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One health agriculture: Heat stress mitigation dilemma in agriculture

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A R T I C L E I N F O

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A B S T R A C T

The concept of One Health was developed as a successful strategy for addressing global crises that impact the health of animals, humans, and plants. The agriculture industry is facing a huge dilemma due to climate change and the impacts of heat stress, which might pose a threat to mankind in the future. In order to enhance the management of heat stress in the agriculture sector (Agri-heat stress), we suggest implementing the One Health approach. This is because the existing methods employed to alleviate heat stress in both livestock and crop farming may have side-effects on the well-being of animals, plants, humans, and the ecosystem. This review article examines the "dilemma" of mitigating heat stress in animal and crop husbandry. It discusses the One Health approach to heat stress, including a recommended strategy for reducing Agri-heat stress using the One Health approach. The study also highlights the benefits of adopting the One Health approach in mitigating Agri-heat stress. In our opinion, the efficacy of the One Health Approach in reducing Agri-heat stress depends on the process of conceptualization. This process includes recognizing the issue or hypothesis, as well as incorporating cooperating teams in the creation of environmentally friendly approaches. The efficacy and challenges of implementing this notion arise from the precise coordination of resources and collaborators.

1. Introduction

The concept of One Health highlights the interconnectedness between the health of humans, animals, plants, and the whole ecosystem/environment. Therefore, it promotes the utilization of a multidisciplinary strategy to manage global crises. The Covid-19 epidemic highlighted the significance of adopting a One Health strategy for the management of zoonotic and infectious diseases, as well as other global challenges like climate change and antibiotic resistance.

Climate change poses a threat to global humanity. Addressing the consequences of this climate change requires comprehensive collaboration among several players including researchers from different disciplines, community members, community opinion leaders, policymakers, policy enforcers, and farmers, all within the framework of a One Health. Climate change results in several ramifications, including the escalation of global temperatures, floods, and the emergence and reemergence of diseases, among others. All of these factors can cause an adverse effect on the agricultural sector, thereby impacting global food security. Of all the aforementioned factors, "global warming/increase in global temperature" is one of the climate change factors that are reported to have a significant effect on Agricultural productivity. A significant number of people worldwide depend on agriculture, therefore, affected agricultural productivity is equivalent to effected human livelihood.

Heat stress occurs when the environmental temperature-humidity index [1–3] exceeds what an individual can tolerate. To clarify, it is

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important to note that heat tolerance levels might differ across species, age groups, genetic variations, and geographical areas. Heat stress may manifest as either acute or chronic. Acute heat stress occurs when an individual is exposed to conditions that exceed thermal neutrality for a short period of time. On the other hand, chronic heat stress occurs when an individual is exposed to thermal neutral settings for an extended period of time. Both environments modify the physiological response of an organism (animals and plants), resulting in acclimatization and maybe even adaptation [4,5]. During this process, animal welfare and plant health are compromised, resulting in a detrimental impact on productivity, hence causing economic losses. According to the IPCC's predictions, ongoing global warming is likely to worsen and pose a threat to global food security [6].

Due to the crucial importance of heat stress in the agricultural industry, many scientists have been motivated to study the impacts of heat stress on both livestock and crop species e.g., [7–10]. Furthermore, they have also proposed many strategies (see, [11,12] to mitigate the adverse effects of heat stress in the agriculture sector. Without caution, several mitigation efforts might further complicate the already intricate picture caused by climate change. This is particularly true if strategy development, implementation and decision-making are driven by specific disciplines, as it may lead to unintended or unexpected side-effects. Due to the complexity involved, it is vital to adopt a systems-based strategy that integrates many disciplines, ideally including all of them, as advocated by the One Health perspective. The goal of developing environmentally sustainable heat stress management systems that prioritize safety from the design stage is essential. Additionally, it is crucial to promote the recognition and study of safety measures both within and beyond academic boundaries.

We believe that some heat stress mitigation techniques may have negative effects on human, animal, plant, and ecosystem/environmental health. Although these concerns of destabilizing the sustainable balance between human, animal, plant as well as environmental health may not have received global attention, they should not be disregarded. We strongly advocate for directing efforts towards mitigating the effects of heat stress in agriculture in accordance with the One Health concept. This approach ensures that all possible concerns on sustainable environmental management are taken into consideration.

Significant efforts have been made to promote the novel concept of One Health. However, a majority of the research conducted to advance this concept has mostly concentrated on subjects such as antibiotic resistance [13,14], zoonotic diseases [15,16], and climate change in general [17]. In addition, several studies have also examined the impact of heat stress on people employed on agricultural farms, for example Hamed et al. [18]. As of the time of writing this paper, no article has been found that expressly discusses the utilization of the "One Health" concept in the mitigation of heat stress in the agriculture industry. Therefore, this review article suggests that in order to promote the sustainable development and use of heat stress mitigation technologies/strategies in crops and livestock production, a transdisciplinary approach should be adopted, based on the One Health concept.

2. Review methodology

To illustrate the importance of heat stress in the agricultural industry. We conducted a brief investigation on the current study trend about heat stress in the agriculture sector. Our hypothesis was that there has been a discernible upward trajectory in research endeavors centered on the topic of heat stress over the course of the last ten years. This exemplified the worldwide importance of heat stress. We conducted a search in the Web of Science database using Boolean operators, namely "AND", "OR", and "NOT", to explore important topics such as heat stress, mitigation, approaches, and strategies. Additionally, we included specific species and production system names of livestock and crop species, such as dairy, beef, poultry, pigs, tomatoes, and maize. We also refined our search by focusing only on topics (which included title, abstract and key words), research and review articles, hence book chapters, periodicals, conference abstracts were excluded from our literature search. We aimed to ascertain the prevailing research and publishing trends from 2014 to date and tested the significance of the trend using Mann-Kendall statistical test implemented in R software.

After establishing trends, we selected literature sources that focused on heat stress mitigation in specific agricultural enterprises. We also incorporated articles that expressed concerns over the safety of certain measures used to alleviate the impacts of heat stress in agriculture. The primary objective of this study is to evaluate the side effects associated with some methods used to mitigate heat stress in agriculture. Additionally, we offer an alternate perspective on addressing climate change effects, specifically emphasizing the "One Health" approach as a method to reduce heat stress in agriculture. We acknowledge that review does not encompass all approaches used to alleviate heat stress in agriculture. This does not suggest that the approaches not addressed herein are insignificant or do not have related adverse effects.

3. Results

The results of our scientific literature search yielded a grand total of 90,909 research and review articles. These consisted of 84,906 research papers and 6003 review articles. Studies focusing on heat stress have exhibited an upward trend since 2014 (Fig. 1), with Mann Kendall test statistic showing significant trend for both research articles and reviews (tau = 0.600, $p = 0.012$; tau = 0.527, $p = 0.029$) respectively.

4. Discussion

We have shown that heat stress is a significant determinant in influencing present agriculture, and it has received increasing attention over the years. The significant increasing trend in the number of publications as well as the massive number of publications (over 90 k) on the subject of "heat stress" in agricultural production systems demonstrates its prominence.

One of the main overarching obstacles confronting the agriculture sector in the context of climate change is heat stress, and there is a noticeable absence of a comprehensive and inclusive plan for effectively controlling the impact of heat stress. While there are several technologies and strategies available for managing heat stress in agricultural production systems, there lacks a comprehensive framework for detecting and mitigating potential adverse effects associated with their use. Risk management is initially incorporated during the design stage while designing heat stress management technologies and strategies. Moreover, it is crucial to promote the sharing of knowledge across different sectors in order to efficiently tackle the consequences of heat stress within their respective professions. This will enhance the development and implementation of reliable frameworks for assessing and determining risks, as well as facilitate the dissemination of risk information to pertinent persons or groups.

4.1. Heat stress mitigation dilemma in livestock sector

Livestock is essential for ensuring sustained global food security. Around 1.3 billion people globally rely on livestock for their livelihoods and food security. According to the Food and Agriculture Organization (FAO), livestock is responsible for around 40 % of the overall worth of agricultural output worldwide [19–21]. According to Cheng et al. [22], livestock account for 33 % of the global protein supply and 17 % of the global calorie intake. Although the livestock industry has significant importance, there is a wide socialized narrative that it is one of the main causes of environmental degradation and a major contributor to climate change. This is mostly due to the release of methane, nitrous oxide, and carbon dioxide emissions [23,24]. The socialized narrative has been termed as misleading and aimed at falsely criminalizing livestock sector as articulated by Scoones, [24] in his review titled " Livestock, methane,

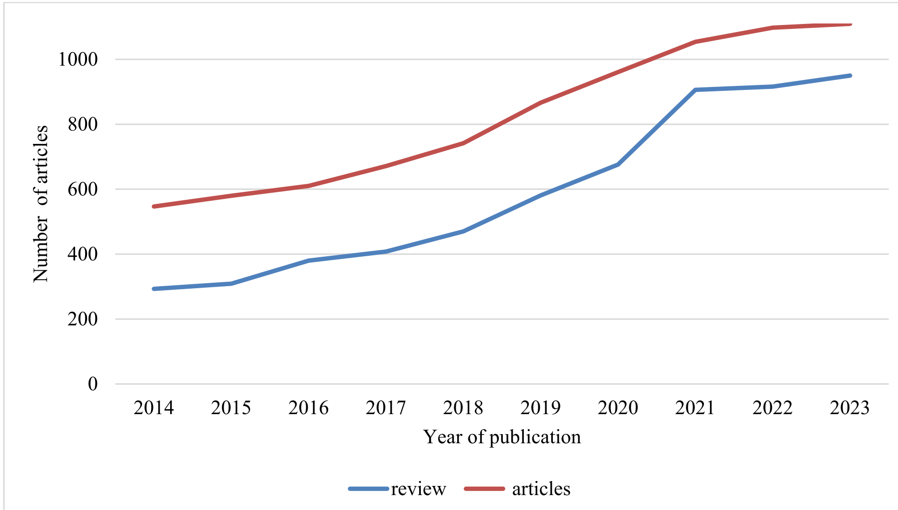

Fig. 1. The publication trend on the topic "Heat stress" in agriculture sector values for research articles were divided by 10.

and climate change: The politics of global assessments", whose sentiments are in congruent with the review by Mottet et al. [23]. According to Mottet et al. [23], livestock sector is a "necessary evil" that cannot be done away with due to its vital role to livestock dependent communities like pastoralists and employees. Therefore, according to the authors, we need to invest in livestock because some emissions are just unavoidable.

The phenomenon of climate change, and consequently heat stress, is a persistent and enduring reality. Heat stress negatively affects animal welfare and has an adverse influence on productivity. In addition, their immune systems suffer significant damage, and breeders/farmers may incur financial losses [25–29]. Heat stress also has detrimental effects on the metabolic balance and gastrointestinal systems, perhaps leading to alterations or reductions in feed intake [30]. In addition, when livestock are subjected to high temperatures, it causes changes in their physiological, behavioral, and immunological systems [25,26]. Furthermore, in some circumstances, like "extreme heat", heat stress can lead to death [31].

Various strategies have been devised to alleviate heat stress in livestock, given its (livestock) global importance. These include employing physical measures such as shade, cooling, and ventilation systems [32,33], and efficient watering systems. Additional approaches to alleviate heat stress include the implementation of breeding and selection strategies for heat-tolerant breeds, as well as the adoption of dietary interventions. Heat-stressing environments can be identified by the observation of animal behavior or by utilizing environmental indicators such as the temperature humidity index, sun radiation, and wind speed (Fig. 2).

In contrast to their role in cooling animals, installed cooling systems are considered to be high consumers of energy. According to Mohsenimanesh et al. [34], the cooling systems used to combat heat stress in dairy cows, such as fans and sprinklers, consume an average of 140 kWh per cow per year, representing 15 % of total electricity usage. Another study conducted by Markou et al. [35] indicated that ventilation, used to cool animals, plays an important role in energy usage in livestock production. Their research found that ventilation consumes 12 % of the total energy in pig farming, 28 % in poultry meat production, and 33 % in egg production. The high energy usage lacks environmental sustainability and economic viability, as is a potential contributor to air

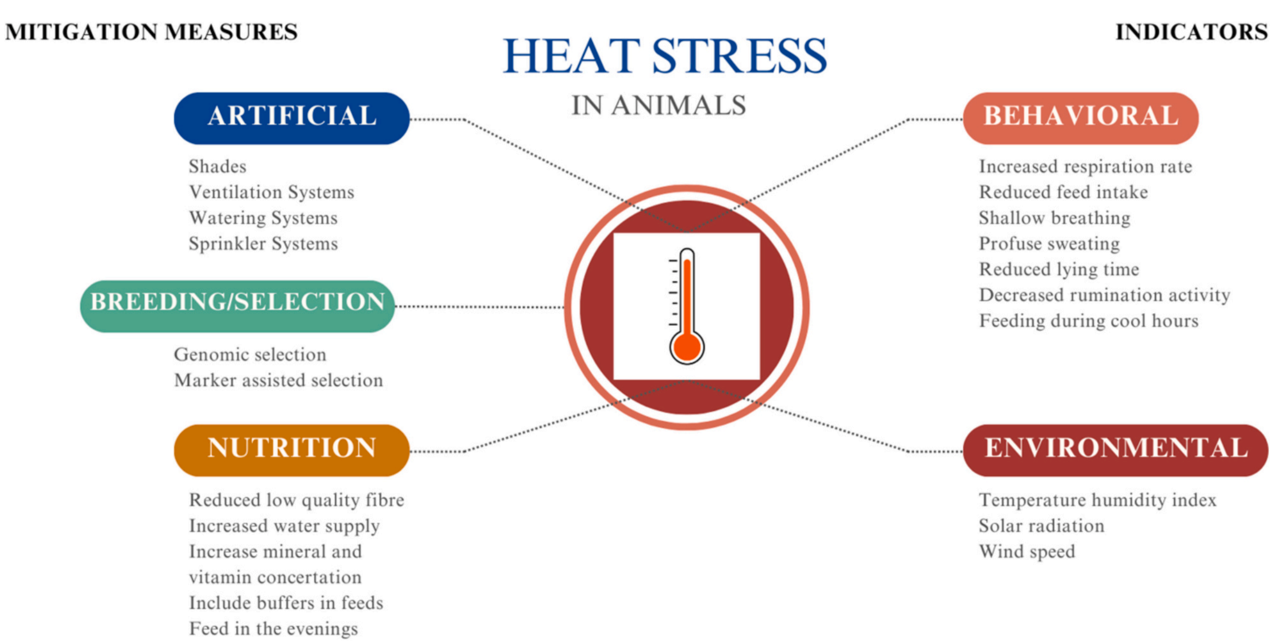

Fig. 2. Strategies for detecting and mitigating heat stress in livestock breeding.

pollution and may increase the carbon footprint of milk production in dairy cows [36]. Water application is an optimal approach for cooling animals during periods of heat stress. Taking dairy cows as an example, effective cooling systems are crucial adaptive techniques for mitigating the adverse effects of heat stress in dairy cows [37]. Installing sprinkler systems at the manger or resting areas is a prevalent technique for cooling cows. However, this procedure consumes a significant quantity of water. According to Farooq & Shahid [38], a Holstein cow on a typical dairy farm may use up to 850 l of groundwater during the semi-arid summer. The water used by sprinkler and fan evaporative cooling systems increases the volume of waste-water output thus worsening the waste-water handling situation. Another study by Means et al. [39] reported that 216 L of water was needed to effectively cool a cow per day in the United States of America. This is in addition to 100 L the average amount of water a Holstein Friesian cows drinks per day in a hot day [40]. Therefore, it is important to note that the major factor influencing water wastage on dairy farm is mitigation of heat stress effects [38]. Besides water wastage, it is also reported that significant energy use by sprinklers for water sprinkling. For instance, Montoya et al. [41], reported that sprinkling 4 L of water for 1 h requires 2708 W of energy. Given the growing shortage of water due to climate change, it is crucial to use water efficiently in order to maintain a sustainable life for humans and animals [42].

4.2. Heat stress mitigation dilemma in crop production

Heat stress tends to significantly affect crops at the biochemical, physiological, morphological and genetic levels. Considering the severity of these effects, crops have also developed an array of responses at each of these levels to cope with the negative situation (Fig. 3). Notwithstanding, mitigating heat stress in crop production is crucial for ensuring food security and sustainable agriculture. Similar to livestock production, various strategies have been explored to combat heat stress, including enhanced irrigation systems, synthetic mulching materials, use of shade netting, genetic modifications, and cover cropping.

Heat stress adversely affects biochemical, physiological, morphological, and genetic processes in crops, leading to reduced yield, compromised nutritional quality, and increased vulnerability to pests and diseases. These impacts pose significant threats to food security, food quality, animal feed availability, and ecosystem stability, while exacerbating environmental degradation through intensified agricultural practices like use of chemical sprays to control pests and diseases.

The crop production sector is highly susceptible to the adverse effects of heat stress because of low precipitation levels and significant evaporative losses [43]. Evaporation plays a crucial role in global evapotranspiration since it prevents plants from obtaining enough water to produce biomass. Approximately 20 to 40 % of the entire global evapotranspiration is attributed to evaporation, while around 50 to 70 % of yearly precipitation is lost due to evaporation [44]. To mitigate evaporation, several methods have been applied in crop production, however without considering their possible side effects. Some of the methods and their side effects are discussed below.

4.2.1. Irrigation

Irrigation is crucial for maintaining crop yield by supplying water and evaporative cooling to mitigate heat stress [45,46]. Irrigation has a notable impact on the surface soil temperature throughout both day and night, therefore influencing the microclimate in a way that is conducive to plant development. The decrease in temperature is also associated with higher vegetation indices and evapotranspiration, suggesting enhanced plant health and water utilization efficiency [47]. In addition, irrigation enables the growth of crops in areas where there is not enough rainfall, mitigating the impact of climatic fluctuations and high temperatures on agricultural output [48]. The economic significance of retaining incoming precipitation and irrigation water in sandy soils, characterized by limited water-holding capacity and delicate structure, is essential for agricultural productivity. Furthermore, Countries like Kenya have reported reduced cases of Anemia as a result of improved irrigated agriculture [49].

However, it is important to note that excessive or inefficient irrigation practices can lead to water wastage, increased soil salinity, and environmental degradation [50]. Moreover, the sustainability of irrigation practices is a concern, particularly in the face of climate change and increasing water scarcity [51,52]. It is essential to balance the

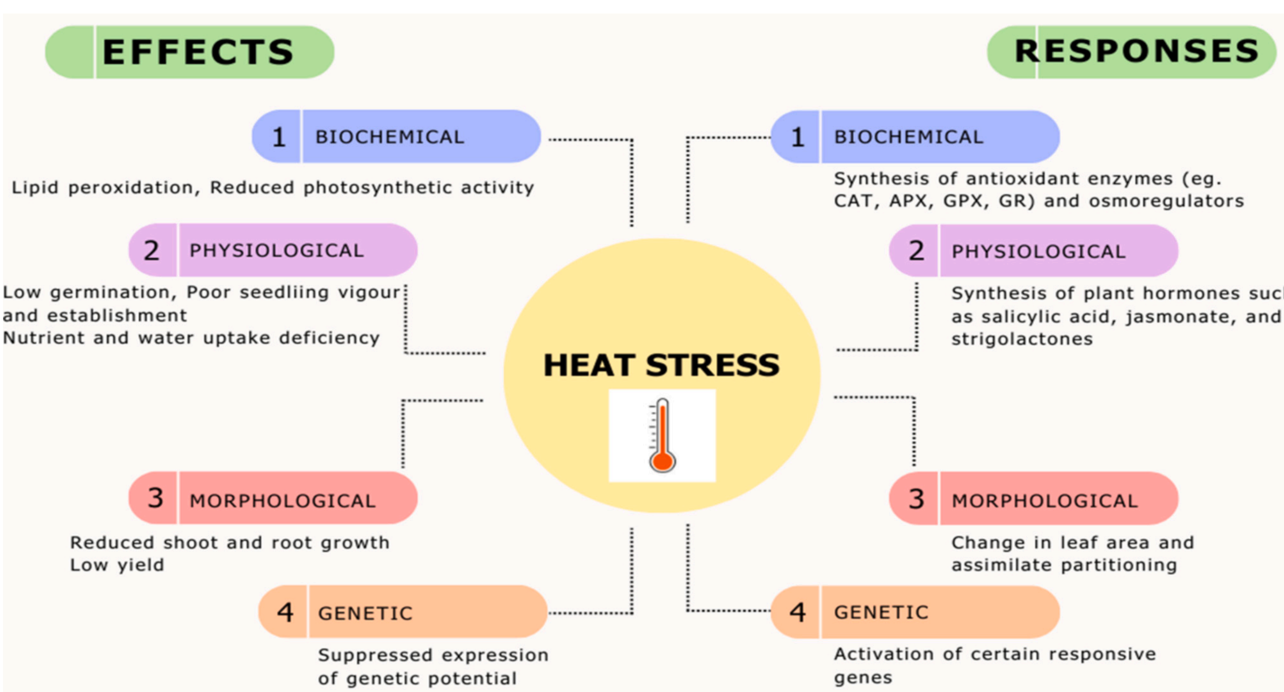

Fig. 3. Plant reactions to and effects of heat stress.
Right: Responses of plants to heat stress environments; left: effects of heat stress on plants.

benefits of irrigation for heat stress mitigation with the need for sustainable water management practices to ensure long-term agricultural productivity while curbing water scarcity for other uses.

4.2.2. Mulching

Mulching is a highly effective method for partially addressing water conservation and mitigating soil deterioration. Various mulching materials, both synthetic and natural, are employed in the cultivation of crops and horticulture [53,54]. Plastic mulch has been demonstrated to induce a greenhouse effect by trapping and preserving solar energy, hence minimizing nocturnal heat dissipation [55]. The mulch material has a significant influence on the retention of water in the soil and the amount of water used in crop production [56]. While the use of permeable materials like plastic sheeting for mulching can reduce evapotranspiration losses, it also restricts the ability of the root zone to absorb the precipitation that falls on the mulch. Nevertheless, water has the potential to infiltrate the permeable mulch layers and access the roots. However, the utilization of this material results in higher rates of evaporation losses compared to other choices. Using mulching materials that have a high-water retention capacity might promote the establishment of insects and the incidence of co-infections [56,57] possibly due to reduced activity of soil enzymes in the anaerobic environment created by the air impermeable mulch.

Furthermore, many synthetic mulches e.g., polyethylene mulching films [58,59] and rubber mulch [60] have a prolonged degradation process or are non-biodegradable, which means that inappropriate disposal might lead to serious ecological issues. These pollutants have the capacity to harm plants' health and pollute groundwater, hence reducing the quality of water accessible for human, plant, and animal use. These examples demonstrate the possible impacts of measures aimed at decreasing evaporation on soil health, as well as on the well-being of humans and animals.

4.2.3. Shade nets

Shading has been effectively utilized in several crop species to improve water availability and alleviate heat stress during the vegetative development stage. Shade nets, particularly those with different colors, are employed to alter the light spectrum received by plants, resulting in enhanced water-use efficiency and total plant development in hot and arid environments, notably in semi-arid and desert regions. Plants are affected differently by shade nets of varying colors. The experimental results published in Mohawesh et al. [61] indicate that the use of bright shade nets led to enhanced growth of pepper compared to standard black nets. Similarly, Blue and red light, enhance plant development, whereas other colors may affect the output and quality of fruits [61,62].

Shade nets generate micro-environments in crop fields, leading to a reduction in wind speed and an elevation in the level of moisture in the air. These environmental changes influence the rate of transpiration and temperature regulation, which are vital for mitigating the impacts of heat stress. Colored shade nets have the capacity to alter the microclimate and light characteristics, enabling plants to flourish and tolerate hot conditions. This characteristic makes them an appealing choice for enhancing agricultural production systems in order to mitigate the effects of heat stress resulting from climate change.

While shade nets offer significant benefits, there are also drawbacks associated with their use in crop production. Improper disposal of shade nets can result in plastic pollution, which in turn harms soil health and the microclimate. Consequently, this has a negative impact on the growth of plants, the functioning of ecosystems, and the well-being of animals and human health. On the other hand, shade nets provide protection for agricultural workers by obstructing detrimental UV rays and mitigating heat stress, hence decreasing the likelihood of heat-related diseases in agricultural workers. However, specific materials used in manufacturing and constructing these nets, such as chemically treated wood or rubber mulch, have the capacity to produce poisonous compounds that can be detrimental to human health. Therefore, the appropriate exploitation and disposal of shade net components will significantly contribute to the promotion of health in the field of agriculture.

Plant hormones, such as auxin, cytokinin, ethylene, gibberellic acid, salicylic acid, melatonin, and brassinosteroids, are frequently used to regulate many aspects of plant growth, development, and responses to environmental stimuli [63]. In addition, they have been topically administered as a means to mitigate heat stress in crops [64–66]. Nevertheless, the inappropriate usage of these external application might potentially cause damage to the environment. Pathogens have the ability to regulate plant defense signaling networks by regulating the amounts of phytohormones. This manipulation has the potential to cause ecological imbalances [67]. In addition, the use of external plant hormones to mitigate stress, such as heat, might interfere with natural plant processes and impact ecosystems [68]. Additionally, the interaction between various plant hormones can lead to the creation of eco-friendly elicitors. However, if these hormones are used incorrectly, they might have unanticipated negative effects on creatures and ecosystems that were not the original target [69]. Excessive accumulation or incorrect usage of plant hormones can have negative impacts on plant physiology and ecological interactions, causing disruptions to the general equilibrium of ecosystems [70]. In order to promote the growth of a strong agricultural and food system, it is crucial to carefully evaluate the method of administering plant hormones to avoid any negative effects on the environment.

4.3. The one health approach to heat stress management

The term "One Health" has been in existence for decades now. It was coined in connection with the outbreak of severe respiratory illness (SARS) in 2003, which was subsequently followed by the spread of pathogenic avian influenza (H5NI). As a result, a set of strategic objectives known as the "Manhattan principles" were formulated based on a gathering of "Wildlife conservation societies, 2004". These principles explicitly acknowledge the interconnectedness of human, animal, and environmental health, as well as the potential risks they pose to global food security, economic stability, and public health [71]. The recent outbreak of the covid-19 pandemic [72,73] intensified the necessity to strictly adhere to the "One Health" concept in order to effectively manage global challenges and develop long-lasting remedies. Significant endeavors have been undertaken to promote the adoption of the "One Health" approach in implementing specific measures to effectively address global crises. For instance, Boqvist et al. [74] advocated for the implementation of One Health in tackling food safety challenges in Europe, while Lombi et al. [75] advocated for the adoption of One Health in the management and application of nanotechnologies in agriculture. Moreover, there is also a push for the implementation of the One Health concept at the molecular level. For example, Djordjevic et al. [76] and Struelens et al. (2024) [77] conducted research on genomic surveillance for antibiotic resistance. Meanwhile, Osei Sekyere & Reta [78] emphasized the application of genomic epidemiology to advance the notion of One Health.

Although heat stress management in the agriculture sector (both livestock and crop production), most of the current physical strategies fail to prioritize the health of human workers in the agriculture industry (occupational health; [79]), as well as the surrounding community and ecosystem. Consequently, we propose a framework as the basis for the theoretical understanding of the components involved in mitigating agri-heat stress using a One Health approach (Fig. 4).

The effectiveness of the One Health Approach in Agri-heat stress reduction is dependent on conceptualization, which involves identifying the problem/hypothesis as well as identifying and involving collaborating teams in the design of eco-friendly methods. The strength and problems of executing this concept stem from the correct coordination of resources and collaborators. In their study on "Scaling up One Health: A

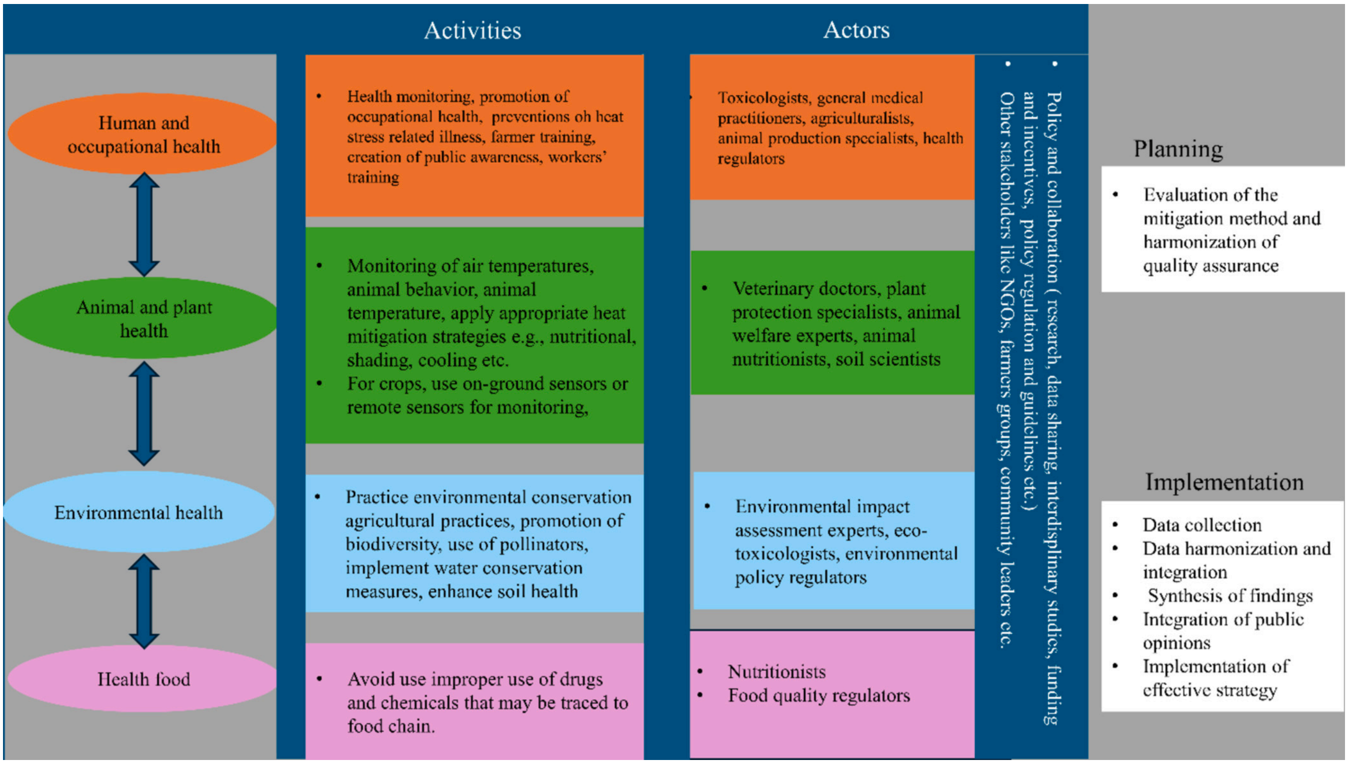

Fig. 4. A possible One Health approach for Agri-heat stress mitigation.

network analysis in Lao PDR", Larkins et al. [80] pointed out that relationships among collaborators, resources, coordination, and priorities are among the key considerations during the implementation of One Health concept.

The suggested framework is comprehensive, bringing together all relevant stakeholders to guarantee that the most effective Agri-heat stress mitigation techniques are developed and implemented. One of the most crucial and often ignored stakeholders in Agri-heat stress mitigation and even fighting effects of climate change in general is farmers, as clearly reviewed by Rezaei [81].

4.4. Benefits of adopting One Health in Agri-heat stress mitigation

Enabling cooperation among diverse researchers and stakeholders offers several advantages that might promote the progress of sustainable global food security. An important advantage of this method is that it allows for the utilization of a wide range of knowledge and resources from all parties involved. By doing so, a more comprehensive approach may be taken to address the intricate aspects of Agri-heat stress reduction, resulting in more effective intervention solutions.

Furthermore, this strategy has the ability to influence legislative changes that give priority to the well-being and safety of workers. The "lobbying scale" might acquire more influence in attracting higher investment in heat mitigation solutions by emphasizing the interrelationships among heat stress, animal welfare, worker productivity, plant health, and food security. This may involve the advancement of heat-tolerant species and breeds, crop varieties, upgraded irrigation infrastructure, and increased worker training programs, among other things. In essence, adopting a One Health strategy can enhance the resilience of agricultural systems to cope with the adverse effects of climate change, including the escalating temperatures and more frequent occurrences of heat waves.

5. Conclusion

Climate change is a permanent phenomenon, and its impact on the agriculture industry is exacerbated by the continuously rising average world temperature. This review paper has outlined the dilemma of mitigating heat stress in the agriculture industry. Various strategies to alleviate heat stress have been suggested and many are being adopted in a haphazard manner, without considering their potential side-effect on the health of humans, plants, animals, and the whole environment. This review paper suggests the adoption and application of the One Health concept to mitigate Agri-heat stress. The successful execution of this strategy relies on conceptualization, which entails defining the problem/hypothesis and engaging collaborative teams in the development of environmentally sustainable techniques. This method will improve the long-term availability of food, as well as the well-being of humans, animals, plants, and ecosystems, ultimately leading to a healthier world.

Author contributions

EM, GW, GAD conceived study, EM, GW compiled the original manuscript; GAD,WB, VT, FK, IMG, GY wrote different sections of the manuscript; DK, VS, GW prepared figures; GW supervised and coordinated the whole process. All authors reviewed and approved the manuscript.

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Declaration of competing interest

The authors declare that they have no competing interests.

Data availability

No data was used for the research described in the article.

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