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Response and resilience of Asian agrifood systems to COVID-19: An assessment across twenty-five countries and four regional farming and food systems

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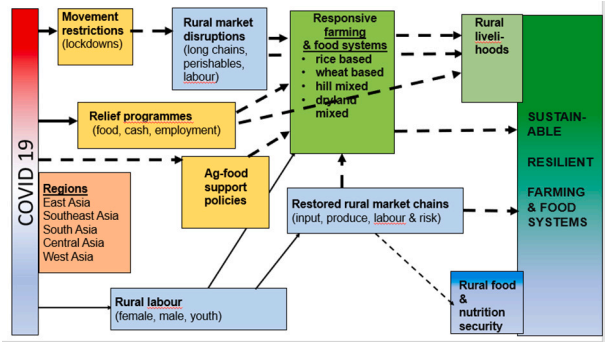
HIGHLIGHTS

- This regional synthesis addresses a major gap in knowledge about the effects of COVID-19 on agriculture and food across Asia
- Key informants from 20 Asian countries assessed early direct and indirect effects on each of four major regional farming and food systems
- The analysis showed Asian farming and food systems were moderately resilient to the pandemic, especially the hill mixed system
- System resilience, food and labour markets, and farm and food chain economic benefits are key priorities for recovery policies and programmes
- This study highlights COVID-19 effects and informs recovery policies and precautionary strategies against future pandemics in Asia and globally

GRAPHICAL ABSTRACT



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ABSTRACT

Context: The COVID-19 pandemic has been affecting health and economies across the world, although the nature of direct and indirect effects on Asian agrifood systems and food security has not yet been well understood.
Objectives: This paper assesses the initial responses of major farming and food systems to COVID-19 in 25 Asian countries, and considers the implications for resilience, food and nutrition security and recovery policies by the governments.
Methods: A conceptual systems model was specified including key pathways linking the direct and indirect effects of COVID-19 to the resilience and performance of the four principal Asian farming and food systems, viz, lowland rice based; irrigated wheat based; hill mixed; and dryland mixed systems. Based on this framework, a systematic survey of 2504 key informants (4% policy makers, 6% researchers or University staff, 6% extension workers, 65% farmers, and 19% others) in 20 Asian countries was conducted and the results assessed and analysed.
Results and conclusion: The principal Asian farming and food systems were moderately resilient to COVID-19, reinforced by government policies in many countries that prioritized food availability and affordability. Rural livelihoods and food security were affected primarily because of disruptions to local labour markets (especially for off-farm work), farm produce markets (notably for perishable foods) and input supply chains (i.e., seeds and fertilisers). The overall effects on system performance were most severe in the irrigated wheat based system and least severe in the hill mixed system, associated in the latter case with greater resilience and diversification and less dependence on external inputs and long market chains. Farming and food systems' resilience and sustainability are critical considerations for recovery policies and programmes, especially in relation to economic performance that initially recovered more slowly than productivity, natural resources status and social capital. Overall, the resilience of Asian farming and food systems was strong because of inherent systems characteristics reinforced by public policies that prioritized staple food production and distribution as well as complementary welfare programmes. With the substantial risks to plant- and animal-sourced food supplies from future zoonoses and the institutional vulnerabilities revealed by COVID-19, efforts to improve resilience should be central to recovery programmes.
Significance: This study was the first Asia-wide systems assessment of the effects of COVID-19 on agriculture and food systems, differentiating the effects of the pandemic across the four principal regional farming and food systems in the region.

1. Introduction

During 2020, the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2; COVID-19) spread rapidly across Asia and the world, affecting health, food and agriculture, livelihoods and economies (di Marco et al., 2020; Laborde et al., 2020). The high level of infectivity of COVID-19 prompted strong public health actions, including restrictions on local, domestic and international movements of people and promotion of good hygiene and social distancing, drawing in part on lessons from earlier viral pandemics (Peeri et al., 2020; CCSA, 2020). Nevertheless, at the end of 2020, serious outbreaks were recurring across Asia and infections were continuing to spread around the globe (Appendix

S1.1).

The pandemic coincided with widespread sustainable development challenges which have intensified over time (Dixon et al., 2001; Beddington et al., 2012; Rockström et al., 2017; Pretty, 2018; ADB, 2020a; FAO, 2020a; Rockström et al., 2020; Otsuka and Fan, 2021). Thus, policy makers expected that COVID-19 would severely reduce productivity and food security, especially of poor rural people (HLPE, 2020a; UNESCAP, 2020). Early estimates indicated that the pandemic could cause a doubling of the severely undernourished population and a surge in extreme poverty (FAO, 2020a; FSIN, 2020; HLPE, 2020b) and major contractions of global and many national economies (World Bank, 2020a). Updated analyses for the Asia and the Pacific region suggest an increase of 89 million of extremely poor and an overall 1% contraction of the regional economy, representing major setbacks for development in Asia (UNESCAP, 2021).

However, relatively little was known about the nature of the effects of COVID-19 on food and agriculture. Hence, the Editors of Agricultural Systems invited rapid assessments of the initial effects of COVID-19 in different continents, including the Asia region (Stephens et al., 2020). As the pandemic spread in Asia, various local surveys and modelling studies had been implemented in some countries in Asia (e.g., Amjath-Babu et al., 2020; Balwinder-Singh Shirsath et al., 2020; FAO, 2020c; FAO, 2020d; FAO, 2020e; FAO, 2020f; Huang, 2020). Nevertheless, a major gap remained in knowledge about the nature and magnitude of COVID-19 effects on agrifood systems at the regional scale in rural Asia; we designed this study to address this gap.

2. Characteristics of farming and food systems in Asia

Of the 3.11 billion ha (bha) of land in Asia, in 2018 approximately 0.59 bha was annually cropped (equivalent to 38% of global cropland), 0.09 bha was under permanent crops, 1.08 bha was grassland and 0.62 bha was forestland (Table S3; FAOSTAT, 2020). Land uses vary greatly between the five sub-regions of Asia (East, Southeast, South, Central and West). Across the region, agriculture supported a rural population of 2.3 b, of whom a high proportion were poor and food insecure; the sector also supplies food to another 1.9 b urban residents (Tables S1, S2; FAOSTAT, 2020). Rice, wheat and maize are the dominant cereals; vegetables, cotton, sugarcane, potatoes, legumes and oilseeds are widely grown as seasonal crops; fruit, tea, rubber, oil palm, coffee, spices and coconut are common perennial crops; and livestock, poultry and fish are also found through much of Asia (Dixon et al., 2001). For the purpose of this assessment, we focused on the farming and rural food systems (FFSs) but did not investigate rural health or urban food distribution and security – in contrast to many agrifood studies (Horton et al., 2016).

Asian agriculture is dominated by smallholder families supporting more than two billion rural livelihoods through the production of diverse mixtures of food and cash produce from annual crops, horticulture, forestry, livestock and aquatic species (FAO, 2020g). Roughly two-thirds of the livelihoods are generated by farm families (inclusive of pastoralists, forest dwellers and fishers) and one-third is created in the associated value chains (Torero, 2020). Typically, Asian farms are managed by households as integrated production-consumption systems within local communal, landscape and institutional settings. Many food system chains are in transition and comprise both traditional and modern technologies and instituti6nal arrangements. Traditional chains generally feature labour-intensive operations linking farm production with towns, cities and international markets. In contrast, modern capital-intensive food system chains often feature large processors, supermarkets and exporters which might account for 20–45% of chains (Reardon et al., 2020).

In Asia, four broad regional FFS zones can be mapped (Fig. 1): lowland rice based (LRB); irrigated wheat based (IWB); hill mixed (HM); and dryland mixed (DM). Each FFS is characterised by contrasting patterns of resource availabilities, production mixes, provisioning services, food marketing arrangements, rural consumption patterns, off-farm income and livelihoods, and development trajectories (Table 1). To illustrate the contrasts between these four FFSs, the LRB FFS contains an average population density of 9.1 persons ha^{-1} cropland, IWB FFS contains 6.2 persons ha^{-1}, HM FFS contains 3.2 persons ha^{-1} and DM FFS contains 0.9 persons ha^{-1} (Table 1). Naturally, within each FFS there is a degree of embedded heterogeneity, such as farm sizes and value chains arrangements (Dixon, 2019).

The LRB FFS zone produces rice and other cereals, pulses, oil crops, vegetables, fruit trees, livestock, aquaculture and artisanal fishing, and is found in deltas, coastal and hinterland areas and some major irrigation schemes in inland plains in all sub-regions. The system contains some major food bowls of the region with well-developed infrastructure,

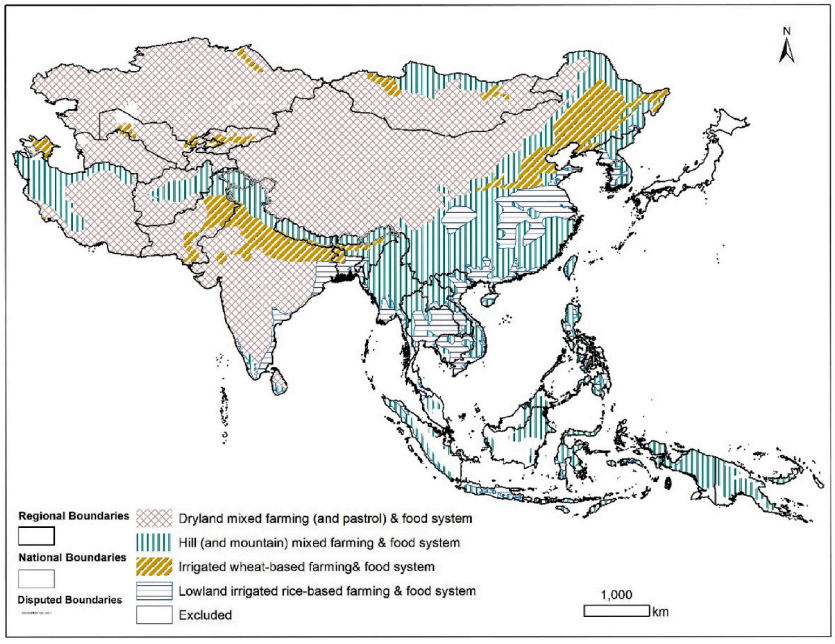

Fig. 1. Map showing four principal farming and food systems in Asia (prepared by IRRI GIS Unit, consolidating and updating Dixon et al. (2001)).

Table 1
Common characteristics of farming and food systems (FFSs) in Asia.

Characteristics	Lowland rice based FFS	Irrigated wheat based FFS	Hill mixed FFS	Dryland mixed FFS
Land area (Mha), population density (persons ha^{-1}, in brackets)	0.255 (2.5)	0.299 (1.2)	0.775 (0.8)	1.271 (0.2)
Crop area (Mha), population density (persons ha^{-1}, in brackets)	0.069 (9.1)	0.061 (6.2)	0.199 (3.2)	0.215 (0.9)
Road density (km Mha^{-1})	1.07	0.82	0.67	0.76
Nature of food system chains	Close to cities; short complex chains, mixed traditional and modern	Medium distance from cities; medium length modernizing value chains, some modern cold chains for perishables	Distant from cities; medium-long value chains, predominantly traditional	Distant from consumption areas; often long traditional value chains
Common foods consumed and diet diversity	Rice, legumes, maize, vegetables, fish, meat, milk, eggs (high diet diversity)	Wheat, rice, pulses, vegetables, meat, milk, eggs (medium diet diversity)	Wheat, rice, barley, buckwheat, maize, millet, pulses, fruit, vegetables, meat, milk, eggs (high diet diversity	Sorghum, millet, wheat, barley, pulses, meat, milk (low to medium diet diversity)
Main livelihoods	Food crops (rice, legumes, maize, vegetables), cash crops, aquaculture, livestock, off-farm income	Food crops (wheat, rice, legumes, oilseeds, vegetables), cash crops (cotton, forages), livestock, off-farm income	Food crops (wheat, rice, barley, buckwheat, maize, millet, horticulture), agroforestry, livestock, off-farm income	Food crops (sorghum, millet, wheat barley, pulses), cotton, extensive livestock, off-farm income
Main vulnerabilities (ecological, climatic and economic)	Flood, typhoons, salinity, drought, pests, diseases, labour supply, markets, climate change	Irrigation water supply, climate (extremes in temperature, rainfall), pests, diseases, labour supply, markets	Drought, soil erosion, landslides, land degradation, market volatility, climate change	Drought, heat waves, land degradation, market volatility

Notes. Author estimates supported by land and population estimates prepared by IRRI GIS Unit, consolidating and updating Dixon et al. (2001); the four FFS contain more than 80% of total regional area, cropland and rural population.

e.g., a road density of 1.07 km Mha^{-1}, and often short complex supply chains to major cities, especially for perishable vegetable, livestock and aquatic food products.

The IWB FFS zone differs in structure and function from the LRB FFS, and features wheat, pulses, oil crops, cotton, vegetables, fruit trees and livestock – including perishables such as fresh vegetables and milk. The system is located in inland irrigated plains in four of the five sub-regions, and underpins important Asian food bowls, especially where wheat is combined with rice. The degree of mechanisation is greater than for other FFSs, and the system features a mix of modernizing and traditional input and food system chains.

The HM FFS zone is located in the low to high altitude hills and mountains, spans tropical to cool temperate climates and produces a variety of staples depending on altitude, as well as pulses, oil crops, vegetables, forest products and livestock. The system is predominantly rainfed often supplemented by limited irrigation in valleys, suffers a high level of poverty, has limited infrastructure, e.g., a road density of 0.67 km Mha^{-1}, and contains some important specialised value chains for cash crops (e.g., vegetable seeds), horticultural and livestock products.

The DM FFS occurs in tropical, sub-tropical and temperate semi-arid and arid areas across four of the five sub-regions, excluding high altitude mountains and plateaux within the HM FFS. The system features mixed rainfed crops and often extensive grazing of livestock, interspersed with irrigated grain and forage cropping niches (large-scale schemes are included in the LRB or IWB FFS), and suffers from a high level of poverty and relatively poorly developed infrastructure. The system is challenged by high climatic variability and frequent droughts. Many of the input and produce market chains long distance and traditional.

Further characteristics of the four FFS appear in Table 1.

3. Approach to assessment

3.1. Conceptual framework to assess the effects of COVID-19 on FFS

The COVID-19 shock to FFS was the most recent of a plethora of diverse shocks to agrifood systems during recent decades (Berchoux et al., 2019; Dixon et al., 2020a; Lioutas and Charatsari, 2021). Approximately 84% of people affected by disasters during 2000–2018 lived in Asia, for which weather is the predominant cause (ADB (Asian Development Bank), 2019). In contrast to the sudden onset and long duration of the COVID-19 pandemic, agricultural shocks from drought generally have a slow onset and directly affect plant and animal productivity and livelihoods (Amare et al., 2018). As with COVID-19, the indirect effects can extend for many years. However, many plant diseases and pests, e.g., wheat rust and locusts respectfully, have sudden onset and can be catastrophic. Generally, public health measures to contain pandemics such as COVID-19 affect both farming and food systems, largely indirectly. Agricultural production policies and welfare policies such as cash payments and food distribution have more direct effects. The resilience of each FFS influences the degree of disturbance and the speed of recovery (Perrings, 2006; Folke, 2016; Meuwissen et al., 2019).

National and regional governments, local communities, health and educational systems, businesses and families are confronted with many difficult decisions for coping with the pandemic. To understand the short- and medium-term effects of COVID-19 on FFS, we conceptualised a system framework (Fig. 2). The interdependence embedded in this systems framework is essential for understanding the linkages between health measures, policies, markets, FFS and food and nutrition security, and identifying appropriate recovery programmes (di Marco et al., 2020). Direct effects of COVID-19 on labour, markets and policies elements and their different indirect effects on each FFS are expected to affect, in turn, rural food security and FFS resilience.

The elements presented in the conceptual framework (Fig. 2) and their effects on the four FFSs were studied using primary and secondary information supplemented by national reports and databases.

4. Methods

4.1. Study sub-regions and countries

This analysis covers five Asian sub-regions: East, Southeast, South, Central and West. Twenty-five countries were selected, excluding countries with fewer than 2 million inhabitants (see Tables S1, S2 and S3 for key agricultural and food statistics for these countries): East Asia

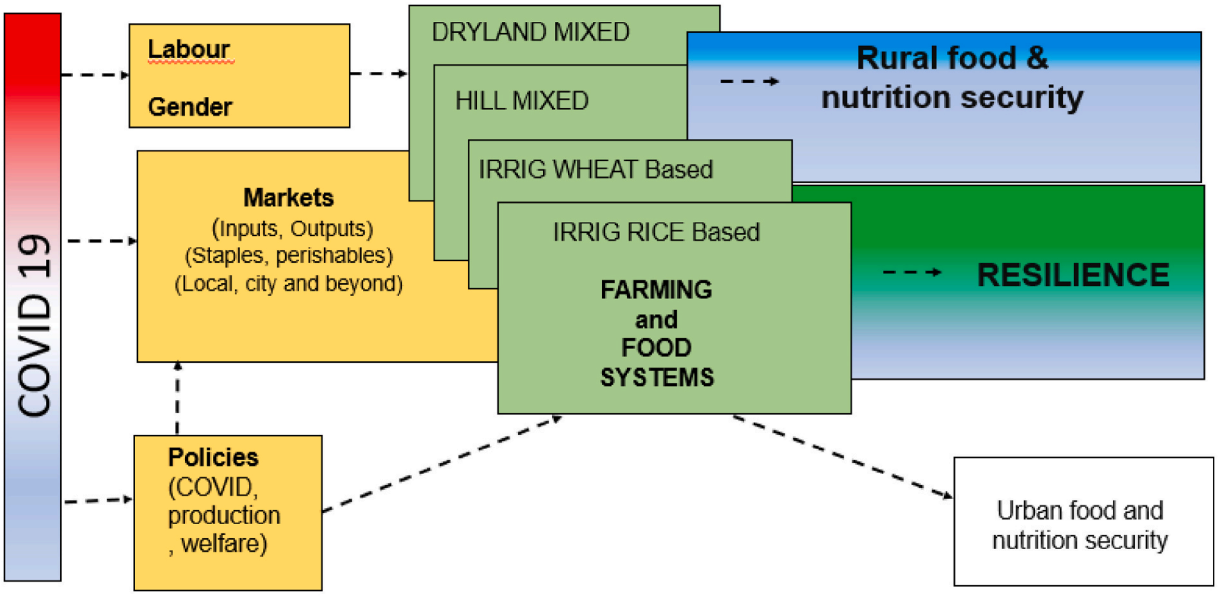

Fig. 2. Systems framework for COVID-19 effects on farming and food systems (dashed lines and overlapping components represent major direct and indirect pathways for COVID-19 effects investigated in this research).

(China, Japan, Mongolia and South Korea); Southeast Asia (Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Thailand and Vietnam); South Asia (Bangladesh, India, Nepal, Pakistan and Sri Lanka); Central Asia (Azerbaijan, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan); and West Asia (Afghanistan and Iran).

4.2. Farming and food systems

The four FFSs cover most of rural Asia (Fig. 1, Table 1). Many farm families depend on their own production for a major part of their diets (Rawe et al., 2019), supplemented by locally produced foods from local markets. Landless workers obtain a major part of their diets from these local markets.

The conceptual model characterizes the pathways and drivers influencing the different effects on each FFS and potentially food and nutrition security (FNS) and system resilience (Fig. 2). The systems model for this study was developed by a core group of authors. In the model, local food and labour markets were linked to FNS outcomes for rural farm- and non-farm-households (in contrast to urban residents who depend on food supply chains from farms). Productivity, natural resource, economic, human and social aspects of resilience were considered for each FFS. Naturally, interdependencies and feedback loops were expected to be important and common (di Marco et al., 2020). Direct effects of COVID-19 could include reduced availability of labour for farm operations and policies to limit community spread of the virus, protect vulnerable populations and stimulate agriculture (Mandal et al., 2020; Stephens et al., 2020). Indirect effects of COVID-19 on FFSs were expected from labour migration following job losses, disrupted markets caused by movement restrictions, improved disposable income of farm households from welfare programmes (Amjath-Babu et al., 2020) and policy and programme support for farm production and marketing. Labour and gender themes were considered to be closely related, and market and policy effects were expected to be strongly interdependent. These four elements could influence FFS performance, sustainability and resilience (FAO, 2020a). These connections and interdependencies informed the design of information acquisition, analysis and presentation of results in this paper.

4.3. Information acquisition and analysis

Following the framing of the Agricultural Systems Special Issue Editorial (Stephens et al., 2020), region-wide information collection was organized on a country-by-country basis from key informants, interviews, local surveys and focus group discussions (FGDs) coordinated by country focal points, supported by grey literature and published reports. Based on the conceptual systems model, the core group of authors developed three rounds of questionnaires, informed by theory and practice of farming systems (Dixon et al., 2001; Dixon, 2019), food markets and policy (Devereux et al., 2020; Qureshi et al., 2015), resilience (Meuwissen et al., 2019; Musumba et al., 2017) and sustainable development (Pretty, 2018). The three rounds of questionnaires focused on: the short-term effects of COVID-19; the timelines of the pandemic and policy responses; and probable medium-term effects and implications for recovery. Approximately half the questions were scoring assessments of FFS vulnerability and the relative severity of COVID-19 effects using Likert scales – generally on a 0–5 scale. Likert scales are popular for social science assessments, for example, for food security by USAID (Coates et al., 2007) and FAO (Cafiero et al., 2018), and for SDG awareness (Manolis and Manoli, 2021). Some questions focused on the degree of recovery as a percentage of pre-COVID system performance, and others on estimated number of months for full recovery, for example of input markets. The remaining questionnaire content comprised closed and open-ended questions on drivers of, pathways to and implications of, COVID-19 effects, supplemented by listings of local reports, studies, media accounts and databases (Appendix S2).

Twenty of the 25 study countries were selected for the collection of key informants' assessments based on relevance to the study themes and the availability of suitable country focal points (Table 2; Table S6). FFSs were purposively sampled across the 20 countries, omitting countries with a small area of any particular FFS: consequently, the LRB, IWB, HM and DM systems were investigated in 15, 9, 13 and 8 countries, respectively (Table 2). Within each selected FFS-country pair, two representative focal areas (often Provinces, States or Districts) were purposively selected (Table S6) subject to the availability of key informants and relevant information on COVID-19 effects.

Three rounds of questionnaires were administered by country focal points in the 20 countries sourcing information from key informants, local reports and databases during June, July, and August 2020. Key

Table 2
Selected farming and food systems by country, and number of informants.

Country	Lowland rice based FFS	Irrigated wheat based FFS	Hill mixed FFS	Dryland mixed FFS
Afghanistan		Y	Y	Y
Bangladesh	Y			
Cambodia	Y			
China	Y	Y	Y	Y
India	Y	Y	Y	Y
Indonesia	Y		Y	
Japan	Y			
Kazakhstan		Y		Y
Kyrgyzstan	Y	Y	Y	Y
Laos	Y		Y	
Malaysia	Y		Y	
Myanmar	Y		Y	Y
Nepal		Y	Y	
Pakistan	Y	Y	Y	Y
Philippines	Y		Y	
Sri Lanka	Y		Y	
Tajikistan		Y		Y
Thailand	Y		Y	
Uzbekistan		Y		
Vietnam	Y			
Sample number of FFS locations	15	9	13	8
Number of informants	1409	397	310	366

(Y identifies the FFS in which questionnaires were applied by study country. Additional information is available in Table S6. Number of informants is based on reports from 17 of the 20 surveyed countries).

informants included researchers, university staff, government officials, NGOs personnel, extension staff, farmers, agricultural company managers and traders; and in addition, information was drawn from ongoing or specially commissioned farm surveys. Country focal points acquired information from 2504 informants in total, of whom 4% were policy makers, 12% were researchers or extension agents, 65% were farmers, and 19% others (Table 2; Table S6). The questionnaires completed, including the consolidation of key informants' assessments, by experienced senior country focal points with good knowledge of the selected FFS and the effects of COVID-19 (Crandall et al., 2018): generally, one focal point was identified in each country, except for China and India in which three country focal points were identified in each country to ensure expert coverage of the diverse agriculture and food conditions.

FFS characteristic and COVID-19 effect scores were compiled in Excel and responses were tabulated. Given the purposive sampling and use of key informants to acquire field assessments, we present the results of the Likert-type data on FFS characteristics and COVID-19 effects using frequencies, bar-charts and radar charts based on medians (Boone and Boone, 2012; Tastle and Wierman, 2006). In the case of quantitative data points or composite indicators constructed during analysis, means and ratios were reported instead of medians (Allen and Seaman, 2007; Boone and Boone, 2012). The interpretation of results was led by the core group who designed the study.

5. Results

The following sub-sections summarise the reported COVID-19 infection caseloads, key effects on each of the four FFSs, and comparisons across FFSs, supported by details in the Supplementary Materials.

5.1. Farming and food systems caseloads

Since the first reported case of COVID-19 in Wuhan, China during December 2019, the cumulative number of reported cases increased to 84 million globally and 15 million in the Asian study countries by 31st December 2020 (Table 3); and the reported mortality was 1.82 million globally compared with 277 thousand in the Asian study countries. The rates of reported infections and deaths per million population in Asia were 3557 and 64 respectively, less than one-third of the equivalent global rates. South Asia (especially India and Nepal) and Central-West Asia (most countries) exceeded the Asia regional average level of infection (Table 3; Table S4). Asia suffered from repeated waves of infection during 2020. In fact, nearly half of the study countries reported peak daily cases (7-day averaged per million population) during the last quarter of the year, viz, during October (Myanmar and Nepal), November (Laos and Mongolia) and December (8 countries; Azerbaijan, Indonesia, Iran, Japan, Malaysia, South Korea, Sri Lanka and Thailand; Table S4, Fig. S1).

Table 3
Reported caseloads and mortality in the 25 study Asian countries by sub-region.

Sub-region	Cumulative cases 2020 – M (per M population)	Cumulative mortality – thousands (per M population)
East Asia	0.4 (244)	8.9 (6)
South-East Asia	1.5 (2215)	34.6 (52)
South Asia	11.6 (6369)	168.5 (93)
Central and West Asia	1.9 (9276)	64.9 (322)
Asian study countries	15.3 (3557)	277.0 (64)
World	83.5 (10,711)	1818.3 (233)

Source: Johns Hopkins University (2021), University of Oxford (2021), effective 31 December 2020. See details in Table S4 and Appendix S1.

The morbidity and mortality due to COVID-19 directly affected the labour supply and productivity in food production and distribution. In addition, the public measures to control the pandemic led to many indirect effects on FFSs, for example, through labour migration, limitations on fieldwork and breakdown of input and produce marketing chains. Other indirect effects arose from COVID-19-related public policies for production support, food distribution and welfare payments, as well as adjustments to management decision by farm families and value chain enterprises. These direct and indirect effects were particularly evident during the initial wave of infections and policy responses.

5.2. Effects of COVID-19 on farming and food system

5.2.1. Lowland rice based farming and food system

The circumstances of the LRB FFS prior to the pandemic influenced the nature and magnitude of the effects of COVID-19 on the system. Prior to the pandemic, the LRB FFS was considered critical to national food self-sufficiency in most countries (Fig. S2; median score 3.5[1]). In this FFS, on-farm diversification and supply of fruits, vegetables, animal products and fish to cities were common (3.0), many farms provided food grains to the cities, and many families received off-farm income. The laborious nature of LRB operations incurred some labour shortages, and male labour shortages were common. This populous system benefited from relatively effective infrastructure, market chains and food policies, notably minimum support prices and public food grain stocks (3.0; Fig. S8), which contributed to the resilience of the FFS prior to the pandemic.

As COVID-19 struck the LRB FFS, Governments responded initially with movement restrictions including lockdowns, and relief programmes including food distribution, social protection and market support programmes were significant (2.0–3.0) for the LRB system (Fig. S6). The effects increased slightly from March to April (around 2.0), then declined slowly in ensuing months even though the COVID-19 caseload increased, because of adjustments by LRB farm families and market chain operators, and expansion of public agricultural support

[1] Median scores in the range from none (score 0), medium/common (score 3.0) to very severe/intense (score 5.0).

and social protection programmes. In relation to the lockdowns to control the spread of the pandemic, the overall effect on LRB system input markets was moderate (2.5; Fig. 3), although the effects on individual inputs varied (Fig. S7). LRB system produce marketing channels were moderately disrupted (close to 3) and affected prices (Figs. 3, 8; Amjath-Babu et al., 2020). In practice, the widespread disruptions of harvesting and marketing of perishables, e.g., aquaculture, horticulture, and reduced produce prices (3.0) was greater than for food grain delivery to cities (2.0; Fig. 8). These market and price effects combined to reduce farm incomes. Among the range of COVID-19-related policies and regulations, the LRB system was moderately affected, negatively, by movement restrictions and urban-rural migration, but benefited from market support and social protection programmes (Fig. 9). LRB production, marketing and food security benefited particularly from input subsidies, irrigation and mechanisation (Fig. S10).

In general, the LRB system experienced a limited to moderate influx of returnees from cities and internationally, in part because of proximity to large cities. The returnees placed additional pressure on rural food systems but had a minimal effect (1.0) on reduction in labour scarcity. Movement restrictions affected male labourers more than female workers. There was moderate (2.5, Fig. 3) gender disruption in the LRB system, mainly for women farm and off-farm work, income, food and economic security, engagement in LRB value chain (wage worker, entrepreneurs, traders, etc.) and workload in the household.

Overall, the effects of COVID-19 on LRB FFS were moderate disruptions in supply and produce chains, labour and gender equity. Moderate effects on food and nutrition security (availability, access and utilisation) in the medium- to long-term (2.5–3.0; Fig. 11) were expected. The magnitude of the effects was moderated by a degree of resilience of the LRB FFS, partly because of pre-COVID-19 enabling policy settings which reduced vulnerability, for example minimum support prices, food grain stocks, social protection and credit provision (Kumar et al., 2020). The recovery of the LRB system to the pre-COVID-19 status was rated 74% by August 2020, when averaged across five sustainability domains (productivity, economic, natural resources, food security and social capital). The pandemic was also expected to reduce moderately the long-term sustainability of the LRB FFS (although more severe for natural resources; Fig. 12).

5.2.2. *Irrigated wheat based farming and food system*

The relatively well-developed IWB FFS is a major source of food calories and protein with significant levels of market access, input use, mechanisation and productivity. Prior to the pandemic, very many farm households were self-sufficient in basic foods (4.0), and on-farm diversification and off-farm income were common (3.0; Fig. S3). Many farms produced surplus food grains for feeding cities (4.0), and the supply of fruit, vegetables, animal and aquatic-sourced foodstuffs to cities was common (3.0). Neither male nor female labour was particularly scarce (2.0). Moreover, a diverse set of agricultural policies supported the resilience of the FFS to the external shocks (2.5).

The effects of movement restrictions on IWB FFS were most severe during March and April 2020 (2.5; Fig. 7) wherein household income was badly affected. Food self-sufficiency and food grain supply from the IWB FFS were affected in the South and Central Asian parts of the FFS, although less so in East Asia. Given that the IWB system zone contains many megacities, there was very substantial labour influx from cities to the IWB system areas (4.0). The movement restrictions had only moderate effects on labour (2.5; Fig. 4) and input marketing channels (2.5) since many governments facilitated access to seed and fertilisers for food grain production (e.g., Bangladesh, China and India). Both local markets and market chains for perishables, e.g., milk, vegetables, were severely disrupted (4.0; Fig. 8) in the early stages of the pandemic, whereas disruption of food grain markets was minor (1.0).

COVID-19-related policies affected the IWB FFS directly, notably food distribution and welfare payments, as well as indirectly, for example labour migration and movement restrictions. Many national governments declared farming and food distribution, especially of staples including wheat, as essential services. As a result, disruptions of wheat and pulse grain markets were minor (1.0; Fig. 4). In general, pre-COVID-19 agricultural policies played a modest role in reducing the vulnerability of the IWB FFS to the pandemic (2.5; Fig. S3). In particular, food grain stock policies were important, and also machinery services, fertilizer subsidies and minimum support prices. In relation to COVID-19-induced policies affecting the IWB system, those related to urban-rural migration and to non-wheat markets had very strong effect (4.0; Fig. 9). The most effective COVID-19-related policies implemented in the IWB system were welfare and poverty alleviation programmes, notably in China, India, Nepal, Pakistan and Uzbekistan (Fig. S9).

The overall effect of the pandemic on gender dynamics in the IWB system was medium (approx. 3.0; Fig. 4) on many aspects, including farm and post-harvest work, income and economic security, livelihoods and food security, off-farm wage work, entrepreneurial activities and household chores (Fig. S11). Women's economic security was the most severely affected (3.5), and their involvement in farm activities was least affected (2.0). There was a moderate increase in women's workload in the home because of home-schooling of children and the enlarged household as members returned from cities or internationally.

There were interactions between some FFS characteristics, e.g., small farm size, cropping intensity, high on-farm diversification and support prices, which influenced the magnitude of the effects of the pandemic. The interaction between mechanisation, input subsidies and market function in the IWB FFS affected its resilience, productivity and sustainability. Wheat harvesting and marketing were delayed to varying degrees across South Asia because of skilled labour shortages. This delay

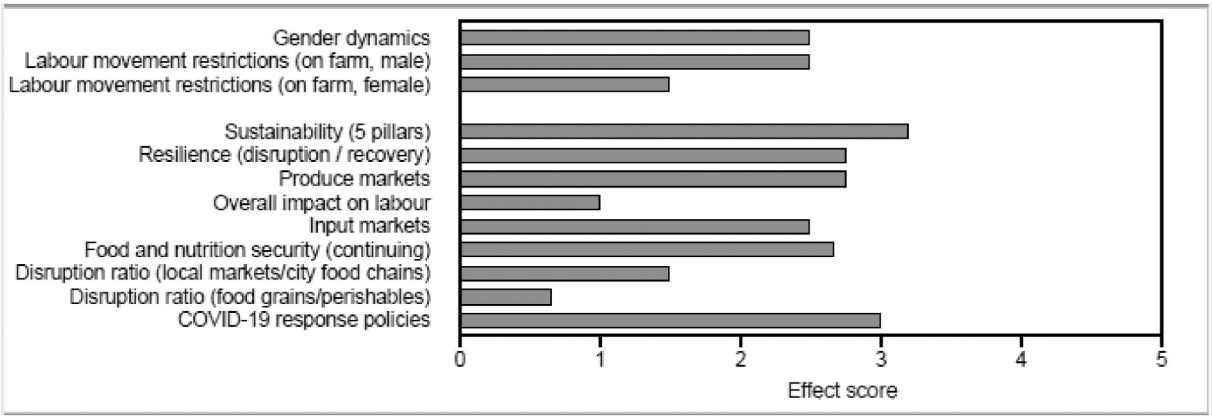

Fig. 3. Selected effects on LRB farming and food system (effect median scores: 0 none, 5 very severe/many).

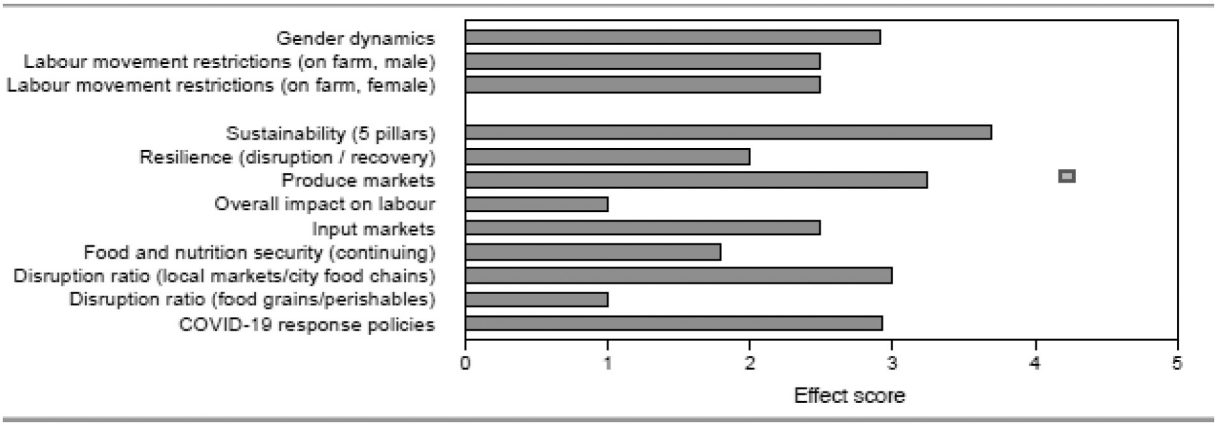

Fig. 4. Selected effects on IWB farming and food system (scores: 0 none, 5 very severe/many).

caused later planting of subsequent rotation crops, especially cotton and rice in South Asia and cotton in Central Asia. The prevalence of mechanised harvesting partially alleviated the problem. Overall, food and nutrition security was slightly affected, especially access and utilisation (3.0; Fig. 11) and the medium- to long-term sustainability of the IWB FFS was severely affected (close to 4.0; Fig. 4).

5.2.3. *Hill mixed farming and food system*

The HM FFS is quite heterogeneous, with variations in altitude, topography, land use and food market chains both locally and across Asia. Some hill areas are moderately well connected to markets, especially in East and South-East Asia, whereas others still practice shifting cultivation and are most dependent on natural resources and forests, e.g., *jhum* shifting cultivators farming at high altitudes in South Asia. Before the pandemic, food-self-sufficiency – based on rice, maize, millets, vegetables and animal products - was moderate (3.0, Fig. S4). Many farms were quite diversified (4.0), and off-farm income was also common (3.0). While the HM FFS was a common source of fruit and vegetables to cities (3.0), the system was only a limited source of food grain, animal, or aquatic sourced food for cities. In practice, local markets also played a major role. Typically, agricultural policies had a minor effect on system vulnerability (1.0; Fig. S8), except for food grain stocks.

The initial relief programmes from Government after COVID-19 struck were moderately effective, especially supports to planting, harvesting and marketing, input distribution and social protection (3.0; Fig. S6). Though in general the overall input market disruptions from the pandemic were minimal across the HM FFS (less than 1.0; Fig. 4, Fig. S7), there were some exceptions due to use of low input levels. In pockets of higher-input horticultural or animal production, significant disruptions were observed in some specialised input markets, e.g., supplies of planting materials, agrochemicals, veterinary items, day-old chicks, fish fingerlings and animal feed. Not surprisingly, the least disruption occurred with food grain seed availability.

The HM system experienced major wastes of perishable vegetables and spices, notably ginger and turmeric, in the early stages of the pandemic due to the movement restrictions. The restrictions, and labour shortages, also delayed planting of maize, turmeric and other crops. The recovery of perishables marketing chains to cities was expected to take, on average, about 4.5 months. Partly because of the contraction in the poultry industry, feed maize production in the lower and mid-hills of the HM FFS suffered reduced prices. Some parts of the HM system that grew export commodities such as rubber and flowers were seriously affected by the collapse of demand associated with the global economic slowdown, e.g., starch quality and export prices for Cambodian cassava.

Overall, the COVID-related policies generally had a limited effect on the HM FFS (2.0; Fig. 9), in part because of low market access and policy reach. However, there were benefits from social protection and employment generation programmes.

The effect of influx of labour on the HM system was quite limited from cities (1.0) and international returnees (1.0) except for Nepal and Pakistan (3.0 for cities, 2.0 for international returnees). The greatest effect of the pandemic in the HM system was on the post-harvest activity resulting from limited movement of male farmers. Effects on women ranged from very limited to limited in the HM system. Women's involvements in trading, wage work, and entrepreneurship were the least affected.

Region-wide, the effects of the pandemic on food security in the HM FFS were generally common (2.5–3.0; Fig. 12). The collapse of off-farm work in urban areas and abroad seriously affected livelihoods and thus household food security. Many areas have vulnerable populations, often ethnic minorities, with extensive poverty and malnutrition, for whom even a slight disruption of their livelihood systems can potentially have severe repercussions. Across the whole HM system, however, the effect of COVID-19 on resilience of the FFS was moderate (2.5; Fig. 5), in large part because of the high level of self-reliance and substantial dependence on local food markets. Overall, the substantial loss of farm household income and uncertainties with international and domestic markets led to a reluctance to invest in farm inputs. Nevertheless, over the medium to long term the assessment indicated a modest to good sustainability (3.5–4.0; Fig. 12), when averaged across the HM FFSs and the five pillars of sustainability.

5.2.4. *Dryland mixed farming and food system*

The DM FFS is characterised by strong crop and livestock components. The resilience and sustainability of the system during the pandemic were strongly linked to the pre-pandemic characteristics of the DM FFS, including agricultural policy settings (Fig. S5). The lack of food self-sufficiency was a considerable challenge for the DM system even before the crisis. Farmers were highly dependent on off-farm income and remittances, making the DM FFS very vulnerable to disruptions to markets and off-farm employment opportunities, i.e., pre-pandemic food self-sufficiency was limited (2.0).

The pandemic-induced lockdowns in the DM system resulted in lack of transport, market restrictions, labour shortages, inadequate supply of quality farm inputs, opportunistic behaviour of food system intermediaries seeking high margins, and restrictions on international trade. However, the overall effects on crop production in the DM system were limited. In contrast, harvest and post-harvest activities of fruits, vegetables, flowers and other perishable commodities were significantly affected (3.0; Fig. 6), mainly due to the shortage of labour and transport, aggravated by the contraction of market demand. Similarly, many smallholder producers could not sell their milk and aquaculture produce. Maize markets in the DM FFS was particularly affected in some countries by the collapse of demand for poultry feed. For example, in

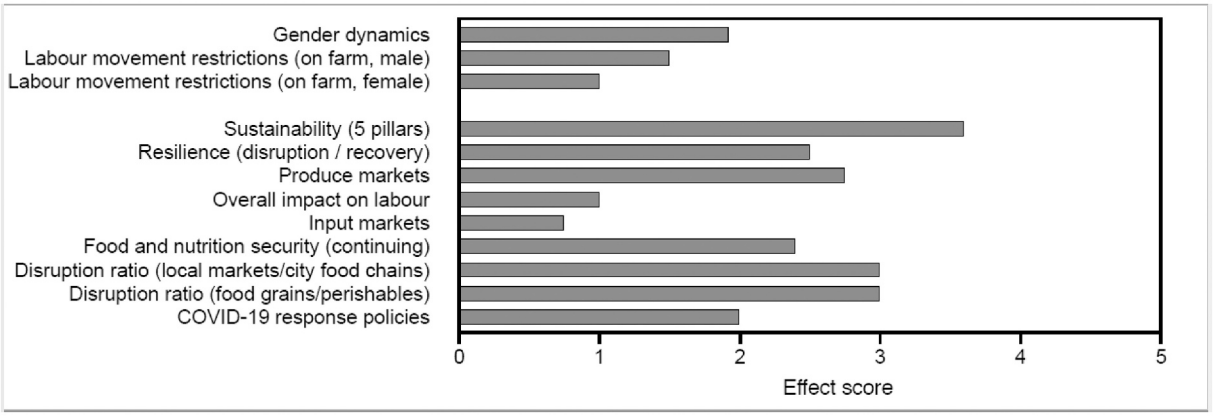

Fig. 5. Selected effects on HM farming and food system (scores: 0 none, 5 very severe/many).

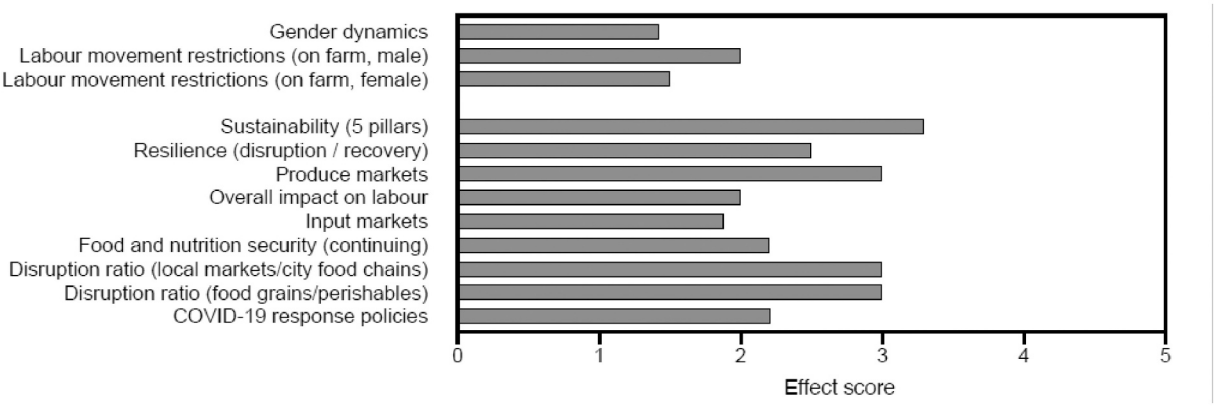

Fig. 6. Selected effects on DM farming and food system (scores: 0 none, 5 very severe/many).

India, poultry consumption had initially declined largely due to fear of its association with COVID-19, and thus the demand for poultry feed and maize grain collapsed. Nevertheless, the adverse effect of the pandemic on input markets was comparatively low (approx. 2.0) and the recovery was relatively quick, particularly in Central Asia.

Off-farm and non-farm earnings and remittances, which constituted about half of DM system farm household income, were severely affected. This significantly affected the food and livelihood security of farm families – for example, there was loss of remittances of up to 25% in Kyrgyzstan and Tajikistan. Prior to the pandemic, off-farm income was a common feature of the DM FFS (Fig. S5).

The governments were more proactive in easing out food supplies as it was the major harvest season in many countries and directly linked to the immediate food security of people. Market recovery took much longer-time in Central Asia, particularly in Kyrgyzstan.

The effect of labour influx from cities and internationally in the DM system was limited (1.5 and 2.0, respectively; Fig. 10) and it had very limited effect on the reduction of labour scarcity in the rural areas for both males (1.0) and females (none). The effects on rural wage rates in the short run were marginal, and there were few reports of changes in wage rates for men or women, or reductions in female labour opportunities, following the influx of workers. While there were limited overall labour effects in the DM FFS, post-harvest activities were affected to a limited degree by restricted male and female labour movement (2.5 and 1.5, respectively). The effects of the pandemic on women's farm work in the DM FFS were generally very limited, although there was a moderate increase in women's household workload.

The sustainability and resilience characteristics of households, consisting of agricultural productivity, economic, social, environmental and human condition, were moderately to strongly affected under the DM system. The perception of key informants was that most domains of the DM FFS would recover well (about 76%) by December 2020. The economic and social dimensions of the farming systems which generally are strongly influenced by rural-urban linkages, employment access and social security policies may take more time to fully bounce back. The limited to moderate on-farm diversification (2.5) helped farm households recover and sustain during the pandemic. Two other key characteristics, namely, common dependence on off-farm income (4.0) and limited supplies of foodgrain to cities (2.0), increased the vulnerability to COVID-19 disruptions but were also the key drivers of recovery and sustainability as the movement restrictions eased.

Food grain reserve stocks and social protection were key pre-pandemic policies that helped improve vulnerability of the DM system (Fig. S8). Reinforcements of social protection, cash transfer and subsidised food grains were noteworthy COVID-19-induced mitigating policies that were critical and effective in buffering livelihoods.

5.3. *Comparative effects of COVID-19 across farming and food systems*

5.3.1. *Timeline of effects across farming and food systems*

To control COVID-19, Asian Governments initiated air and land border closures and local lockdowns as initial waves of infection struck (Fig. S1; Table S4). FFS operations were generally considered essential and were soon exempted from some movement restrictions in most countries; consequently, disruptions to food supplies were minimized in most Asian countries. As spread of the virus was initially controlled, movement restrictions were eased and FFS rapidly regained substantial functionality until numerous secondary outbreaks and repeat waves of

infections led to further restrictions. Almost half of the study countries experienced secondary waves with the highest intensity of infection during the last quarter of 2020. This study focused on the nature and magnitude of disruptions across the four FFSs during the first half of 2020, considering crop, livestock and marketing calendars, farming practices and labour management. Considering all FFSs and the entire region, disruptions were most severe in April but diminished by June (Fig. 7A). By April, the HM FFS was the least affected followed by the LRB FFS, yet the Malaysian and Nepalese HM FFSs experienced particularly severe effects (data not shown). The DM and IWB FFSs were significantly affected whilst the LRB FFS was least affected. In relation to average effects on farming families across the four FFSs for the March to June period (Fig. 7B), household income was moderately affected, while there were limited effects on crop and livestock operations. The adverse effects on food and nutrition security were largely due to loss of off-farm income. Of the various crop and livestock operations, marketing was severely affected, especially in April. Overall, wheat and boro rice harvests and marketing that peaked during April and May were more affected than the establishment of monsoon rice. In case of livestock and aquaculture, disruptions in marketing were greater than those for crops. In general, perishables (vegetables, fruits, milk, poultry, fish and other aquatic products) were affected seriously because of food system disruptions in market supply chains and storage.

5.3.2. *Market and policy effects across farming and food systems*

The primary indirect effect of COVID-19 on the FFSs arose from movement restrictions disrupting input and output value chains. However, since many national governments declared food and agriculture as essential services, the initial disruptions of food grain markets generally reduced over the ensuing months as support programmes became more effective, and FFS adjusted systems and operations. This sub-section compares the reported effects in different FFSs of particular market arrangements and policies (see further details in Appendix S1.5).

In general, input market disruption across the region was least in the HM FFS, followed by the LRB and DM FFSs, and despite the government support it was most severe in the IWB FFS (Fig. S7). The HM and DM FFSs had limited demand for external inputs. However, both these systems had pocket areas practicing higher-input production, e.g., vegetables in the HM FFS in Malaysia, where input marketing channels were disrupted.

In general, the disruption of output markets varies between the FFSs (Fig. 8). The effects on perishable distribution chains were severe in HM FFS (4) and medium across the other three FFSs (Fig. 8). Food grain markets were the least affected particularly in the LRB and HM FFSs. The effects of reduction of producer prices were common across all FFSs. Local markets disruption was severe in the IWB FFS, common in the LRB and DM FFSs, but only limited for the HM FFS.

In general, pre-pandemic food and agricultural policies played a modest role in reducing the vulnerability of the four FFSs to COVID-19 disruptions (Fig. S8). Among the reported policies, food grain stocks were the most effective, most especially for the DM FFS. Overall, pre-pandemic policies reduced the vulnerability of the irrigated, more intensive, FFSs, i.e., IWB and LRB, compared with the lower-input HM and DM FFSs, particularly machinery services, fertilizer subsidies and minimum support prices. Comparing LRB and IWB FFSs, the LRB FFS benefited more from grain support prices whereas machinery subsidies favoured the IWB FFS. Key COVID-19 policies implemented during the pandemic provided the greatest benefit to IWB FFS and the least benefit to the HM FFS (Fig. 9).

Support policies that were reported as particularly effective included mechanisation for LRB FFS (notably East Asia) and IWB FFS (notably South Asia), irrigation for LRB FFS (notably Southeast Asia), credit for HM FFS (notably East Asia), livestock production for DM FFS (notably South Asia), and food safety for DM FFS (notably Central Asia) (Fig. S10). There were also another set of welfare policies and programmes implemented during COVID-19 which tended to have broader effectiveness across FFSs and strengthened livelihoods and purchasing power. Welfare policies which were particularly reported included poverty alleviation, cash transfers, food-for-work and rural employment generation and guarantee and financial support for small and medium-sized enterprises (SMEs).

5.3.3. *Labour and gender effects across FFSs*

Labour market failures had a profound effect on off-farm income of smallholders and the worker availability for labour-intensive farming and value chain operations in all FFSs, to different degrees. Differences in the timing of movement restrictions *vis a vis* the main farming and marketing operations led to local variation in the labour-related effects of COVID-19.

Overall, the HM FFS was least and the IWB FFS most affected in terms of labour (Fig. 10). In fact, the IWB FFS was most affected from labour influx from cities (although not particularly from international returnees), and from movement restrictions for males and females for harvest and post-harvest activities, especially in South Asia (conversely, there was limited effect on harvest operations in the IWB FFS in East Asia). Effects of the pandemic on the DM FFS on short-term productivity were common, especially in relation to male labour. The HM FFS was most affected by movement restrictions on male labour (1.5; Fig. 5).

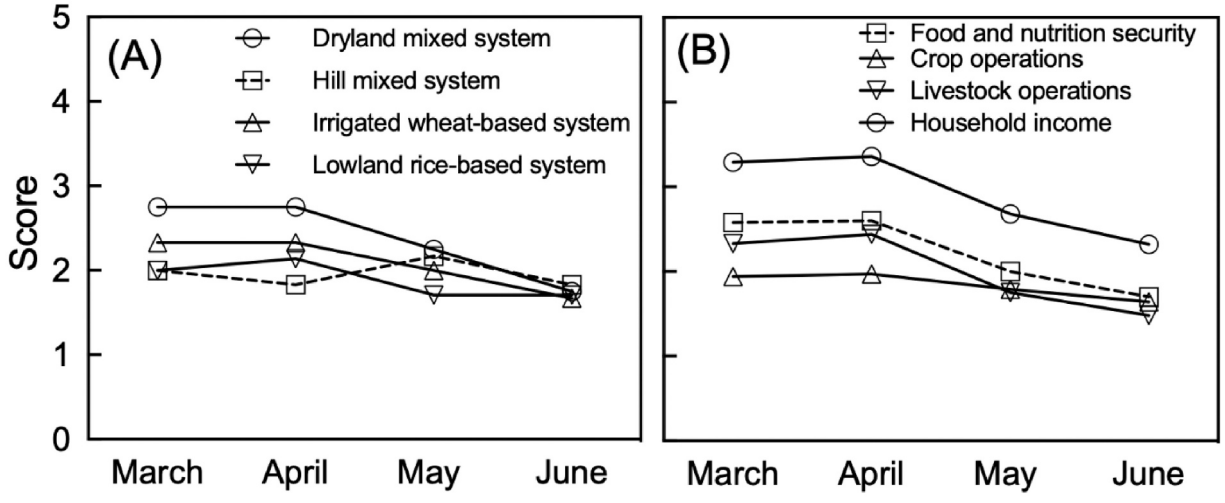

Fig. 7. Severity of effects by month during March to June 2020. Panel A: FFSs effect timeline; Panel B: farm family operations effect timeline (scores: 0 none, 5 very severe).

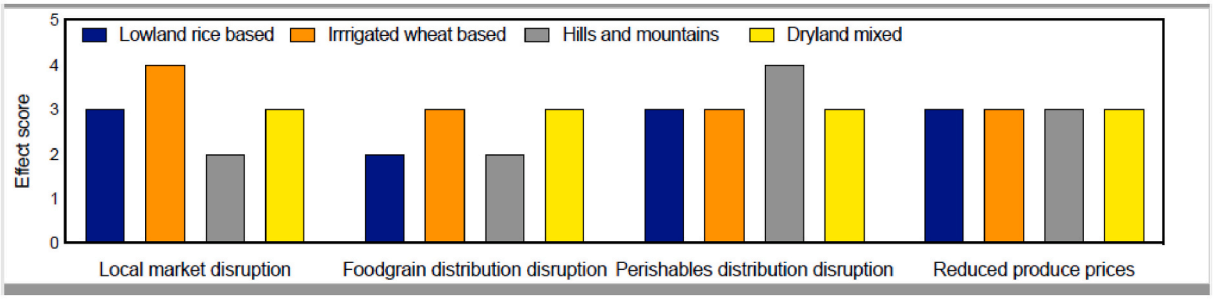

Fig. 8. Disruptions on output markets across the four FFSs (scores: 0 none, 5 very severe).

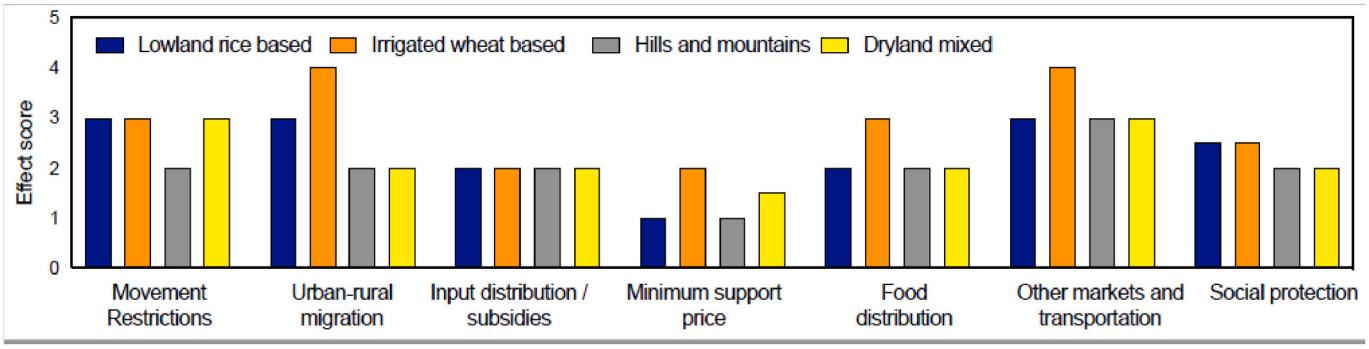

Fig. 9. Key COVID-19-induced policies affecting FFSs (scores: 0 none, 5 very effective).

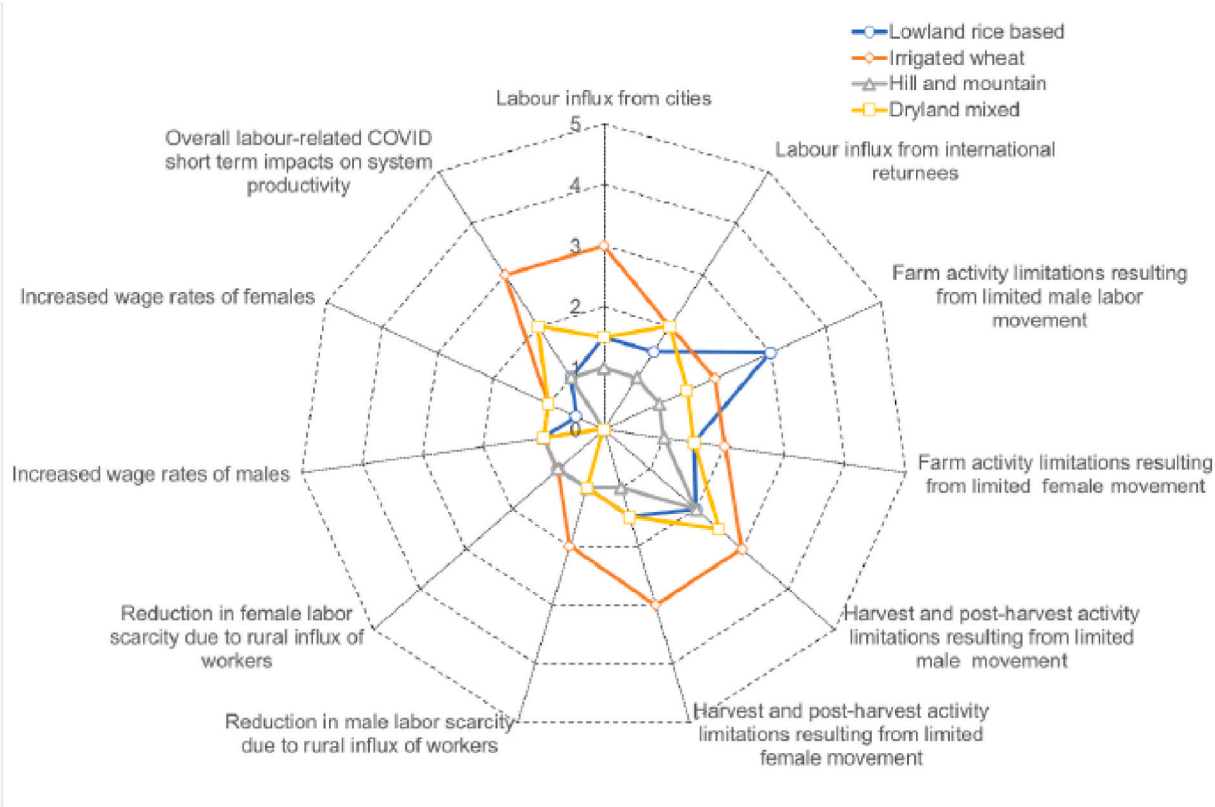

Fig. 10. Female and male labour and associated labour effects across four FFSs (scores: 0 none, 5 very severe).

Despite the influx of labour in some areas, and the disruption of some seasonal labour migration, for example for rice transplanting in the LRB FFS or fruit picking in the HM FFS, there were few reports of significant changes in wage rates for men or women, or reductions in female labour opportunities following the influx of rural workers.

Key informants anticipated contrasting outcomes for youth

engagement in agriculture over the next year, potentially increasing in nearly half of the study countries but decreasing in around one-third of countries studied. Many of the expected opportunities for youth were associated with the return of labourers back to rural areas and the potential expansion of rural service providers (see later). In countries reporting decreases, particularly those in Southeast Asia, key informants commented that the decline in youth involvement in agriculture mirrors pre-COVID-19 trends.

An increase in farmers' access to and use of agricultural machinery was anticipated in the medium-term, along with an increase in rural service providers resulting from governments' policy responses to COVID-19 in more than half of the study countries. Importantly, a potential reduction in food traders ('middle-men') was reported in many countries given agricultural development planners' interest in shortening agricultural value chains and using digital technologies to accelerate purchase and sales of perishables. None of our key informants anticipated a decrease in agricultural mechanisation or rural enterprise services in the coming years.

The immediate effect of COVID-19 among women and men farmers across the FFSs ranged from relatively limited to strong, depending on the activity (Fig. 11, Fig. S11). The strongest effect was on harvest and post-harvest activities due to lockdowns limiting mobility in the IWB FFS, where wheat farm labourers in India experienced 'very severe' effects while Kazakhstan and Tajikistan farmers experienced 'severe' effects. The effects were considered particularly severe among women wheat farmers because of farm activity limitations resulting from reduced labour movement. Where female household members were involved in production and post-harvest operations of vegetables and poultry which were disrupted by the pandemic, they were more severely affected than male members. Where there was significant urban-rural migration, returning male migrant workers sometimes replaced women workers on farms.

Key informants reported on the potential medium-term effects of COVID-19 on women farmers, with strong effects likely in the LRB and IWB FFSs. Women farmers in the LRB FFS were most affected in terms of their farm work, off-farm income, livelihoods, food and economic security, and their involvement in post-harvest activities, as well as their workload in domestic household activities such as caring for family members, cooking, and cleaning. Those female household members who were running family businesses were at greater risk of COVID-19 infection. Increased household workload was commonly reported. Overall, women farmers in the IWB FFS were most affected, in terms of their involvement in farm, post-harvest, trade, wage work and entrepreneurial activities. Very severe effects were observed on women's involvement in farm activities, wage workers, traders and entrepreneurs, e.g., in Central Asia.

5.3.4. *Food and nutrition security*

In both rural and urban areas Government food distribution and employment programmes supported food and nutrition security (FNS). Findings of this study indicate the limited to moderate effect of COVID-19 on medium-term food availability, access and utilisation (Fig. 11). The overall effect on the expected medium-term FNS was slightly stronger in the DM FFS, followed by the HM FFS, and more limited for the IWB and LRB FFSs. Across the four FFSs, the expectations were that food availability would be slightly less affected than food access, which in turn would be slightly less affected than food utilisation – probably because of reduced household income, especially from off-farm sources, and, in some areas, increased food prices.

In all the four FFSs, local production including backyard gardens, livestock, poultry and, in the case of LRB FFS, rice-field fisheries played a key role in stabilizing food availability and access and especially nutritional security during the pandemic. Although market chains to cities were significantly disrupted, fruits and vegetables were still available in many local rural markets, e.g., Nepal, China. The HM FFS provided diverse food items because of the integration of food crops, vegetables, fruits, livestock, and perennials, though it provided smaller volumes of cereals, pulses, and oilseeds. During lockdowns, in the LRB and IWB FFSs the reliance on locally-available, often packed, food items led to a focus on caloric intake and a less diverse diet – although this effect was less common for the HM and DM FFSs.

Survey results reveal diverse government and community interventions to minimise the disruption to food availability and its access and utilisation especially for the most vulnerable groups. Local communities and volunteers played key roles in food distribution to the poor in many countries, supported by national and sub-national government food distribution, partially offsetting the loss of publicly provided school meals as schools closed during lockdowns. As well as expanding existing programmes, there were many institutional innovations, e.g., the Tamil Nadu State Government in India packed vegetables (carrots, potatoes, onions and tomatoes) for delivery to households and sale at fixed prices (Singh, 2020). In many countries the use of e-commerce increased dramatically for the acquisition and distribution of foodstuffs, e.g., Peninsular Malaysia. Nevertheless, in all countries a core issue was not

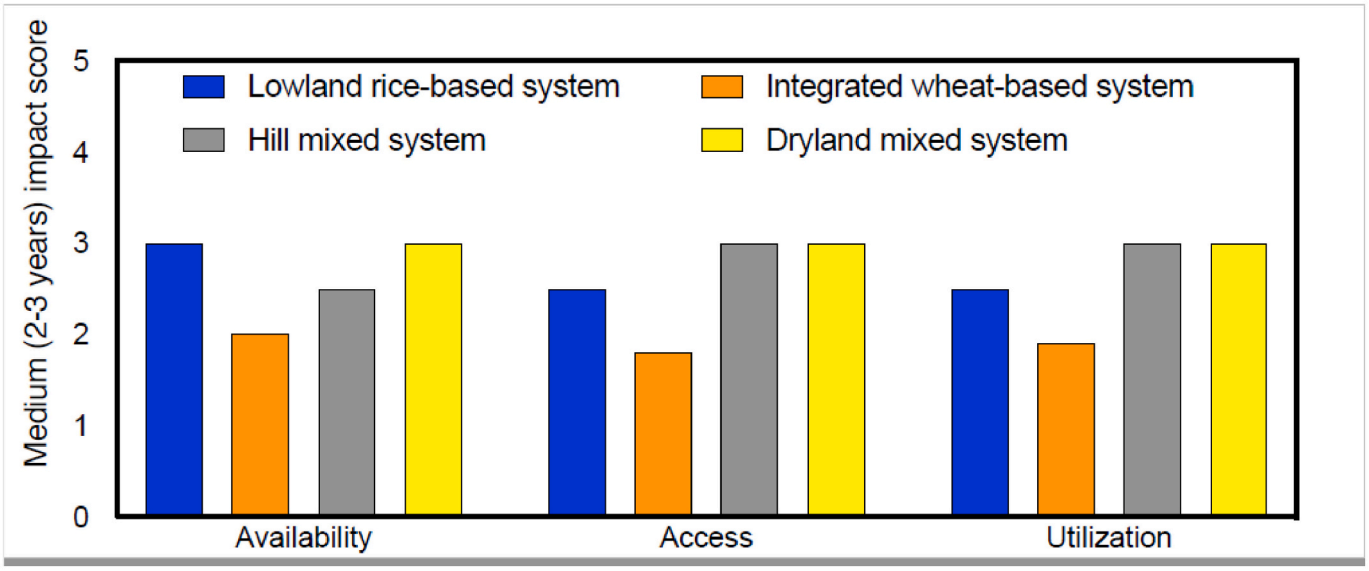

Fig. 11. Effects of COVID-19 on food and nutrition security by FFS (scores: 0 none, 5 very severe).

food availability per se but rather reduced access and lack of affordability of nutritious foods because of losses in household income.

5.3.5. Resilience and sustainability

The resilience to the COVID-19 shock was assessed by the degree of initial recovery of five domains of each FFS, viz, productivity, economic, natural resources, human condition and social. The assessment revealed a relatively high level of resilience of all FFSs to the initial wave of the pandemic, stemming from system robustness and speed of recovery, ranging from 87% recovery of the HM natural resources domain to 59% recovery of the IWB economic domain (Fig. S12). The overall rank order of domain resilience was (from greatest to least): natural resources (83%), productivity (78%, with slightly faster recovery for perishables than food grains), social (78%), human (72%, with somewhat less for food security) and economic (64%, with family cash reserves the slowest to recover). There was some variation between countries: East and Southeast Asia, where the first wave of the pandemic was controlled by April–May, reported greater recovery compared to countries such as Indonesia and India where COVID-19 continued to spread, even in late 2020.

The rank order of FFS's combined resilience was: HM FFS (78%), LRB FFS (76%), DM FFS (71%) and IWB FFS (70%). The resilience of the HM FFS was associated with low population density, modest productivity, relatively low inputs and, often, traditional market chains. The LRB FFS benefited from good infrastructure and water management, as well as shorter market chains to urban centres. The DM FFS had, in general, low productivity and input use with less developed and longer market chains. The IWB FFS had relatively high productivity and cropping intensity and greater dependence on input and produce markets and, to some degree, cold chains and storage. Other vulnerabilities included the coincidence of lockdowns with labour-intensive farm and marketing operations, and lack of flexibility of harvest and planting dates for some perishable products or intensive crop rotations.

In relation to the speed of agricultural market recovery, improvements were expected to be fastest in the IWB system followed by the HM, DM and LRB systems (data not shown). The recovery of perishables marketing chains to cities was estimated as 3.7 months across all FFSs. However, in the HM FFS, major parts of which are often distant from urban centres, 4.5 months was anticipated for recovery. The estimated recovery time for output markets (3.8 months) was faster than for input markets (5.4 months), and food grain markets would take longer (4.6 months) to recover than local output markets. Input markets would take longer to recover, and seed input markets were expected to take approximately 8 months on average to recover compared with 6 months for public extension services. The credit market would recover quickly, possibly due to informal lending and government support. Among the four FFSs, market recovery in the LRB FFS was expected to be the slowest.

The expected degree of sustainability after COVID-19 was assessed against the five domains of productivity, economic, natural resources, food security and social capital. In part supported by moderate recovery rates, all five domains and all FFSs had medium to strong long-term sustainability (Fig. 12). The HM FFS was rated more sustainable than the other three FFSs, notwithstanding its low overall level of economic development. It was rated above medium sustainability in terms of all five domains, whereas the IWB FFS was rated above medium for economic and social domains, and the LRB and DM FFSs were rated as moderately sustainable for four of the five domains.

6. Discussion

6.1. Salient implications for the region

Sustainable intensification and diversification of production is required in the coming decades in order to meet the diverse needs of societies with greater disposable income and changing consumption preferences whilst enhancing natural resource management and ecosystem services (FAO, 2020a). Such intensification and diversification face multiple constraints and challenges, including widespread degradation of natural resources (Pretty, 2018), climate change (Beddington et al., 2012), the limits of planetary boundaries (Rockström et al., 2017), the urgent need to transform food systems (Steiner et al., 2020; Kugelberg et al., 2021) and foster inclusive development (World Bank, 2020a). COVID-19 has exacerbated these challenges (WFP, 2020; OECD, 2021) and created new opportunities (FAO, 2020h; World Bank, 2021).

During 2020, the Asia region successfully contained COVID-19 at infection levels which averaged only one-third of the global average. Nevertheless, some countries were severely affected, and most countries faced repeated waves of infection (often more severe than the initial wave) or local outbreaks maintained the uncertainty through 2020. By assigning policy priorities to the health and agrifood sectors and committing about 15% of regional GDP (ADB, 2020a) to support and economic stimulus packages, Governments maintained the overall performance of FFS and aggregate food production (FAO, 2020b), minimized the effect on FNS and assisted, to some degree, vulnerable populations who were most affected by the pandemic. Early in the pandemic East Asia including China brought COVID-19 under control and shifted to a 'new normal' (Huang, 2020; Supplementary Materials appendix 2). After the initial shocks to perishable food chains and casual work in Southeast Asia, the aggregate effects on agricultural production in the Mekong area of Southeast Asia were limited, although later waves of infection during 2020 seriously affected the Philippines and Indonesia. Caseloads across South Asia exceeded the Asian average and many vulnerable groups, including farmers and casual labourers, faced severe income, food and nutritional insecurity. In response,

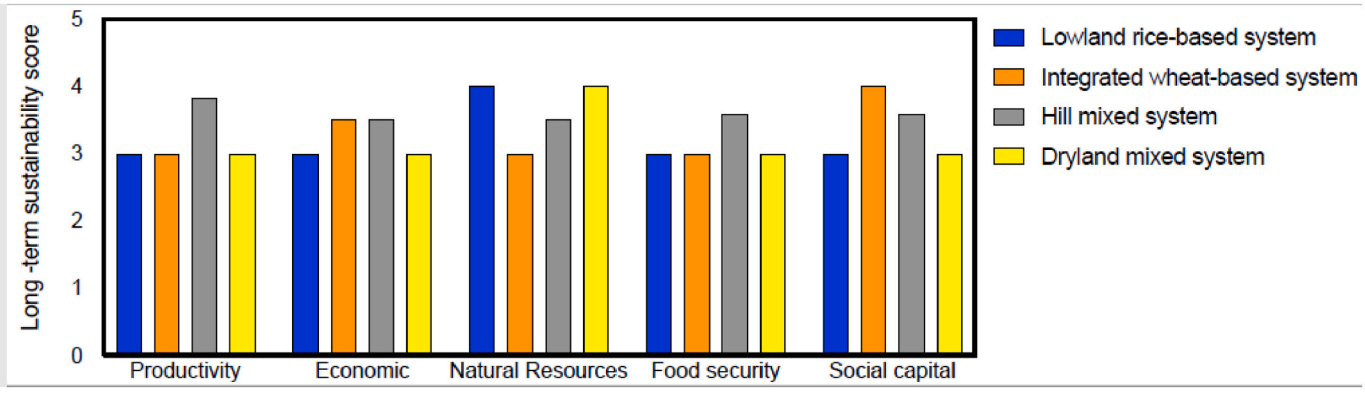

Fig. 12. Sustainability after COVID-19 by domain and FFS (scores: 0 none, 5 very strong).

Governments implemented public food and cash distribution and employment programmes which prevented widespread food insecurity. In Central and West Asia, although caseloads were high, notably in Azerbaijan and Iran, effects on agriculture and food production were modest, although food imports to some countries were affected. In many cases the poorer and more marginal suffered the most (Horton, 2020), particularly landless rural households and smallholders with major dependence on off-farm income.

Our findings underscored the overall resilience of smallholder Asian FFSs during the pandemic (section 4.3.5; Fig. S12). Compared to urban areas, rural areas have lower population densities, most especially in the HM FFS and DM FFS, with slower coronavirus transmission than in cities. The greatest resilience was observed in the HM FFS where smallholder farms are relatively diversified with significant, although declining, self-sufficiency, and access to local markets for many farm and household needs, except during periods of obligatory closure, lockdown or supply chain disruption – also noted by Ceballos et al. (2020). For many food crops, farmers could take advantage of the inherent plasticity in diversified systems and avoid major reductions in productivity. Sound resilience was also observed in the LRB FFS for somewhat different reasons, viz, reliable irrigation, good transport networks and many short market chains to major markets in cities.

The inherent resilience of the smallholder FFS was reinforced by the policy responses of Governments including food distribution, cash transfers and employment programmes – which all afforded relief to the vulnerable – and priority support for agriculture and food systems through, *inter alia*, assistance with harvesting and marketing, input supply logistics and credit. Our study found that some pre-COVID-19 policies reduced the vulnerability of the FFS to shocks such as the pandemic, including the procurement of crops at minimum support prices and social protection (Ceballos et al., 2020; Fan, 2020; Sudha and Shree, 2020). Our findings distinguished robustness from speed of recovery, representing complementary dimensions of farming system resilience (Meuwissen et al., 2019). We also acknowledge that, as Gelfand et al. (2021) point out, resilience may partly be due to social norms which vary from country to country.

The study highlighted a number of institutional weaknesses, notably the widespread indirect effects of agricultural input and produce market disruption (section 4.3.2; Fig. 13; Supplementary Materials appendix 1), especially related to the asymmetries associated with commercializing small farms facing modern food chains – in contrast to larger organized producers negotiating with modern chain operators or marginal producers selling surplus product in local markets. The chain operators also faced many issues including movement restrictions, transport impediments, labour shortages, demand contraction and financial constraints, as anticipated by other analyses (Qureshi et al., 2015; Reardon et al., 2020) or confirmed by other studies during the pandemic (ADB, 2020b; Biswal et al., 2020). Food grain marketing generally experienced, overall, limited disruption, often benefiting from public sector support. Conversely, in the early stages of the pandemic many perishables faced major issues of shortages of labour for planting, harvesting or milking, and marketing constraints for storage, transport or collapse of demand – with potential nutritional implications (Harris et al., 2020). Clearly, improvements in local institutions and market innovations such as smartphones are key elements for the required food market chain transformation called for by many Governments and agencies (FAO, 2020h).

Another set of institutional weaknesses relate to inclusive development in relation to opportunities and outcomes (OECD, 2021), most particularly in relation to casual labour, women, youth and other vulnerable groups (section 4.3.3; Supplementary Materials appendix 1). Of the various dimensions of FFS resilience, natural resources,

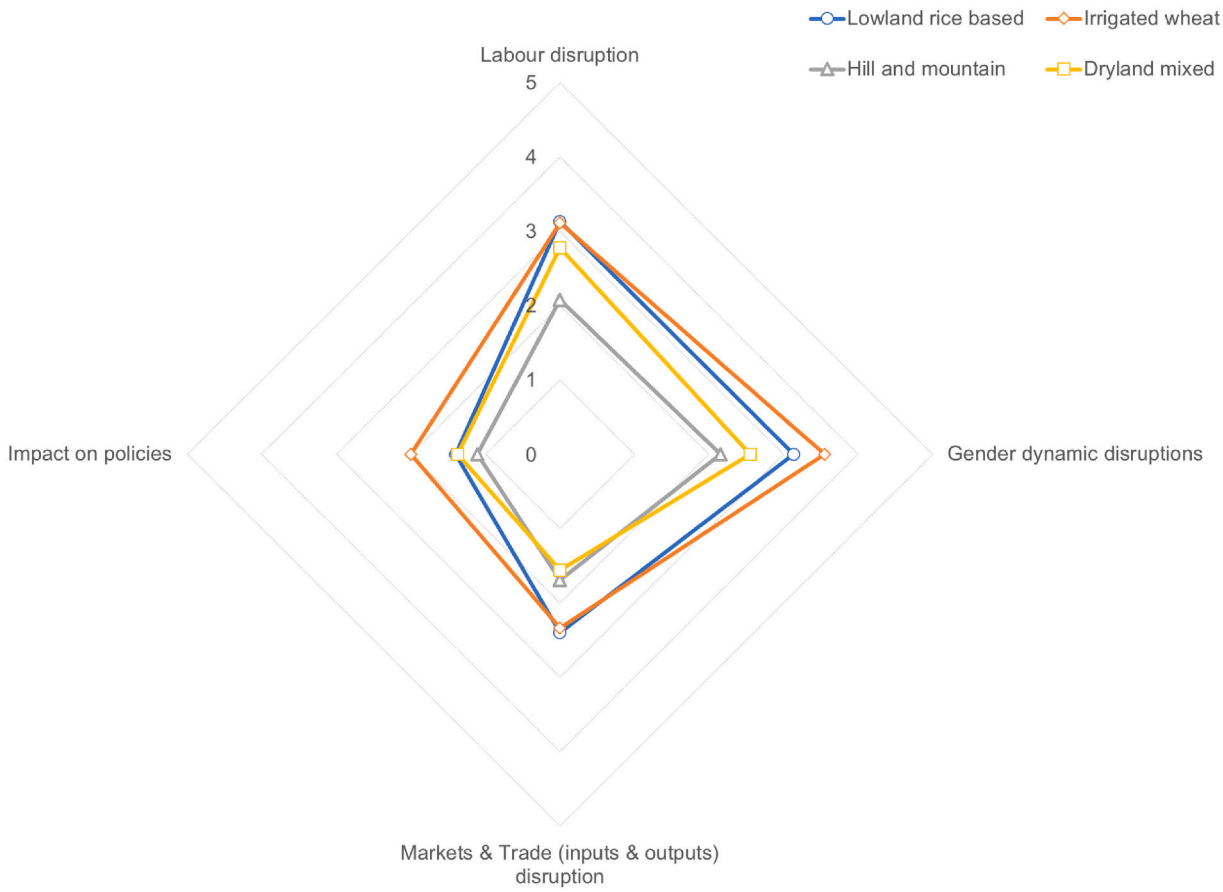

Fig. 13. Comparison of effects across FFSs (scores: 0 none, 5 very severe/many).

productivity and social capital remained sound, but economic aspects were slower to recover. Hence, the recent estimate of an additional 89 million Asians driven into extreme poverty during 2020 by COVID-19 is not surprising (UNESCAP, 2021), especially when compared with the rural population of 2.3 billion. The contraction of economies and the disruption of labour markets especially for low skilled workers including farm families could readily contribute to increased poverty and undermine progress to realizing the SDGs. In these respects, our findings are supported by similar qualitative studies in Asia on the effect of Covid-19 (Adhikari et al., 2021; Goswami et al., 2021).

Disruptions for women were more severe than for men – as found also by Hutt (2020) – and were especially prominent in the IWB FFS and LRB FFS (Fig. 13). Not only did many rural women lose off-farm income in urban work, for example with the closure of textile factories during the pandemic, these two FFS are characterised by relatively high population density, cropping intensity and productivity, and experienced significant influxes of returning migrants from cities and international destinations which added pressure to the multiple roles of women in rural households. These observations are consistent with the findings of Esworthy (2020), PANAP (2020) and UNESCAP (2020). Although gender disruptions from the pandemic were less severe in the DM FFS and the HM FFS, women still carry disproportionate burdens of farm and household work, accentuated by remoteness and poor access to public social and medical services (Sharma et al., 2016; ICIMOD, 2020). In fact, there are many unrealised opportunities for rural women in Asia (Nichols et al., 2020; Ragasa and Lambrecht, 2020). The economic contractions also led to a great loss of jobs by youth, especially in agriculture (ILO-ADB, 2020). Enhanced local social capital, along with needed rural institutional reforms, would foster inclusive strategies for women, youth and marginal groups in sustainable development (Sharma et al., 2016; Pretty et al., 2020; UNESCAP, 2021).

6.2. Considerations for recovery in each farming and food system

Many of the adverse effects of COVID-19 on the LRB FFS could be alleviated by the wider application of existing institutional or technological innovations and programmes – a phenomenon also documented by Ceballos et al. (2020). For example, potentially severe effects of COVID-19 were moderated through continued implementation of pre-pandemic policies, notably minimum support prices, food grain stocks, social protection and credit provision (Kumar et al., 2020). We observed some new institutional innovations where supply chains were severely disrupted, for example, public sector coordination of labour and machines for boro rice harvesting (Amjath-Babu et al., 2020; Mandal et al., 2020). Other examples included temporary public support for marketing and distribution of key food crop and livestock products, and for the expansion of e-commerce platforms to link farmers directly with consumers (ADB, 2021; World Bank, 2021). More generally, high diesel prices increased irrigation costs and fostered the spread of solar pump sets, supported by many Governments. In contrast, the continuation of large-scale modernization of existing irrigation systems to foster double rice cropping (Huaxia, 2020) might miss the opportunities for crop diversification to meet shifting future demand and for many rapidly-developing innovations suitable for the LRB FFS, e.g., pump sets, small tractors, smartphones.

The IWB FFS was severely affected in many respects (Fig. 13) despite irrigation infrastructure and supporting market services. The system features complex inter-dependencies between labour, mechanisation and markets (Paroda, 2018) and exhibits high cropping intensity and diverse crop rotations, e.g., rice, cotton, pulses, forage (Timsina and Connor, 2001). In such an intensive system, the coincidence of COVID-19 waves and peak farm operations affected farm management. Potential effects were very large, e.g., production losses (~24%) and economic losses (US$ 1.5 billion) in Punjab and Haryana States in northwest India, if not countered by specific policy or programme actions (Balwinder-Singh Shirsath et al., 2020). In the intensive IWB rice-wheat cropping system, COVID-19-induced delays in crop operations may also encourage a return to widespread rice residue burning and exacerbate seasonal air pollution and associated morbidity and mortality (Shyamsundar et al., 2019). The IWB FFS, and other systems, suffered from market-mediated effects such as the poultry-maize nexus in South Asia. Early in the pandemic, the consumption of meat and chicken declined due to a mistaken association with COVID-19 infection. As the demand for poultry declined, the poultry feed market collapsed and the price of maize fell by one-third, before recovering later in the year. More generally, the pandemic might well prompt wider adoption of proven innovations such as e-commerce to modernise marketing chains and promote rural entrepreneurship (FAO, 2020h; World Bank, 2021), laser land levelling and precision agriculture to increase irrigation water use efficiency, further mechanisation to manage labour shortages, and conservation agriculture based sustainable intensification with the no-till 'Happy Seeder' to counter climatic risk (Islam et al., 2019; Dixon et al., 2020b).

The HM FFS was more robust and less disrupted than other FFSs (Fig. 13), albeit with major yield gaps and poverty – a finding confirmed for Nepal by Adhikari et al. (2021). The HM system is highly diversified, integrating multiple crops, animals, trees and kitchen gardens, farmers are moderately self-sufficient and the input and produce chains are also diversified. Although less efficient than many modern value chains, we observed that the traditional chains and local markets were quite resilient during the pandemic. There were some exceptions: some vegetable producers were adversely affected by lockdowns, and some poultry farmers were affected by poor supply of chicks and feed – as Ramakumar (2020) also found. Many households were severely harmed by the loss of off-farm employment during lockdowns, limiting purchases of food and farm inputs – this effect was also identified in several FFS by Chantarat et al. (2020). The widespread influx of migrant workers who sought to return to their villages added to family and local food demand. The influx caused both labour shortages and over-supply in different contexts, reflected also in other studies (ACAPS, 2020; Htoon, 2020; World Bank, 2020b). Within the HM system, there was intense competition at the interface between cropland and forests which, taking into account disruption of habitat for wildlife, is a potential source of future zoonoses (Kress et al., 2020; di Marco et al., 2020). The recovery from the pandemic is an opportunity for wider promotion and uptake of proven innovations to boost livelihoods while enhancing natural resources, such as systems agronomy to reduce the yield gaps and further diversify, on-farm grain storage to reduce losses in the market chains (Huss et al., 2021), digital marketing (World Bank, 2021), community forestry and agroforestry, and institutional innovations for payment for ecosystem services including carbon drawdown.

Overall, the DM FFS saw limited immediate effect on dryland crop production and livestock populations. High value diversification, which in normal conditions was a key strategy in favourable production pockets of the DM system to minimise risk and improve family income and nutrition, was significantly affected by the collapse of markets for perishable commodities in the early stage of the pandemic – as also found for Indian dairy farmers (Biswal et al., 2020). Off-farm earnings and remittances, which constituted about half of the farm household income in the DM FFS, were most severely affected, for example by up to 25% in Kyrgyzstan and Tajikistan. Compared to other FFS, the DM system confronts great climatic variability which requires continuous adaptive management supported by insurance. Food grain reserve stocks and social protection were key pre-COVID-19 policies that reduced vulnerability and underpin the value of a public role in food systems alongside businesses which operate the agrifood chains. Promising innovations during recovery include index-based insurance, improved matching mechanisms for off-farm work, feed-centred integration of crops and restoration of pastoral areas. These innovations could be incorporated in decentralised and resilient FFS featuring context-specific and market-led diversification, affordable small farm mechanisation and digital information accompanied by organisational

solutions for increasing productivity and reducing transactions costs (Carberry and Padhee, 2020).

6.3. Resilience during recovery and beyond

Despite the vulnerabilities exposed by the pandemic, resilience of the FFSs emerged as one key finding of the study; and a key question is how to reinforce such resilience against future pandemics or other agricultural shocks. Historically, resilience of agriculture underpinned survival of empires (Haldon et al., 2020). Analytical approaches to resilience and their applications have developed during recent decades, such as numerous frameworks (IISD, 2013; UNESCAP, 2018; OECD, 2020), analytical metrics (Constas et al., 2020) and incorporations in policy design (Capano and Woo, 2016; Grafton et al., 2019; UNESCAP, 2021).

There are many ways to build resilience of FFS against future shocks. In the case of COVID-19, FFS were primarily affected indirectly, often from movement restrictions, market disruptions and policy actions. The robustness of FFS derived in part from diversified farm activities, low dependence on external inputs, active local markets and mixed traditional-modern food chains. Conversely, off-farm income and specialisation in perishables turned out to be vulnerabilities. Policy settings were important: prior to the pandemic; during the initial stages for social protection and support to key farm operations, including harvesting, marketing and distribution of critical farm inputs. The second aspect of resilience is recovery, for which our analysis showed that the fastest quartile for recovery of farm services comprised local markets, perishable markets and veterinary supplies. In contrast, the slowest recovery quartile comprised advisory services, fuel and seed systems – all critical supports for commercializing smallholders.

Even though vulnerabilities would differ for different shocks in the future, for example, animal diseases, e.g., swine fever, or plant diseases, e.g., rice blast, or new zoonoses, there is much to learn from the early experience with COVID-19 in Asia. Clearly, preparedness was at a low level in many countries, despite the experience of Asia with SARS. Most Governments and organizations budget tiny amounts for preparedness, in comparison with the enormous direct and indirect costs of pandemics such as COVID-19, despite the high frequency and cost of natural disasters in Asia (ADB, 2019). Recalling that the vulnerable were most affected by COVID-19 – as with many disasters – national strategies, plans and policies should incorporate pillars of resilience and inclusiveness alongside productivity (OECD, 2021). The inclusion of resilience would recognise the value of stocks including food reserve stocks and critical inputs, e.g., seed and their decentralised location. Inclusive development would, over time, reduce the number of vulnerable rural people. Because many COVID-19 effects in agriculture and food arose from interactions between components of FFS, e.g., production, markets, stocks, labour, innovation, resilience analyses and planning must take a systems approach which leads naturally from agricultural growth to sustainable intensification and diversification (Pretty, 2018).

Comprehensive real-time data would enable vulnerability assessments and planning as epidemics threaten and empower leaders during the management of the shock and for recovery (UNESCAP, 2021; World Bank, 2021). Strategies and plans for resilience can be closely aligned with agricultural sustainability. The development trajectories, resilience and sustainability of the four FFS could be appraised using the Sustainable Intensification Assessment Framework (SIAF) of the Sustainable Intensification Innovation Lab (SIIL) at Kansas State University (Musumba et al., 2017). The five sustainability pillars of the SIAF could be complemented by five equivalent resilience pillars to form the Sustainable and Resilient Intensification Assessment Framework SRIAF (Dixon et al., 2020a).

6.4. Recovery and development policies

Our study shows the effectiveness of a wide variety of policies and programmes implemented during the crisis, including enhanced food security arrangements, food distribution, cash payments, infrastructure funds, employment programmes, infrastructure funds, employment programmes including youth (section 5.1), cast within a productivity-resilience-inclusiveness framework to be implemented across sectors (OECD, 2021) and empowered by agricultural and food assessment tools such as the SRIAF (section 5.3; Dixon et al., 2020a). Other studies confirm our findings (Balwinder-Singh, 2020; DA-AFID, 2020; Pan et al., 2020).

The COVID-19 pandemic is not over. In contrast to a post-pandemic return to development-as-usual, many organizations are calling for a transition to green, resilient and inclusive development (World Bank, 2021). Despite the disruptions and loss of livelihoods, the resilience of FFS was a foundation for the emergence of some winners, e.g., digital and agricultural technology companies, and new opportunities, e.g., policy reform, improved gender relations (Nichols et al., 2020; Ragasa and Lambrecht, 2020) and transformations of food systems (FAO, 2020a, 2020b; Gregorio and Ancog, 2020; Sampath et al., 2020). The Online Platform for Sustainable and Resilient Recovery from COVID-19 ("Platform for Redesign 2020") identified five relevant pillars for a green and resilient recovery from COVID-19 which, in the context of these findings, emphasise: people-centred planning, implementation and monitoring; sustainable intensification, diversification and market chains; environmental, economic and social resilience; innovation; and cooperation and learning across the region. These can be harnessed as part of a rural transformation and transition to a 'green economy' (Amjath-Babu et al., 2020; Kumar et al., 2020; Stephens et al., 2020; Adhikari et al., 2021; UNESCAP, 2021) in a globalized world with heightened risks of emergent zoonoses and disease transmission (di Marco et al., 2020; Shrestha et al., 2020; Zhang et al., 2020).

7. Conclusions

The COVID-19 pandemic, the most recent of a series of coronavirus zoonotic diseases, has generated major social and economic crises in many countries in Asia, exploiting institutional, social, and economic vulnerabilities and aggravating existing food insecurity and poverty. However, this study illuminated the resilience of the FFS covering more than 80% of Asian land and rural populations; and identified promising innovations, institutional reforms and policy initiatives. The paper identified lessons in relation to the effects of COVID-19 and recovery from the crises, which offers an opportunity for rural transformation and changed development trajectories leading towards green agrifood systems.

COVID-19 revealed the vulnerabilities of modern agricultural and food economies. While all four Asian FFSs were affected by the pandemic, and especially vulnerable groups in rural areas, the HM FFS was the most resilient system and the IWB FFS was the most severely affected. The resilience of the FFSs was evaluated positively in relation to productivity, natural resources, and social capital, although the recovery times for economic performance appeared to be slow in all systems. Diversification was a critical feature of resilient and sustainable systems, and short value chains and ICT connectivity also contributed to resilience.

The disruption of domestic agricultural and labour markets contributed to major short- and medium-term effects on the FFSs. The market dependent IWB FFS was affected to a greater degree than other FFSs. The movement restrictions affected labour-intensive segments of production and value chains to a substantial degree. Although public policies and programmes ensured that staples were available to most segments of the population, the milk, fish and vegetable markets were initially disrupted. Another consequence of the disrupted labour markets was widespread loss of off-farm work which severely affected rural households dependent on off-farm incomes.

The policy priorities for agriculture and food, in parallel with health, effectively reinforced the resilience of FFSs and ensured aggregate food supplies. All FFSs were affected by COVID-19-induced disruption in

labour, gender, markets and resilience and the associated policy responses, especially the movement restrictions which disrupted input and produce market chains.

This study has attempted to fill gaps in knowledge about the effects of COVID-19 on major FFSs and effectiveness of Governments' policy measures to contain the virus and assist smallholder farmers to maintain their agricultural productivity and livelihoods under the recurrent COVID-19 outbreaks in Asia. This study has also revealed some 'known unknowns' related to ongoing short- and long-term effects of COVID-19 and potential future opportunities. Important 'unknowns' include: in the medium term, will the pandemic cause adverse secondary effects on natural resources (soil, water, forests and biodiversity)?; will COVID-19-mediated learnings guide the agenda for boosting the much-needed sustainable intensification and diversification in FFSs?; will COVID-19 be a tipping point for a transition to a green economy and the acceleration of achievement of the SDGs? We suggest that these questions should be added to future research agendas.

Looking forward, this study identified a number of critical areas for consideration by policy makers during the recovery from COVID-19. Inclusive programmes are required to support women and youth engagement and employment in agriculture and mechanisation, as well as to foster innovation and entrepreneurship. Parallel training for farmers is needed to build capacity to take full advantage of the knowledge economy and digital connectivity for sourcing inputs, diversifying and managing their farms, and for fair marketing of their produce. Structural adjustments and programs are needed to improve equitable development – particularly for gender outcomes – because COVID-19 accentuated existing inequities.

The four FFSs will benefit from sustainable intensification and diversification, including legumes, agroforestry and high value enterprises, and digital platforms to link producers, local markets and consumers. Insurance and risk management require particular attention, as well as local food, feed and seed reserve stocks. One of the many lessons from the pandemic is that policy and program development needs to be better supported by real time disaggregated data and cross-sectoral coordination mechanisms monitoring vulnerabilities and for swift and effective management of future shocks to agrifood systems. Because of the multiple sources of risk and uncertainty including climate variability and change, sustainable decarbonisation should be a central plank of recovery programmes. Finally, resilience should be central to all future programming and investment in FFSs, and concept such as the Sustainable and Resilient Intensification Assessment Framework could be embedded in agricultural and food development strategies and plans.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that influenced the analysis and findings reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2021.103168.

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