoun-Medagbe et al., 2020), the prioritization of CSA needs to be also viewed from gender perspectives. This study considered the ability of technology to reduce a specific constraint faced by women (eg., labor time and drudgery) as an indicator of gender inclusivity.

Current business models employed by technological innovation providers are not always optimized to current market demands, and as such was reported to be one of the limiting factors to the scaling, adoption, and impacts of technological innovations (Nkonya and Koo, 2017; Sitko and Jayne, 2018; Thornton et al., 2018). Besides, the alignment of technologies attributes with the social and cultural context can help accelerate adoption at the local level. However, the indicator for social and cultural context was not finally included in this study because all the technologies were considered fully aligned with the local context of Mali by the stakeholders. Each indicator of implementation feasibility was evaluated by using a 0–5 Likert Scale, where 0=no relevant, 1=very low importance, 2=low importance, 3=medium importance, 4=high importance, and 5=very high importance. The CSA implementation feasibility indicator was normalized between 1 and 5 using the normalization approach (Eq. 2).

$$CSA - IF = \beta_1 * technical\ feasibility\ score + \beta_2 * cost\ of\ technology\ score + \beta_3 * gender\ inclusivity\ score + +\beta_4 * demand\ by\ market\ score \quad \text{(Eq. 2)}$$

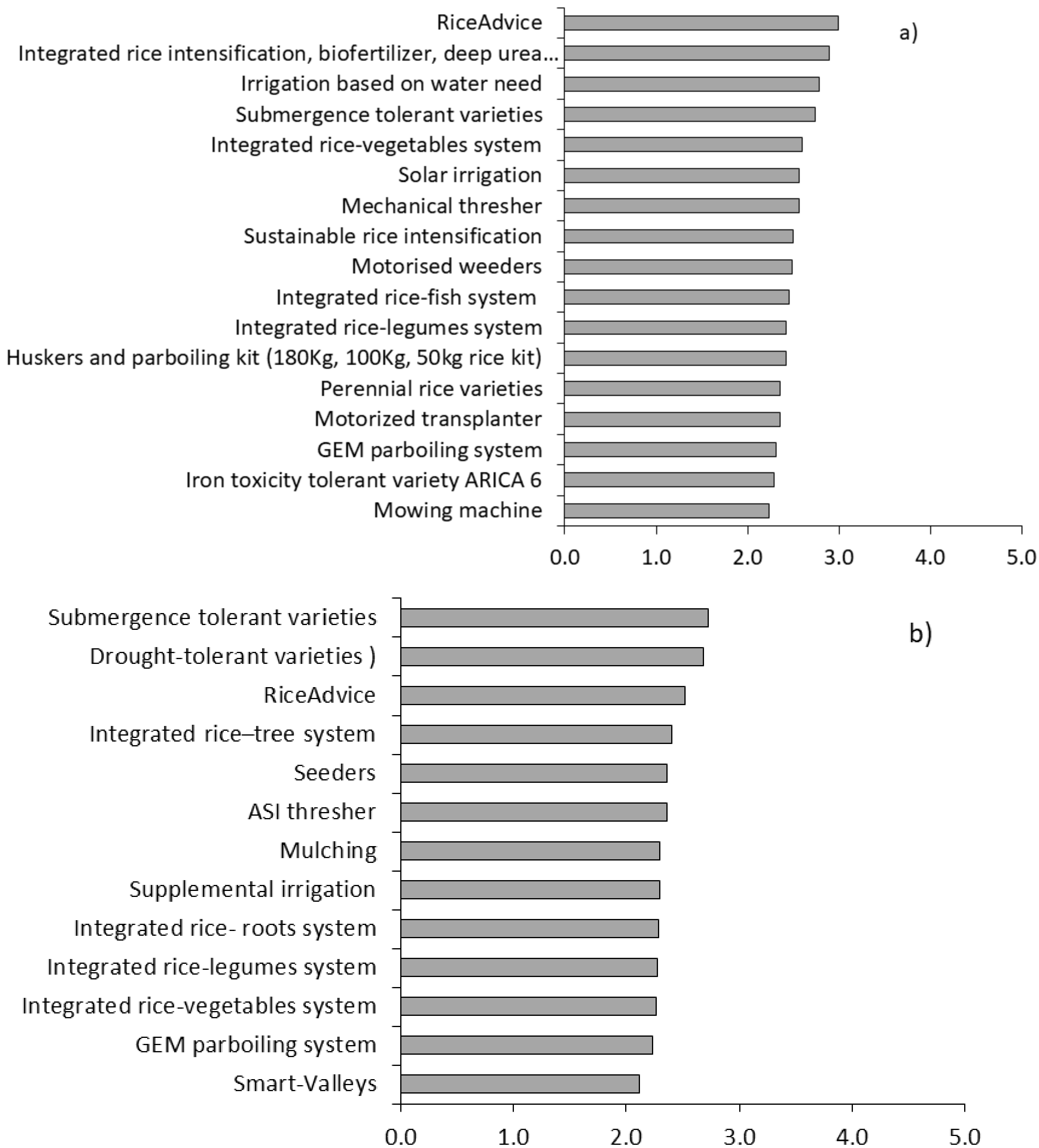
where, CSA-IF=CSA Implementation feasibility Index, β_1=0.30, β_2=0.30, β_3=0.15, β_4 = 0.25 are weight for each indicator of CSA estimated based on stakeholders' response.

A comparison of adaptation and mitigation benefits and implementation feasibility scores was conducted using a quadrant analysis. In the quadrant analysis, two categories of the score (CSA performance indicator vs. implementation feasibility) were mapped into the four quadrants: i) high CSA performance indicator – Low implementation feasibility, ii) high CSA performance indicator – high implementation feasibility, iii) low CSA performance indicator – low implementation feasibility, and iv) low CSA performance indicator – low implementation feasibility. The criteria of the quadrant were median values of implementation feasibility (CSA-IF) and performance indicator (CSA-PI).

3. Results

3.1 Assessment of CSA performance

Fig. 2 presents stakeholders' evaluation of the technologies based on the CSA performance indicator for each of the major rice production systems. In the irrigated lowland, RiceAdvice, irrigation-based on need assessment, the package of integrated rice intensification, biofertilizer, deep urea placement, pest management, and direct-seeding machine, submergence tolerant varieties, integrated rice – vegetable, mechanical thresher, solar irrigation, the system of rice intensification and motorized weeder received a high rank in their CSA performance indicator. Integrated rice-fish, integrated rice – legume, husker, and parboiling kit, perennial rice varieties, motorized transplanter, GEM parboiling, iron toxicity tolerant varieties, and mowing machine received low CSA performance indicator. In the rainfed lowland, submergence tolerant varieties, drought-tolerant varieties, Riceadvice, integrated rice – tree system, seeder, and ASI thresher received a high rank in their CSA performance indicator. Mulching, supplemental irrigation, integrated rice – root, integrated rice – legume, integrated rice – vegetable, GEM parboiling, and Smart-Valleys received low ranking in their CSA performance indicator. In the rainfed upland, RiceAdvice, and drought-tolerant varieties received a high ranking in their CSA performance indicator, while integrated rice – legume, vegetable or tree systems, ASI thresher, and GEM parboiling received low ranking. In the submergence system, RiceAdvice, submergence tolerant varieties, integrated rice-fish system, huskers, and parboiling kit received high ranking, while perennial rice varieties, GEM parboiling, and motorized transplanter received low ranking in their CSA performance indicator.



a)
RiceAdvice
Integrated rice intensification, biofertilizer, deep urea...
Irrigation based on water need
Submergence tolerant varieties
Integrated rice-vegetables system
Solar irrigation
Mechanical thresher
Sustainable rice intensification
Motorised weeders
Integrated rice-fish system
Integrated rice-legumes system
Huskers and parboiling kit (180Kg, 100Kg, 50kg rice kit)
Perennial rice varieties
Motorized transplanter
GEM parboiling system
Iron toxicity tolerant variety ARICA 6
Mowing machine
0.0
1.0
2.0
3.0
4.0
5.0
b)
Submergence tolerant varieties
Drought-tolerant varieties)
RiceAdvice
Integrated rice–tree system
Seeders
ASI thresher
Mulching
Supplemental irrigation
Integrated rice- roots system
Integrated rice-legumes system
Integrated rice-vegetables system
GEM parboiling system
Smart-Valleys
0.0
1.0
2.0
3.0
4.0
5.0

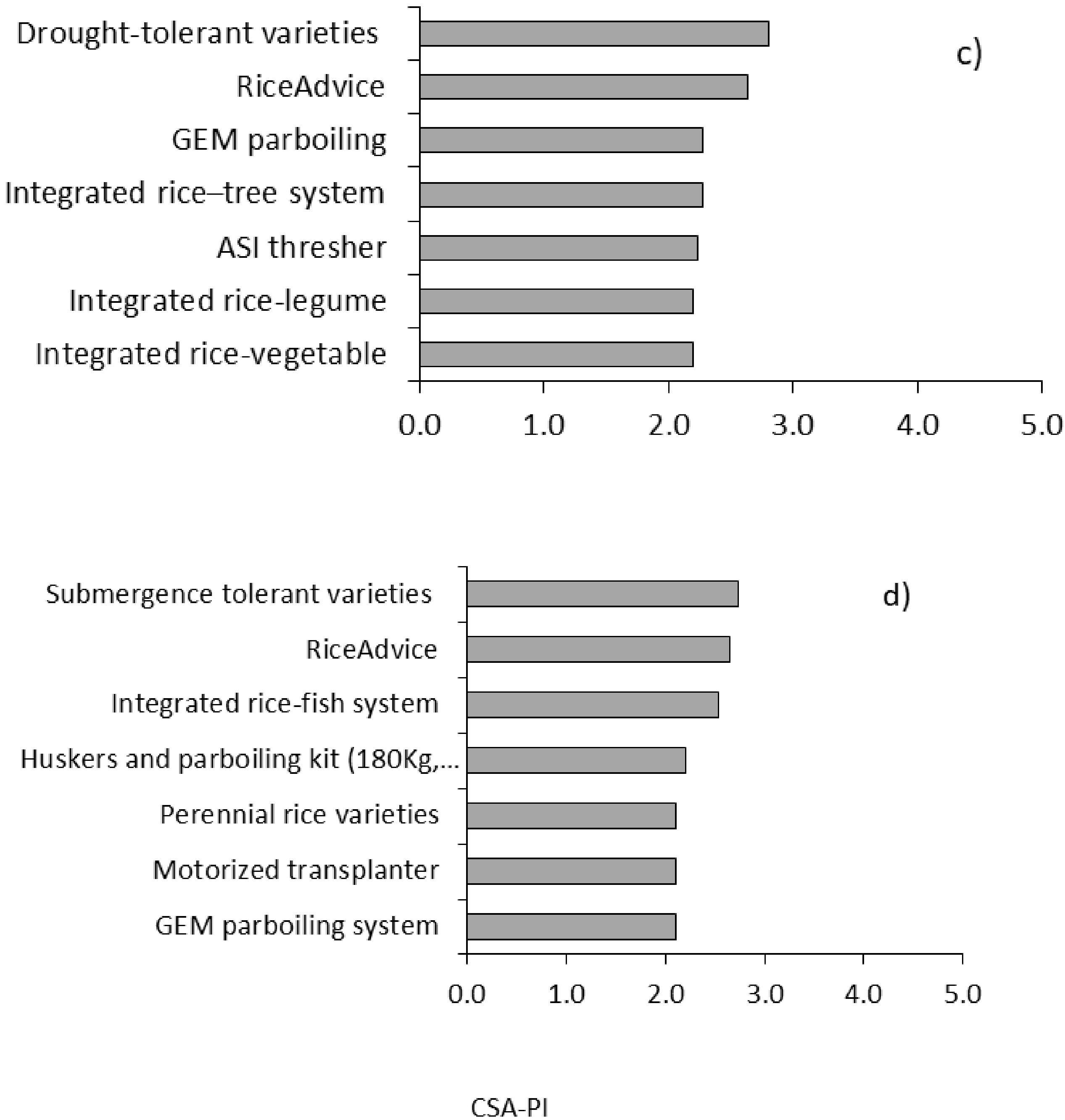
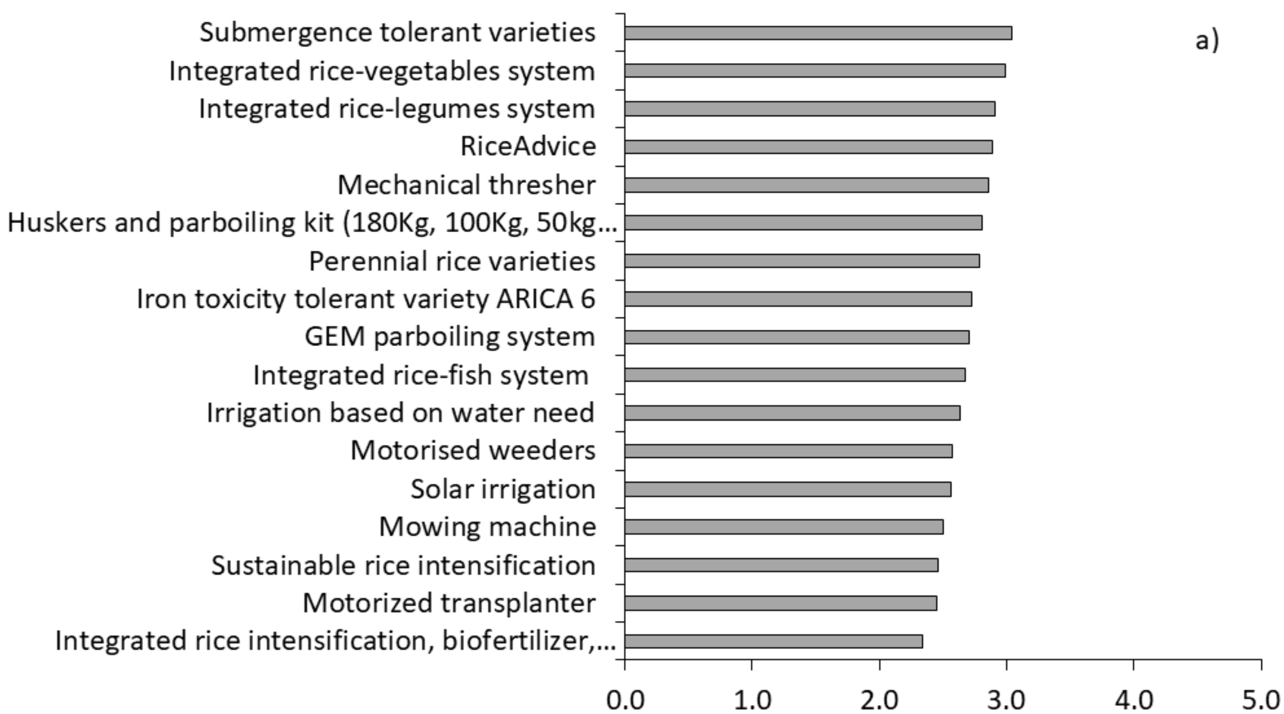
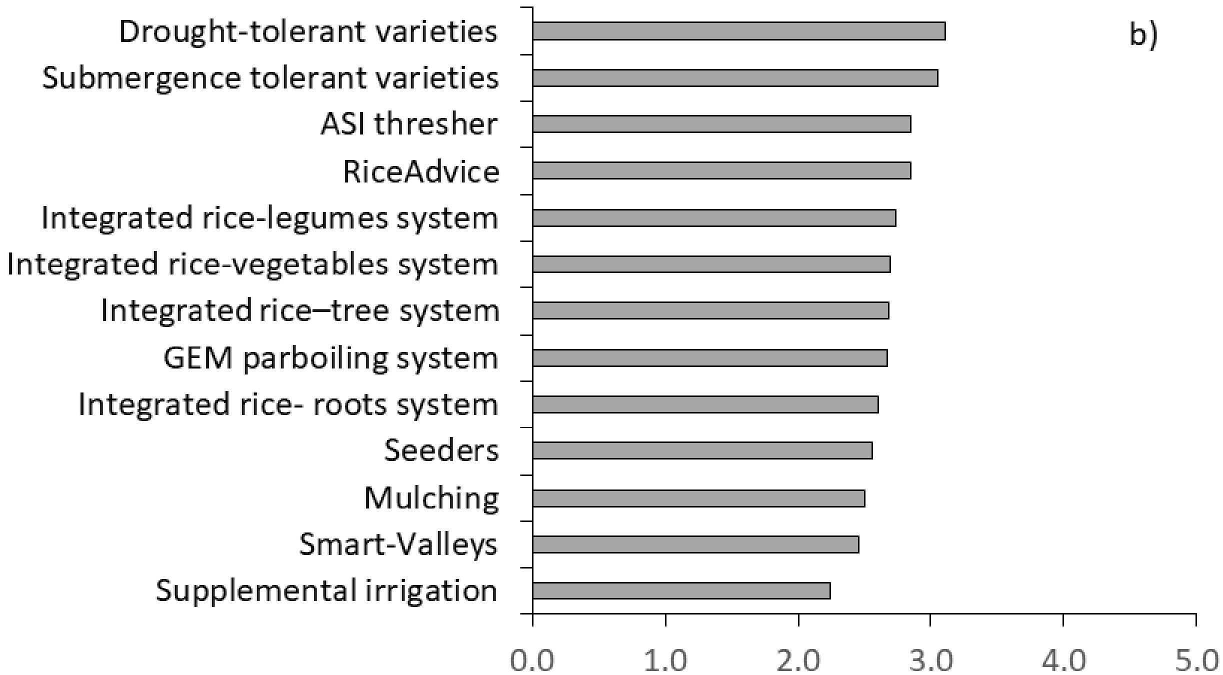


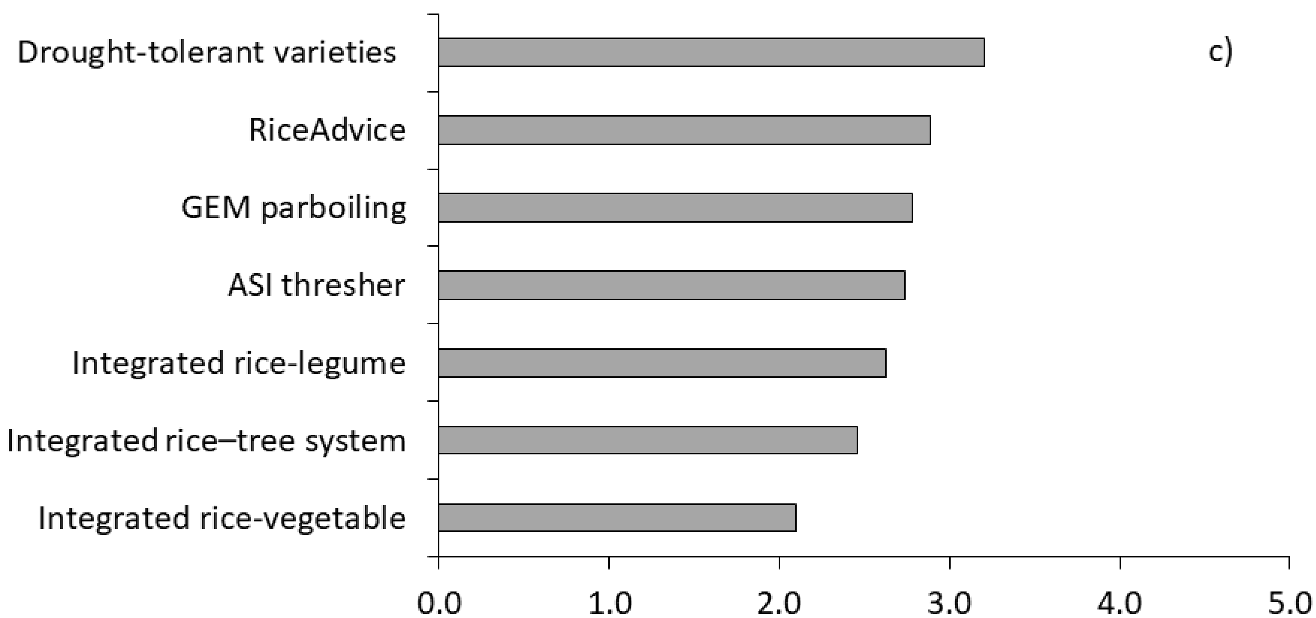
Fig. 2. Stakeholders' evaluation of technologies based on CSA performance indicators in a) irrigated lowland, b) rainfed lowland, c) rainfed upland and d) submergence rice production systems in Mali

3.2 Assessment of implementation feasibility

Stakeholders evaluated the technical feasibility, cost, gender inclusivity, and demand by the market of all technologies in each of the four major rice production systems. The implementation feasibility of the technologies was more determined by the technical feasibility, cost, and market demand, and to a lesser extend on gender inclusivity, with 30, 30, 25, and 15% contribution, respectively based on the stakeholders' evaluation. In the irrigated lowland, huskers and parboiling kit, mechanical thresher, RiceAdvice, integrated rice-legume or vegetable systems, and submergence tolerant varieties received high implementation feasibility ranking, while the package of integrated rice intensification, biofertilizer, deep urea placement, pest management, and direct seeding, and the following technologies: motorized transplanter, sustainable rice intensification and mowing machine received low ranking (Fig. 3). In the rainfed lowland, RiceAdvice, ASI thresher, submergence tolerant varieties, and drought-tolerant varieties received high implementation feasibility ranking, while supplemental irrigation and Smart-Valleys received low ranking (Fig. 3). In the rainfed upland, GEM parboiling, RiceAdvice, and drought-tolerant varieties received a high implementation feasibility score, while integrated rice-vegetable, tree or legume, and ASI thresher received low implementation feasibility score (Fig. 3). In submergence system, integrated rice-fish system, RiceAdvice, submergence tolerant varieties, and motorized transplanter received high implementation feasibility score, while GEM parboiling, huskers, and parboiling kit and perennial rice varieties received low implementation feasibility score (Fig. 3).




b)
Drought-tolerant varieties
Submergence tolerant varieties
ASI thresher
RiceAdvice
Integrated rice-legumes system
Integrated rice-vegetables system
Integrated rice–tree system
GEM parboiling system
Integrated rice- roots system
Seeders
Mulching
Smart-Valleys
Supplemental irrigation
0.0
1.0
2.0
3.0
4.0
5.0


c)
Drought-tolerant varieties
RiceAdvice
GEM parboiling
ASI thresher
Integrated rice-legume
Integrated rice–tree system
Integrated rice-vegetable
0.0
1.0
2.0
3.0
4.0
5.0

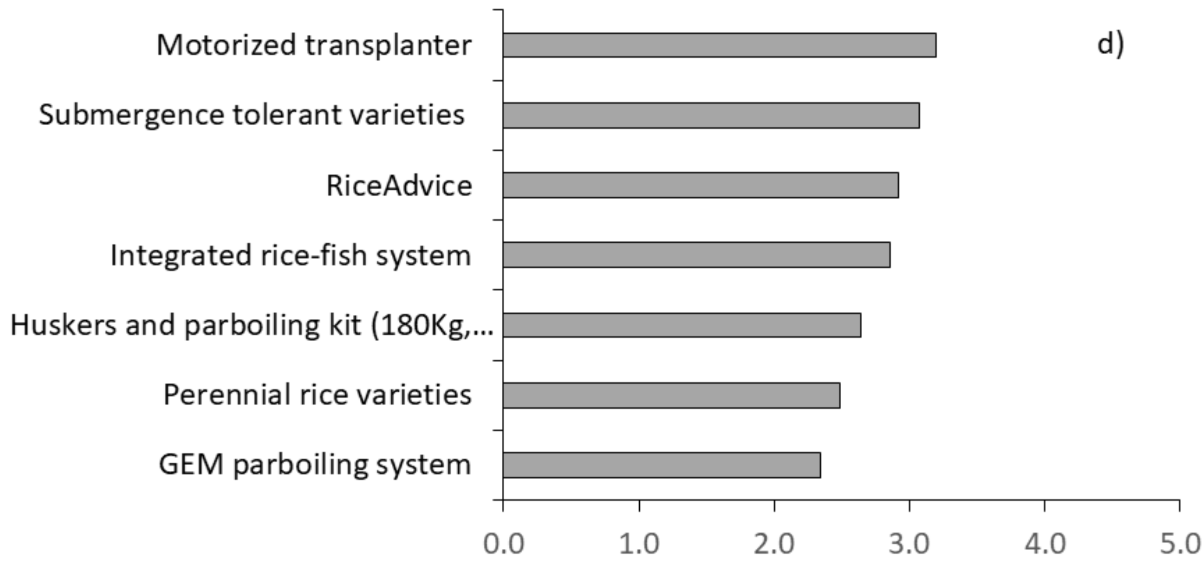


Fig. 2. Stakeholders' evaluation of technologies based on implementation feasibility in a) irrigated lowland, b) rainfed lowland, c) rainfed upland and d) submergence rice production systems in Mali

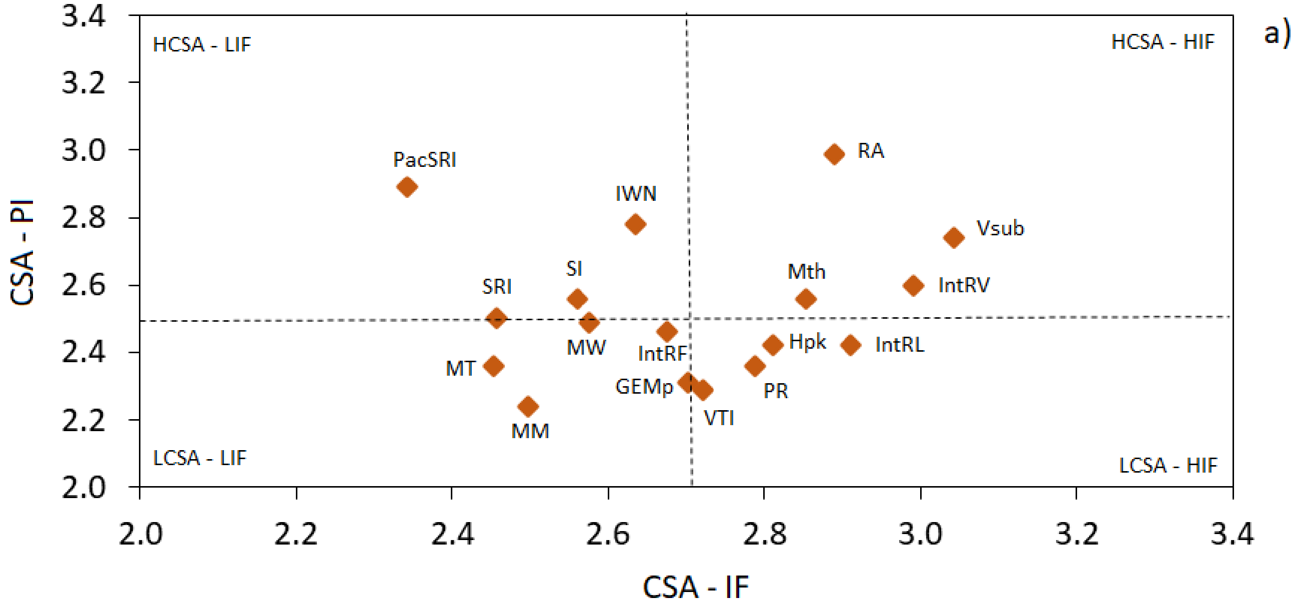
3.3 Adaptation and mitigation benefits of technologies against their implementation feasibility

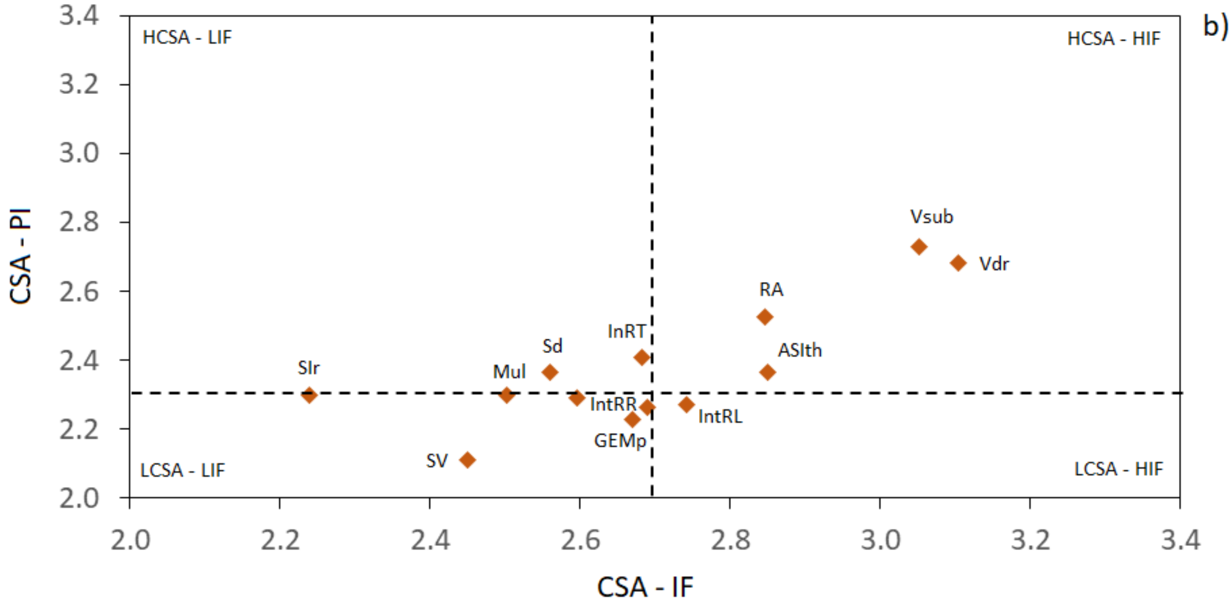
Figure 3 shows the potential adaptation and mitigation benefits of technologies against their implementation feasibility for each of the four rice production systems in Mali. In the irrigated lowland, RiceAdice, submergence tolerant varieties, integrated rice – vegetable, and mechanical thresher had a high CSA performance score, and high implementation feasibility scores. The package of integrated rice intensification, biofertilizer, deep urea placement, pest management, direct-seeding machine, irrigation-based on water management, and solar irrigation had a high CSA performance score, but low implementation feasibility. Integrated rice – legume, huskers and parboiling kit, perennial rice varieties, and varieties tolerant to iron toxicity had low CSA performance indicators and high implementation feasibility. Motorized transplanter, mowing machine, motorized weeder, GEM parboiler, and integrated rice-fish had low CSA performance score and low implementation feasibility scores.

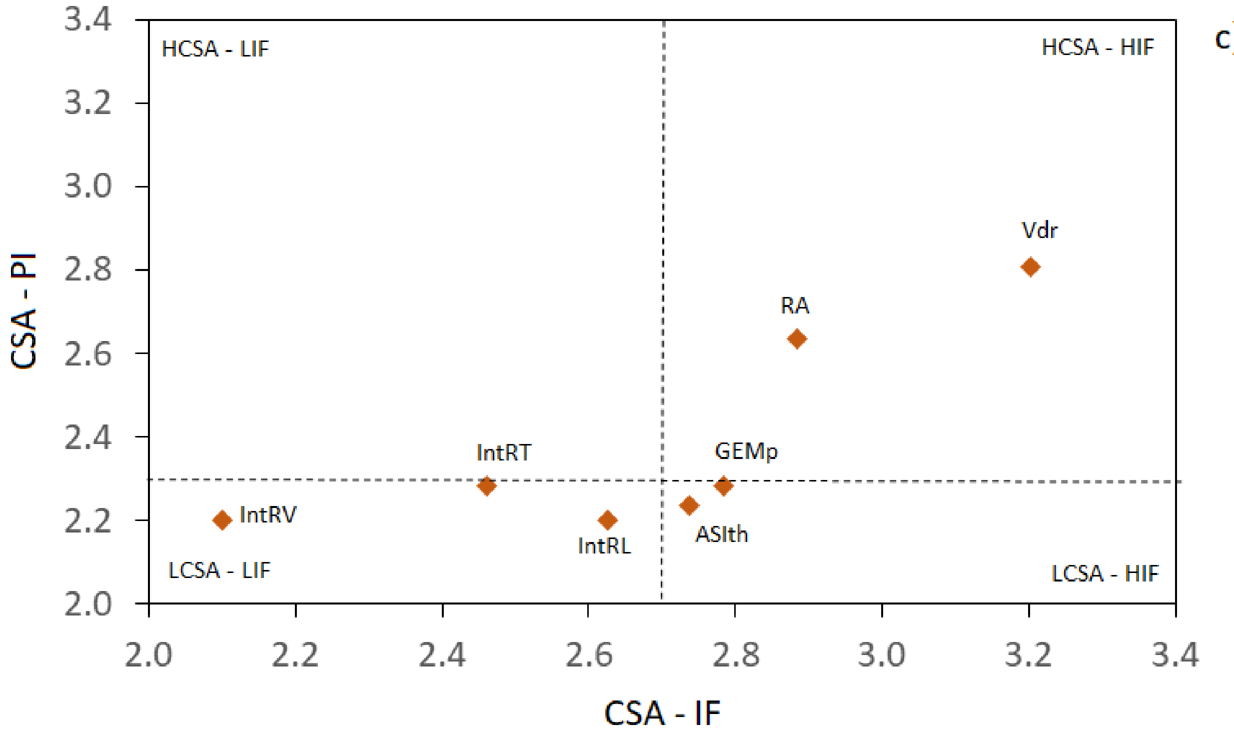
In the rainfed lowland, submergence tolerant varieties, drought-tolerant varieties, RiceAdvice, and ASI thresher had high CSA and high implementation feasibility scores. Integrated rice tree and direct seeder had a high CSA performance score and low implementation feasibility score. The integrated rice – legume system had a low CSA performance indicator and low implementation feasibility score. Smart-Valleys, GEM parboiler, and integrated rice root system had low CSA performances score and low implementation feasibility scores.

In the rainfed upland, drought-tolerant varieties and RiceAdvice had a high CSA performance score and a high implementation feasibility score. ASI thresher had a low CSA performance score and a high implementation feasibility score. The integrated rice–vegetable system had a low CSA performance score and low implementation feasibility score.

In the submergence system, submergence tolerant varieties, and RiceAdvice had a high CSA performance score and high implementation feasibility score. The integrated rice – fish system had high CSA performance score and a low implementation feasibility score. Perennial rice had a low CSA and high implementation feasibility score. Motorized transplanter and GEM parboiler had a low CSA performance score and a low implementation feasibility score.




b)
HCSA - LIF
HCSA - HIF
LCSA - LIF
LCSA - HIF
CSA - PI
CSA - IF
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
Vsub
Vdr
RA
InRT
Sd
ASIth
SIr
Mul
IntRR
IntRL
GEMp
SV


c)
HCSA - LIF
HCSA - HIF
LCSA - LIF
LCSA - HIF
CSA - PI
CSA - IF
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
Vdr
RA
IntRT
GEMp
IntRV
IntRL
ASIth

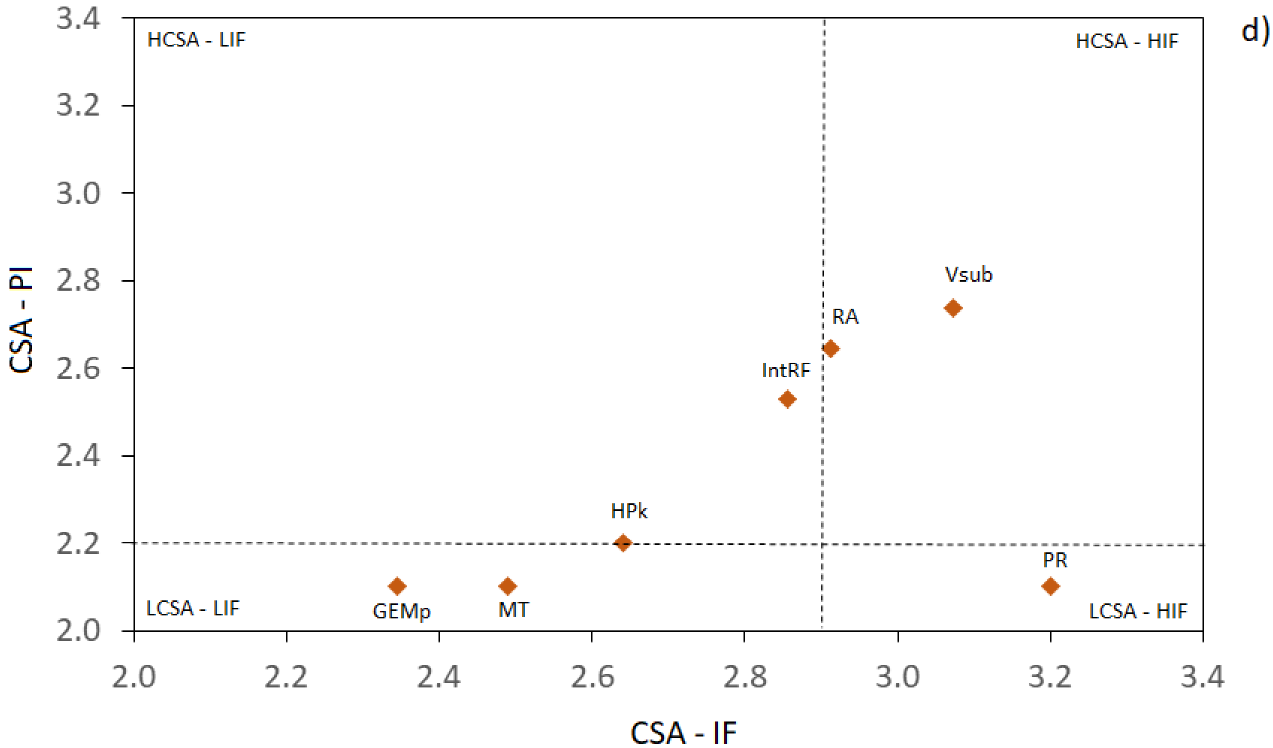


Fig. 3. CSA performance scores and implementation feasibility in a) irrigated lowland, b) rainfed lowland, c) rainfed upland and d) submergence systems.

HCSA – HIF: high CSA performance score and high implementation feasibility; HCSA – LIF: high CSA performance score and low implementation feasibility; LCSA – HIF: low CSA performance indicator and high implementation feasibility and LCSA – LIF: low CSA performance indicator and low implementation feasibility. PacSRI: Integrated rice intensification, biofertilizer, deep urea placement, pest management, and direct-seeding machine; MT: Motorized transplanter; SRI: Sustainable rice intensification; MM: Mowing machine; SI: Solar irrigation; MW: Motorized weeders; IWN: Irrigation based on water need; IntRF: Integrated rice-fish system; GEMp: GEM parboiling system; Vit: Iron toxicity tolerant variety; PR: Perennial rice varieties; HPk: Huskers and parboiling kit; MTh: Mechanical thresher; RA: RiceAdvice; IntRL: Integrated rice-legumes system; IntRV: Integrated rice-vegetables system; Vsub: Submergence tolerant varieties; Sir: Supplemental irrigation; SV: Smart-Valleys; Mul: Mulching; Sd: Seeders; IntRR: Integrated rice-root system; IntRT: Integrated rice–tree system; ASIth: ASI thresher; Vdr: Drought-tolerant varieties

4. Conclusion and perspectives

This study evaluated the performance of technologies, and practices based on their CSA performance indicator (increase in productivity and resilience and reduction in greenhouse gas emission) and their implementation feasibility (technical feasibility, cost, gender inclusivity, and demand by the market) in each of the four rice production systems in Mali. Best bet CSA technologies and practices with high CSA performance indicator and high implementation feasibility score were RiceAdvice, submergence tolerant varieties, integrated rice – vegetable, and mechanical thresher in the irrigated lowland; submergence tolerant varieties, drought-tolerant varieties, RiceAdvice, and ASI thresher in the rainfed lowland; drought-tolerant varieties and RiceAdvice in the rainfed upland, and submergence tolerant varieties and RiceAdvice in the submergence system. Sustainable and inclusive business models can be identified and piloted to bring to scale these technologies with high CSA performance indicators, and high implementation feasibility. Promising technologies and practices with high CSA performance indicator and low implementation feasibility such as the package of integrated rice intensification, biofertilizer, deep urea placement, pest management, and direct-seeding machine, irrigation-based on need assessment, and solar irrigation in the irrigated lowland, integrated rice – tree system, and direct seeder in the rainfed lowland, and integrated rice-fish system in the submergence system will require capacity strengthening of the stakeholders for their implementation and provision of investment for bringing them to scale. Scaling of technologies with low CSA performance indicator even with high implementation feasibility should not be promoted. Further study should ascertain the barriers that farmers face in the adoption of technologies, and practices, incentive mechanisms to promote the CSA technologies, and the suitable socio-ecological niches for efficient and equitable scaling of the technologies.

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Supplementary information

SI Table 1. Potential technologies in irrigated lowlands

Type of technologies	Constraints	Name of technology	Characteristics
Diversification options	Low soil fertility	Integrated rice – fish system	Introduction of fish in rice systems to reduce use of chemical fertilizer and increase soil fertility and income
Diversification options	Water scarcity	Integrated rice – legume	Introduction of legume in rice systems to reduce water use compared to rice - rice systems
Diversification options	Water scarcity	Integrated rice – vegetable	Introduction of vegetable in rice systems to reduce water use compared to rice - rice systems
Diversification options	Water scarcity	Integrated rice – tuber	Introduction of tuber in rice systems to reduce water use compared to rice - rice systems
Diversification options	Water scarcity	Integrated rice – root	Introduction of root in rice systems to reduce water use compared to rice - rice systems
Mechanization	Labour scarcity	Mechanical weeders	Machine for weeding
Mechanization	Labour scarcity	Mechanical seeders	Machine for direct seeding
Mechanization	Labour scarcity	ASI thresher	Machine for harvesting
Nutrient management	Low soil fertility	RiceAdvice	Fertilizer recommendations based on soils, climate, and farmers target yield. It provides appropriate quantity and times of fertilizer application
Nutrient management	Low soil fertility	System of Rice Intensification	Single and wide spacing, young seedling (21 to 28 days old), combination of organic and chemical fertilizer and alternate and drying irrigation
Post-harvest	Low rice quality	GEM parboiler	Improved parboiling technique to increase nutrition content in rice
Varieties	Flooding	NERICA-L19-sub 1 / WITA 4-sub-1	Variety's yield is not affected by flooding
Varieties	Iron toxicity	ARICA 6	Variety's yield is not affected by iron toxicity
Varieties	Labour scarcity	Perennial rice variety	Is harvested at least three times a year without additional planting or sowing
Varieties	Salinity	IR63275-B-1-1-3-3-2 / WAS73-B-B-231-4	Variety's yield is not affected by salinity
Water management	Water scarcity	Alternate wetting and drying	Use of field water tube to monitor water level in rice fields. Irrigate when the crop needs water. It reduces irrigation water amount while maintaining rice yield compared to continuous flooding

Water management	Water scarcity	Solar irrigation	Use of sun's energy to power a pump which supplies water to crops

* Crop calendar construction generates all possible sowing date configurations for a specific crop or crop rotation in order to maximize total yield while avoiding climate-related stresses like drought, flooding, and cold.

SI Table 2. Potential technologies in rainfed lowlands

Type of technology	Constraints	Name of technology	Characteristics
Diversification options	Limited access to agricultural information	Integrated rice – tree system	Introduction of fish in rice systems to reduce use of chemical fertilizer and increase soil fertiliy and income
Diversification options	Low soil fertility	Integrated rice – legume	Introduction of legume in rice systems to improve soil fertility and farmers' income
Diversification options	Low soil fertility	Integrated rice – vegetable	Introduction of vegetable in rice systems to improve soil fertility and farmers' income
Diversification options	Low soil fertility	Integrated rice – tuber	Introduction of tuber in rice systems to improve soil fertility and farmers' income
Diversification options	Low soil fertility	Integrated rice – root	Introduction of root in rice systems to improve soil fertility and farmers' income
Mechanization	Labour scarcity	Mechanical weeders	Machine for weeding
Mechanization	Labour scarcity	Mechanical seeders	Machine for direct seeding
Mechanization	Labour scarcity	ASI thresher	Machine for harvesting
Nutrient management	Low soil fertility	RiceAdvice	Fertilizer recommendations based on soils, climate, and farmers target yield. It provides appropriate quantity and times of fertilizer application
Post-harvest	Low rice quality	GEM parboiler	Improved parboiling technique to increase nutrition content in rice
Varieties	Flooding	NERICA-L19-sub 1 / WITA 4-sub-1	Variety's yield is not affected by flooding
Varieties	Iron toxicity	ARICA 6	Variety's yield is not affected by iron toxicity
Water management	Drought	Smart-Valleys	Low cost and participatory approach for water harvesting to mitigate drought and flooding
Water management	Drought	Supplemental irrigation	Provision of water when rainfall fails to provide sufficient moisture for normal plant growth
Water management	Drought	Mulching	Application of crop residue on soil surface to increase soil moisture

SI Table 3. Potential CSA technologies in rainfed upland

Type of technology	Constraints	Name of technology	Characteristics
Diversification options	Limited access to agricultural information	Integrated rice – tree system	Introduction of fish in rice systems to reduce use of chemical fertilizer and increase soil fertility and income
Mechanization	Labour scarcity	ASI thresher	Machine for harvesting
Post-harvest	Low rice quality	GEM parboiler	Improved parboiling technique to increase nutrition content in rice
Variety	Drought	NERICA 4 / ARICA 4 / ARICA 5	Variety's yield is not affected by drought
Diversification options	Low soil fertility	Integrated rice-vegetable	Introduction of vegetable in rice systems to improve soil fertility and farmers' income
Diversification options	Low soil fertility	Integrated rice-legume	Introduction of legume in rice systems to improve soil fertility and farmers' income

SI Table 4. Potential CSA technologies in submergence rice

Type of technology	Constraints	Name of technology	Characteristics
Post-harvest	Low rice quality	Huskers and parboiling kit	Improved husking and parboiling technique to increase nutrition content in rice
Post-harvest	Low rice quality	GEM parboiler	Improved parboiling technique to increase nutrition content in rice
Varieties	Labour scarcity	Perennial rice variety	Is harvested at least three times a year without additional planting or sowing
Mechanization	Labour scarcity	Motorized transplanter	Reduced labour requirement in tramsplanting
Nutrient management	Low soil fertility	RiceAdvice	Fertilizer recommendations based on soils, climate, and farmers target yield. It provides appropriate quantity and times of fertilizer application
Diversification options	Low soil fertility	Integrated rice – fish system	Introduction of fish in rice systems to reduce use of chemical fertilizer and increase soil fertility and income
Variety	Flooding	NERICA-L19-sub 1 / WITA 4-sub-1	Variety's yield is not affected by flooding