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# Ecological adaptation of smallholders to tropical climate change in the highland zone of South Sulawesi, Indonesia

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**Abstract.** *Busthanul N, Demmallino EB, Sultani HR, Lampe M, Ismail A, Yassi A, Daris L, Saudi MY, Zainuddin A. 2023. Ecological adaptation of smallholders to tropical climate change in the highland zone of South Sulawesi, Indonesia. Biodiversitas 24: 5328-5335.* Climate change has adversely affected the stability of agricultural production and livelihood systems, threatening the well-being of farmers in Indonesia, particularly small-scale farmers with limited resources. To mitigate the impacts of climate change on agricultural production, innovative approaches are required. Ecological adaptation is one of such approaches which addresses the threat of climate change. However, studies on ecological adaptation in Indonesia have mostly been concentrated on food crops, with limited attention to horticultural commodities in mountainous regions. This study aims to explore how horticulture farmers in the mountainous region of Enrekang District, South Sulawesi, adapt to the effects of tropical climate change. This study employs a post-positivistic approach, to a case study of the impact of climate change on the horticulture farming community in Enrekang District. The study uses a household survey method to gather quantitative data, while focus group discussions and key informant interviews were used to collect qualitative data using semi-structured and unstructured questionnaires. The study's findings revealed diverse ecological adaptation patterns among horticulture farmers, which include adjustments in planting timing, management of pests and diseases, crop rotation, and the use of pumping systems. In addition to these scientifically based strategies, local knowledge also played a crucial role in adaptation processes. Furthermore, to ensure the sustainability of these ecological adaptation strategies, there is a need for the government and scientists to support and empower local communities collectively. This recognition and collaboration are vital for ensuring the resilience and effectiveness of adaptation efforts in mitigating climate change.

**Keywords:** Adaptation pattern, Enrekang District, global warming, horticulture, local knowledge

## INTRODUCTION

Global climate change, characterized by events such as droughts, floods, and rising air temperatures (global warming), has exerted significant influence on the agriculture sector (Wichern et al. 2019). These climatic shifts have adverse implications for both agricultural production stability and the livelihoods of farmers (Arifah et al. 2022). Predictions regarding climate change paint a challenging picture, especially for the world's most economically vulnerable regions, where adaptive capabilities are limited (IPCC 2014). Mountainous and high-altitude areas (typically above 1000 meters above sea level) are particularly susceptible linked to the effects of climate change, such as erratic in rainfall patterns leading to soil erosion and degradation, increased flood frequency, and heightened risk of prolonged drought due to rise in temperature (Negi and Mukherjee 2020; Nguyen and Leisz 2021).

The agriculture sector plays an important role in Indonesia, employing approximately 88.89% of the domestic workforce in 2022 and making substantial contribution to the country's GDP (BPS-Statistics Indonesia 2023). Despite its significance as a source of employment and income for the Indonesian populace, the agricultural sector remains extremely vulnerable to the impacts of climate change. A stark example of this vulnerability is the 8.23% decrease in agricultural productivity witnessed in 2020, directly attributed to climate change (Government of the Republic of Indonesia 2021). Various studies in Indonesia highlight the factors behind this decline, including crop stress and crop failure (Arifah et al. 2021), amplified occurrences and severity of drought (Brown et al. 2019), increased incidences of pest-related crop damage (Skendžić et al. 2021; Arifah et al. 2022), and substantial reductions in farmers' incomes (Rahman et al. 2022).

Effective adaptation strategies must be tailored to the specific socioeconomic, environmental, and cultural contexts of communities. Climate change exerts diverse impacts across the globe, and small-scale farmers employ a wide array of adaptation strategies, drawing upon both contemporary and traditional knowledge systems and technologies (Demem 2023). Farmers have implemented various adaptive measures to stabilize production and augment their incomes, including selection of drought-resistant crop varieties (Arifah et al. 2022), improving the efficiency of irrigation systems (Wossen et al. 2018), and the deployment of early warning systems (Asfaw et al. 2021). Research on adaptation strategies in Ethiopia, for instance, has identified crop diversification, soil and water conservation, and seasonal migration as primary adaptation strategies undertaken by farmers (Demem 2023). However, in the Indonesia context, while there is a growing interest in adaptation studies, most of the research has concentrated on major food crops, such as the introduction of drought-resistant rice varieties (Yuliawan and Handoko 2016; Arifah et al. 2022). Research on ecological adaptation in horticulture, particularly in high-altitude zones in Indonesia, remains relatively limited and underrepresented in the literature. It's important to recognize that adaptation strategies are inherently location specific and contingent on agro-ecological zones, which are defined by distinct climatic conditions in various areas due to the diversity of farmers' adaptive knowledge (Aniah et al. 2019).

Horticultural crop production holds enormous potential, driven by the global surge in demand for fruits and vegetables, alongside the growing preference for tropical fruits and vegetables owing to their health and nutritional attributes (Zhang et al. 2023). However, small-scale fruit and vegetable producers in Indonesia grapple with the adverse impacts of climate change. In regions like Banjarnegara, Central Java, Indonesia horticultural farmers report decreased crop yields and increased pest and disease outbreaks due to prolonged droughts and elevated temperatures (Turasih et al. 2016). These climate-induced stressors are not unique to Indonesia, as tomato producers in Mozambique are grappling with similar challenges, including floods, excessive rainfall, and elevated temperatures affecting their livelihoods and crop growth. Ethiopia has observed erratic rainfall patterns coupled with rising temperatures, leading to diminished potato yields (Adem 2021), while Williams et al. (2019) have demonstrated how climatic variability impacts both the quality and quantity of pineapple production. These circumstances highlight the pressing need for further research aimed at elucidating effective adaptation strategies in response to challenging climate change conditions faced by the horticultural sector.

In light of these considerations, the present study aims to evaluate how small-scale horticultural farmers in mountainous areas are respond to climate change. Through a detailed case study approach, the study aims to elucidate the impact of climate change on horticulture crops, investigate adaptive strategies employed by farmers, and assess the constraints hindering the implementation of these adaptation strategies, in Indonesia, with a particular focus on operating in vulnerable high-altitude zones.

## MATERIALS AND METHODS

### Study area

This research was conducted in Enrekang District, South Sulawesi, Indonesia, characterized by topography dominated by mountains and hills, with elevations reaching up to 3,200 meters above sea level. Geographically, this District is situated between 3°14'36" - 3°50'0" South Latitude and 119°40'53" - 120°6'33" East Longitude (Figure 1). Enrekang experiences a tropical climate with an annual average temperature of 26.6°C and receives abundant rainfall, even during the driest month (August).

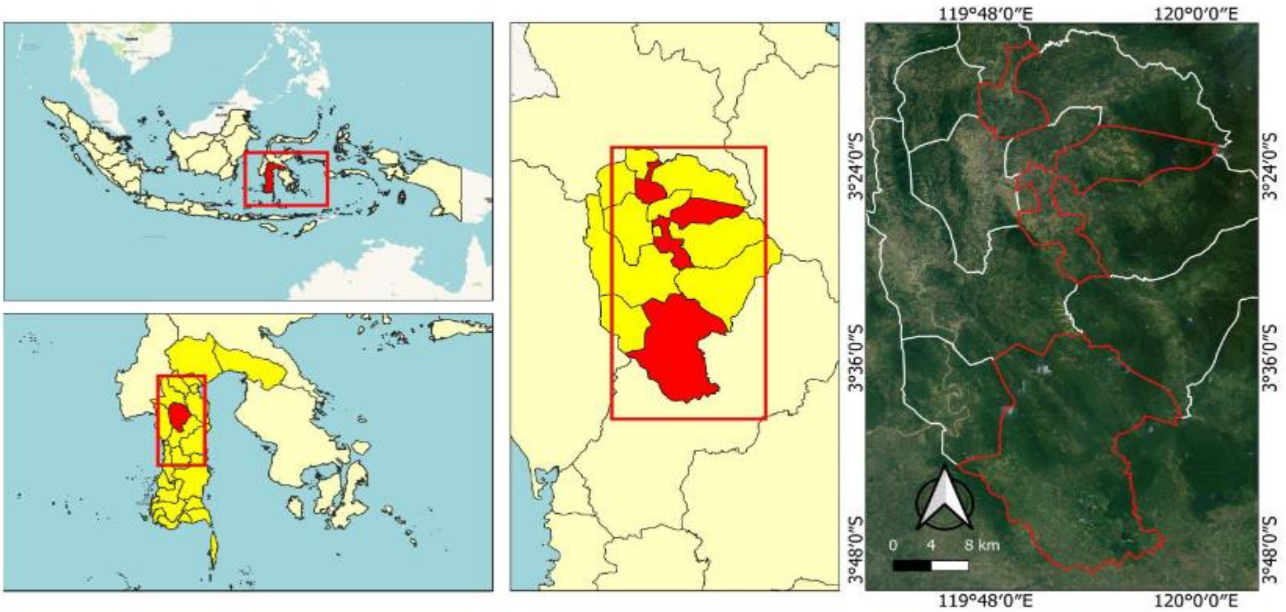


**Figure 1.** Research location in Enrekang District, South Sulawesi, Indonesia

Enrekang District is renowned for its significant horticulture producing production, providing shallots, potatoes, cauliflower, and cabbage to various regional and national markets. The horticultural sector contributes 46% of gross domestic income, with the largest production in the Districts of Malua, Baroko, and Curio, covering a combined land area of 3,022.45 ha (BPS-Statistics of Enrekang District 2023). For the purpose of this study and based on interviews with local government officials and community leaders, two sub-districts, namely Malua and Baroko were identified as the focal areas for an in-depth survey. These areas were selected due to their susceptibility to extreme weather events and their significance in horticultural farming. The total population of horticultural farmers in these two districts is 21,355 farmers.

### Data collection

This study employed the Human Instrument as a research tool, particularly for obtaining primary and secondary data from the Meteorology, Climatology, and Geophysics Agency (MCGA), as well as from horticulture farmers within the study site. Data collection involved a comprehensive approach, commencing with the collection of documented data from MCGA. Subsequently, on-site observations and in-depth interviews with several key informants selected through a snowball sampling technique among the horticultural farmers at the study site. In general, the sampling strategy adopted in this study aimed to identify highly knowledgeable respondents suitable for in-depth interviews. Selecting respondents with a wealth of information offered opportunities to gain extensive insights and a profound understanding of climate change issues (Cresswell 2014). Given the constraints posed by limited resources and time, exacerbated by the Covid-19 pandemic, this study purposively selected 75 households across the two designated sub-districts.

### Data analysis

To enhance the quantitative data, the study integrated qualitative methodologies, including in-depth interviews, focus group discussions, and participant observation (Cresswell 2014). The collection and analysis of qualitative data constitute an iterative process. Typically, the need for additional information or informants is determined as concurrent data collection and analysis progresses (Miles and Huberman 1999). While conducting the home questionnaire survey, the study also facilitated focus group discussions and interviews with key informants carefully selected based on their agricultural knowledge and experience in dealing with climate change. These interviews, conducted in the local language (duri), varied from 30 to 35 minutes and were carried out either on the farm or at the respondent's home. Ethical permission for this work was granted by the Hasanuddin University Ethical Clearance Committee.

Furthermore, qualitative data obtained from interviews and Focus Group Discussions were analyzed holistically through the following stages of analysis: data collection (including data optimization), data categorization (based on thematic content: local tropical climate change phenomena, their impacts on horticultural crops, and farmers' ecological adaptation patterns), and data interpretation. Subsequent stages of analysis encompass data visualization (causalities-mapping) and drawing conclusions (drawing conclusions from research findings) (Cresswell 2014; Miles and Huberman 1999). Microsoft Excel was employed to analyse quantitative data from the questionnaire.

## RESULTS AND DISCUSSION

### Historical changes in local climate

Based on data from the MCGA (BPS-Statistics of Enrekang District 2023) it was observed that temperatures (including maximum, minimum, and average temperatures) in South Sulawesi have exhibited a consistent upward trend over the past decade (2011-2021). The average increase in air temperature in South Sulawesi amounts to + 0.03731˚C. The lowest recorded temperature was in 2011 at 22.4964˚C, while the highest temperature was observed in 2021, reaching 23.1220˚C (Figure 1). Over the last decade, air temperatures have risen by approximately 0.6256˚C. These findings align with the global temperature increase trend (Yuliawan and Handoko 2016). However, it is worth noting that the average temperature rise in South Sulawesi is relatively lower due to the region’s geographic features, characterized by numerous mountains, valleys, forests, lakes, rivers, and coastlines distributed across the archipelago. These unique climatic characteristics distinguish local climate change from the broader context of global climate change.

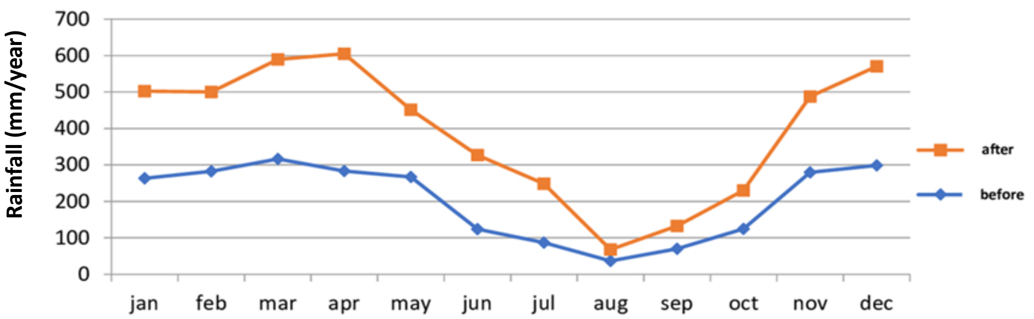


**Figure 2.** Rainfall pattern distribution (mm/year) before climate change (2002-2010) and after the impact of climate change (2011-2021) in Enrekang District, South Sulawesi Province, Indonesia

South Sulawesi experienced the El Niño phenomenon in 2015, resulting in an extended six month dry season, particularly in the eastern sector. Meanwhile, the western and transitional sectors suffered a reduction in rainfall intensity from May to November. However, according to Oldeman, there was an increase of nine wet months in 2016. Climate change has the greatest impact on rainfall patterns. Data from five stations of Meteorology, Climatology, and Geophysics Agency (MCGA) located near the horticultural development center in South Sulawesi reveal two major shifts in weather patterns in the recent decade, occurring in 2015 and 2018. The average rainfall during these two years is categorized as low, although there were notable variations during the rainy season, particularly in 2018, with 7-8 wet months. In 2015, there were five wet months of climatic type C. Overall, the horticulture development area in Enrekang District has maintained an agricultural climate classification of type B throughout past decade.

**Climate change impact and horticultural crop production**

According to data from the Central Bureau of Statistics information gathered through interviews with a several key informants, there was a significant decline in horticultural crop production during the two years of extreme climate change events (2015 and 2018) (BPS-Statistics of Enrekang District 2023; Arifah et al. 2022). During the first extreme event in 2015, characterized by an extreme dry season due to El Nino phenomenon, a decrease in cabbage production was observed. Moreover, several other horticultural crops had experienced declining production since 2014 when the rainfall patterns began to change. These included Chinese cabbage, tomatoes, carrots, green beans and red peppers.

During the second extreme event in 2018, a substantial decrease in production was observed, particularly in the case of potato crops. Production dwindled to a mere 1.83 quintals/ha, a significant decline from the previous year's yield of 75.86 quintals/ha. The primary factor behind this decline was the absence of rainfall or drought that persisted from July to November, which is typically the dry season. Elevated temperatures, coupled with the decreasing trend of rainfall, led to increased evapotranspiration and water pressure, impacting groundwater levels and the availability of irrigation water. Additionally, water stress elevated soil salinity, which in turn, affected water retention within plant cells (Williams et al. 2019). Remarkable, shallot production remained relatively stable during extreme climate events. To compensate for water scarcity, farmers employed pumping methods to draw water from the nearest water source, such as watershed. However, in 2019, farmers encountered challenges in combating pest infestations on shallot plants, resulting in a reduction in production to 6 tons/ha from the preceding year.

The data provided in Table 1 reveal that farmers have managed to sustain and even enhance agricultural productivity despite extreme weather events or changes in rainfall patterns, both in the years following 2015 and after 2018. Notably, cabbage production even reached its zenith during the second extreme weather event in 2018. This prompts an intriguing investigation into how horticultural farmers are ecologically adapting to extreme weather fluctuations, enabling their agricultural systems to recuperate across socio-cultural, economic, and technological or agronomic dimensions.

**Smallholder farmers adaptation strategies**

This study aimed to identify and rank climate change adaptation strategies implemented by horticulture farmers to enhance crop production. The research results regarding the adaptation strategies used by small horticultural farmers in Enrekang District reveal the presence of five adaptation practices, which include fertilization and pest control, crop rotation, the utilization of drought and pest-resistant crop varieties, the development of pumping technology, and approaches based on local knowledge (Figure 3). The ranking of these adaptation practices identified pumping technology as the most significant and crucial adaptation practice.

*Developing pumping technology*

In response to the water shortages caused by extreme climate events in 2015 and 2018, farmers innovatively turned to pumping as a solution (Van Huynh et al. 2019; Arifah et al. 2022). This proactive approach reflects the adaptability of farmers addressing challenges posed by climate change with limited resources, drawing upon knowledge and available materials (Arifah et al. 2022). Small-scale farmers have developed water management techniques to cope with extreme weather conditions by incorporating local knowledge and cultural practices that are embedded in their social and community structures (Dhakal et al. 2021).

**Table 1.** Production of horticultural plants (quintals/year) in Enrekang District, South Sulawesi Province, Indonesia

| Commodity | Production (100 kgs/year) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
| Shallots | 344699 | 330178 | 392950 | 441880 | 583574 | 851736 | 1116123 | 735811 | 800173 | 1028726 | 1509113 |
| Potato | 13125 | 11338 | 770 | 2564 | 250 | 2784 | 3869 | 2376 | 3006 | 2883 | 896 |
| Cabbage | 401390 | 426820 | 498930 | 363705 | 265195 | 353819 | 451224 | 405543 | 288300 | 363606 | 356406 |
| China cabbage | 36530 | 31810 | 30080 | 25428 | 19210 | 27016 | 16868 | 29255 | 25643 | 22598 | 14629 |
| Tomato | 122445 | 139338 | 161180 | 108120 | 159025 | 295654 | 472850 | 453893 | 332996 | 372568 | 308842 |
| Carrot | 44170 | 33810 | 37040 | 39874 | 35100 | 66410 | 60464 | 54667 | 40013 | 58431 | 28339 |
| Beans | 37882 | 34515 | 35950 | 24340 | 19080 | 48347 | 41245 | 62429 | 35696 | 29256 | 36367 |
| Red Chilli | 39768 | 189572 | 50910 | 13770 | 26969 | 75405 | 65973 | 61899 | 55563 | 53199 | 54926 |

Source: BPS-Statistics of Enrekang District (2023)

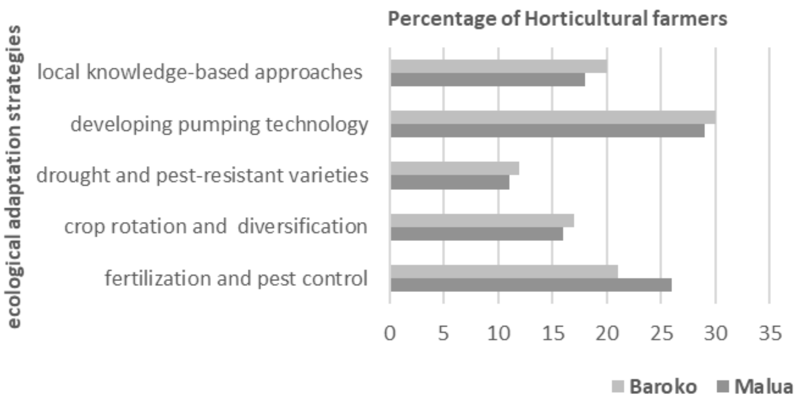


**Figure 3.** Adoption of adaptation strategies in Enrekang District, South Sulawesi Province, Indonesia

Pumping has emerged as the primary strategy chosen by horticultural farmers in the two research locations, with 30% of farmers in Baroko and 29% of farmers in Malua opting for this method. Farmers channel water from nearby rivers into specially constructed holding tanks within their planting areas. This water is then distributed through a piping system to the planting areas at regular intervals. The placement of water tanks at an elevated position within the planting area facilitates the manual or machine-assisted distribution of water.

The introduction of pumping systems has alleviated water scarcity issues for farmers during the dry season, encouraging them to prefer horticulture during the dry season over the rainy season. This shift is motivated by the challenges posed by pathogenic fungi during the rainy season, which can lead to crop diseases such as wilt and result in losses for farmers. However, the practice of pumping is considered somewhat inefficient, as each farmer needs to purchase their own pumping machine and pipes for their respective planting areas. Those with greater financial resources may extend support to less affluent farmers by lending them pumps and pipes, exemplifying a mutual assistance culture known as “gotong royong”. This observation is consistent with the findings Arifah et al. (2022), emphasizing the significance of social networks is evaluating farmers' adaptability, hinging on trust, communication, and support within the adaptation process.

*Fertilization and pest control*

Changing climatic conditions have led to reduced soil fertility, making fertilization a paramount concern for farmers. Over the last century, improved fertilizer and pesticide use has played a crucial role in enhancing agricultural production (Gemeda et al. 2023). Both organic and inorganic fertilization, which augment nutrient availability and soil fertility, are essential for horticultural farmers. Farmers employ a range of fertilizer practices, including domestic organic fertilizers (compost), local inorganic fertilizers, and more costly imported inorganic fertilizers. While fertilization is considered a soil conservation practice, it is also of significant importance in agriculture-based countries such as Indonesia, Vietnam (Nguyen and Drakou 2021), and Ethiopia (Teklewold et al. 2019). Nevertheless, farmers generally do not adhere to recommend procedures for inorganic fertilizer application, still relying traditional practices post-planting.

In addition to fertilizers, farmers employ an array of pesticides, encompassing insecticides and fungicides. The use of pesticide on horticultural crops, particularly shallots, revealed the application of up to 67 different pesticides, administered twice daily (morning and evening) at varying concentrations. This indiscriminate use of pesticides is also believed to exacerbate insect infestations in the planting area (Mehmood et al. 2021).

The primary pests affecting horticultural crops in the study area, especially shallots, are caterpillar (originating from butterfly eggs) and wilt disease (*Fusarium* spp.). Caterpillars, particularly wilt, inflict significant damage on farmers' crops, leading to decreased yields and, in severe cases, crop failure (Escarcha et al. 2020). The frequency of crop failures necessitates both chemical adaptations (the use of fertilizers and pesticides) and biological adaptations (using high-quality seeds, crop rotation, and localized technological innovations) (Williams et al. 2019). The continued utilization of traditional methods is believed to contribute to the persistent occurrence of wilt disease, especially in shallot plants which are over 40 days old. Education and knowledge are instrumental in facilitating an efficient and effective adaptation process (Guo et al. 2021; Ricart et al. 2022).

The excessive use of insecticide has led to outbreaks of secondary pests (Rakib et al. 2019). Fahad et al. (2021) observed that escalating insecticide usage to control primary pests correspond to the development of pest resistance and increased secondary pest populations. Furthermore, the widespread use of pesticides in agricultural production gives rise to health risks, financial burdens, productivity losses, and environmental damage (Mahmood et al. 2021). The persistent application of various chemicals, including insecticides, herbicides, and fungicides, coupled with nutrient leaching into groundwater and greenhouse gas emissions from agricultural field, has caused significant harm to natural ecosystems (Fahad et al. 2021).

*Local knowledge-based approach*

In addition to drawing from scientific knowledge, horticultural farmers in Enrekang District have embraced adaptation strategies rooted in local wisdom to combat the impacts of climate change. Since pesticide usage exceeded prescribed levels in 2017, farmers have adopted the practice of using ultraviolet lamps, positioned above a container of soapy water, around their planting areas (Figure 4). These lamps serve to deter butterflies from laying eggs in the shallot fields, thereby averting potential attacks on the crops. Any butterflies trapped by the ultra-violet lamps die by falling into the soapy water.

This approach has proven successful, leading to a significant reduction in pesticide usage, up to 50%. Recognizing this achievement, the local government supplied electricity to farmer's huts in each planting area in 2019. In 2020, this method was further developed with the addition of a yellow lights mounted taller poles than the ultra violet lamps. These lights serve a dual purpose: they not only repel butterflies but also provide lighting for the surrounding community. Beyond the lighting method, farmers have also adopted an alternative butterfly trapping technique in 2022, involving the use of mosquito nets within the planting area. These nets are structured like camping tents, affording farmers the flexibility to carry out their daily activities such as planting, watering, and spraying without hinderance. Although this strategy is more costly in terms of acquiring cover for the planting area, it is perceived as more effective (Solichah and Rangga 2018).

The success achieved by farmers with their methods highlights the significance of local knowledge, which is derived from their personal observations and experiences, as a valuable resource for addressing the repercussions of climate change. This observation aligns with the findings of Zarei et al. (2020), indicating that farmers' informal knowledge, rooted in their experiences, learning, and observations, is among the most reliable and acceptable source of knowledge. The active participation of the government in adoption of these strategies highlights the government's acknowledgement of the value of local knowledge in mitigating the impacts of extreme climatic conditions. The involvement of multiple stakeholders in the development of new knowledge can be categorized as a process of knowledge co-production. Knowledge co-production represents an adaptation strategy that is particularly relevant in the context of the increasing frequency of climate change-induced disasters, as it fosters collaborations between local and scientific knowledge (Singh et al. 2021; Arifah et al. 2023).

*Drought and pest-resistance varieties*

Climate change is causing an expansion in the geographic range of pest infestations, making their development less predictable. Consequently, enhancing farmers' capacity to swiftly adapt to climate disturbances and changes is becoming increasingly vital. One climate change adaptation technique involves the use of crop varieties that are well-suited and resilient to environmental stresses, and possess resistance to pests and plant diseases. This method aims to mitigate the threat of new pest and disease outbreaks, as well as to counteract the detrimental effects of existing pests.

However, based on the insights gained from interviews with farmers in the study areas, it appears that this adaptation approach is less favored by horticultural farmers compared to other strategies. Farmers predominantly opt for new varieties originating from Bima District (West Nusa Tenggara) or Brebes District (Central Java). These seeds are generally considered to be more resistant to pest attacks and demonstrate higher growth potential compared to local seeds or crops. Nonetheless, further research is needed to establish the suitability of these new varieties addressing the impacts of climate change. Compatibility of these new varieties with local agro-ecological factors requires scientific testing and validation to ensure higher productivity during challenging periods (Omerkhil et al. 2020).

The ability of local communities to adapt their pest management practices is contingent on their physical, social and financial resources. Farmers engaged in supplementary activities are more inclined to consider alternative methods for mitigating climate-related adversities (Omerkhil et al. 2020). Other factors influencing farmers' adoption of drought and pest-resistant crop varieties include the role of agricultural extension workers and access to climate information.

This finding is consistent with a study conducted in Afghanistan, which reported that variables like access to agricultural extension services and delays in the rainfall significantly influence households in using drought-resistant crops as a climate change adaptation strategy (Gemeda et al. 2023). Implementing measures to curtail the proliferation, of pests will necessitate new agricultural practices and the adoption of integrated pest management approaches that not only reduce adverse environmental impacts but also enhance agricultural yields and economic benefits.

**Diversification and crop rotation**

The incidence of crop failure due to extreme weather events has compelled horticulture farmers to diversify and implement crop rotation practices. This aligns with the findings of Gemeda et al. (2023), which indicates that production losses and drought events significantly influence the decisions-making of farmer households in southwestern Ethiopia, prompting them to adopt diversification and crop rotation.

**Figure 4.** The use of ultraviolet light to protect onion plants from butterfly attack

In the study area, farmers have transitioned from predominantly cultivating shallots to diversifying and rotating horticultural crops such as cabbage, chili peppers, and leeks. This approach holds greater significance for horticultural producers in both study locations compared to employing drought and pest-resistant varieties, which rank fourth in the hierarchy of adaptation methods. This suggests that horticultural farmers in the region preferred crop rotation and diversification over the cultivation of drought and pest-resistant varieties. Interestingly, this finding contrasts with farmers in southwestern Ethiopia, who exhibit a higher inclination towards implementing drought-resistant crops as a climate change adaptation strategy rather than diversifying their crop portfolio (Gemeda et al. 2023).

Crop rotation and diversification are crucial tools for enhancing the climate resilience of crop production systems (Kumar et al. 2020). In Enrekang District, horticultural farmers employ crop rotation and diversification when their shallot crops cease to be productive or when pest infestations become controllable with pesticides. These practices effectively disrupt the pest and disease cycles (e.g., worms, fungal infections, and wilt) that may exacerbate with increased climate variability (Yassi et al. 2019; Makate et al. 2023).

Successful crop rotation has contributed significantly to soil fertility and organic matter, resulting in improved yields. However, the effectiveness of crop rotation is contingent on good management and farming practices. Crop diversification and the enhancement of cropping patterns are critical adaptation strategies that play an important role in mitigating food vulnerability (Mallari and Ezra 2016; Blackmore et al. 2021).

### Farmers' challenges in responding to changing climate

In conjunction with the development of adaptation strategies to cope with ecological changes, the need for funding for the maintenance of horticultural crops is increasing, and many farmers lack the financial means to support their farming endeavors. Farmers who are financially constrained resort to a variety of strategies. Some are compelled to leave their land uncultivated, while others opt to lease their land through profit-sharing agreements. Some may seek financing from banks that offer credit systems with payments scheduled after the harvest. Notably, the primary costs incurred by farmers in connection with their adaptation efforts include the acquisition of pumping and drainage systems for their land, the procurement of lights and butterfly trap tents, and the purchase of pest and drought-resistant seeds.

Research has revealed that farmers' ability to adapt to climate change depends on a range of factors such as economic resources, infrastructure, access to information, social capital, agro-ecological arrangements, and land accessibility (Williams et al. 2019). Additionally, farmers establish social connections with financial backers or banking institutions to address their mounting funding requirements, encompassing both equipment procurement costs and operational expenses that they obliged to incur.

Adaptation strategies are not solitary, individual choices; they are intricately linked to the social and cultural systems that support agriculture (Múnera and van Kerkhoff 2019). Employing hybridization techniques that meld knowledge and socio-cultural considerations with the recognition of cultural aspects, traditions, knowledge and experiences of farmers in their interactions with nature holds great promise for agricultural sustainability (Charatsari et al. 2020; Faye 2020). This reflects how farming households are intertwined with a shifting ecological context, which informs their farming decisions.

In conclusion, the ecological adaptation pattern of horticultural farmers in Enrekang District can be classified into two primary patterns. The first pattern is the technological adaptation pattern, which includes pumping, the use of lights, fertilization, crop rotation, the utilization of mosquito nets, the adoption of superior seeds, and application of pesticides to combat the effects of climate change, including water scarcity and increased pest attacks. The second pattern is the social adaptation pattern, involving the mobilization of capital from individuals and financial institutions to finance the growing operational costs resulting from the utilization of various adaptive technologies within the horticultural farmers' ecological adaptation pattern.

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