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Livestock farming sustainability and forage production in volcanic-hazard prone areas of Indonesia's active volcano

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ABSTRACT

Volcanic eruptions have varied and complex impacts on small-scale livestock farming located in volcanic hazard-prone areas due to diverse stock, rearing, and feeding practices. The study was aimed to clarify the critical factors for designing forage recovery and sustainable livestock production in high-risk-prone areas of active volcanic mountains. A total of seventy-five ruminant livestock farmers located in the eruption-impacted areas of five active volcanoes were surveyed on flock size, rearing, and feeding practices. They were interviewed about their experiences of the eruption's impact on the animals, forage feed, and livestock mitigation regarding survival efforts. Forage plants and soil samples were collected to analyze dry matter and crude nutrient composition and estimate the botanical composition, biomass production, and carrying capacity. Results showed that there were five species of ruminant animals reared in small flock size (< 7 heads/farm): beef cattle, buffalo, horses, goat, and sheep. Beef cattle and goats were the most popular farm animals raised in different breeds, rearing, and feeding systems. The volcanic eruption caused animal loss and health problems due to exposure to volcanic materials, forage damages, and animal mitigation constraints, resulting in flock size decrease and economic loss. The impact of the eruption on farm animals and forage plants varied among the volcanoes due to diverse eruptive characteristics, stock breed, rearing, and feeding practices. Livestock farming recovery post-eruption depended largely on the survival flock and the regrowth of forage plants. In conclusion, sustainable beef cattle farming in volcanic hazard-prone areas might be realized by effective livestock mitigation efforts, selecting appropriate types of animals and rearing/feeding systems based on agroecological conditions, and improving forage capacity and survival rate during and post-eruption.

Keywords: Active volcano, Beef cattle, Eruption-impacted areas, Livestock recovery, Livestock mitigation, Volcanic eruption

INTRODUCTION

As a part of the Pacific ring of fire, Indonesia has a high frequency of volcanic eruptions (Weill, 2004). Volcanic eruptions will produce several hazards for people, animals, and vegetation in high-risk zones. More than 8.6 million Indonesians live in the high-risk volcanic zones 10 km from the eruption center (FAO, 2020). The high-risk zones are generally inhabited by small-scale family farmers who make a living from subsistence agriculture and livestock farming (Rozaki *et al*., 2022a). The volcanic mountains are climatically and ecologically diverse, resulting in a wide range of agricultural and livestock farming practices (Wilson *et al*., 2012). The farmers grew various horticultural and annual crops and kept farm animals (Tampubolon *et al*., 2017; Rozaki *et al*., 2022b; Rozaki *et al*., 2023). Farm animals were dominated by ruminant types, primarily cattle, goats, and buffalo, which utilize feed sources of agricultural byproducts and forages derived from various types of wild vegetation grown around the farm or villages (Priyanti and Ilham, 2011; Umami *et al*., 2015). The farm animals play an integral part in agricultural farming and are involved in farm production as dough power and a source of organic fertilizer (Rozaki et al., 2023; Priyanti and Ilham, 2011; Umami *et al*., 2015).

Volcanic eruptions generate material hazards of ashfall, pyroclastic flows (hot clouds), toxic gases, and lahars, which are significant disturbances in the high-risk hazard zones. The active volcanoes are diverse in eruption characteristics and period. The eruption might encompass a large agricultural area and last for a short time or continue to erupt episodically over a relatively long period. The first eruption is likely to be followed by a sequence of further outbreaks during the upcoming weeks, months, or even years, resulting in varied and complex impacts on small-scale farmers, farm animals, and forage plants living in high-risk volcanic zones. Agricultural farming and other economic activities (trading, mining, tourism) could be inactive for a long time due to severe damage to crop plants, properties, and public and agricultural infrastructure of roads, bridges, and waterways (Naspiah *et al*., 2017; Utami *et al*., 2018; Rozaki *et al*., 2022a; Dede *et al*., 2022).

Farm animals are also susceptible to health problems and starvation due to hazardous volcanic materials and feed shortages. Volcanic ash and toxic gases may be poisonous and result in various clinical diseases, including hypocalcemia, fluorosis, forestomach and intestinal damage, and secondary metabolic disorders, resulting in economic loss due to animal and body weight loss, delayed reproduction, and price fall (Wild *et al*., 2019; Wilson *et al*., 2012). Forages may be damaged or destroyed by volcanic ash, leading to a shortage of feed supply for farm animals (Neild *et al*., 1998).

Efforts to evacuate livestock from the disaster areas are impractical due to poor road network, ashfall blockage, and remobilized ash inhibiting visibility (Wilson *et al*., 2012). Economic losses in livestock animals are devastating for smallholder farmers. There were a few cases of human victims due to reluctance to be evacuated because they didn't want to leave the livestock (Rozaki *et al*., 2022b). The role of animals not only supports farm production but also acts for saving and convertible income (Leneman *et al*., 2012). Livestock should, therefore, be protected from the negative impact of eruption and must be evacuated closely related to human evacuation efforts.

The eruption's impact on livestock and forage feed sources could be different among the active volcanoes due to the different characteristics in eruption, height and topography, vegetation, agroclimatic, and farming systems (Neild *et al*., 1998). Grass and other wild plants destroyed during an eruption outbreak will be recovered post-eruption, making them available for feeding ruminants. The types of vegetation or plants surviving and recovering after volcanic eruption depend upon eruption characteristics, rainfall, the nutrient content of volcanic materials, and the distance from the volcanic activity (Haryadi *et al*., 2019; Sutomo and Wahab, 2019; Ishaq *et al*., 2020).

The present research was aimed to assess livestock farming practices and the diversity, availability, and quality of forage plants in the eruption -impacted areas in five active volcanic mountains in Indonesia. The current findings might contribute to designing an appropriate approach for sustainable livestock farming, feed supply, and mitigation efforts in the volcanic disaster-prone areas.

MATERIALS AND METHODS

Study Sites

The study was conducted in five active volcanic mountains in Indonesia. They are distributed on five different islands. They were Agung Mountain (Bali Island), Gamalama Mountain (North Maluku), Lokon Mountain (North Sulawesi, Merapi Mountain (Central Java), and Sinabung Mountain (North Sumatra). The selected mountains were among Indonesia's twenty most active volcanoes (Hariyono and Liliasari, 2018). They have different characteristics in eruption, height and topography, vegetation, agroclimatic, and agricultural and livestock farming systems, and at least they have had 2-3 eruptions in the last ten years. Table 1 shows geography characteristics, major farming systems, eruption histories, and eruption-impacted areas of the selected volcanoes.

Field Survey on Livestock Farming and the impact of the Eruption

A field survey was carried out from July to August 2023 in the eruption-impacted areas to gain information on livestock farming practices and forage feed potency, the impact of the eruption and volcanic material spewed on farming activities, farm animals, and fodder feed in eruption-impacted areas, and mitigation effort for protection and survival of livestock animal during the eruption. Seventy-five ruminant livestock farmers (15 farmers of each mountain area) were selected purposively, as respondents. They were selected as key respondents of high-risk volcanic zones since they had experienced the disaster of volcanic eruptions (Table 2).

The respondents were visited and interviewed on the farm using a questionnaire for their experiences on the eruption's impact on the animal, forage, and mitigation regarding survival efforts during and post-eruption. Data included the type and number of livestock, raising and feeding practices, the impact of erupted ash and other volcanic materials on farm animals and forage feed, and mitigation and protection efforts for animals and feed sources pre-, during, and post-eruptions.

Collection and Analysis of Forage and Soil Samples

Samples of plants were collected in the eruption-affected areas to define the diversity, availability, and quality of forage feed post-eruption. Plant samples were taken in the areas where farmers usually collected forage for feeding their animals or their farm animals were frequently grazed and tethered. The sampling method applied stratified random sampling to represent the diversity of plants at different altitudes and distances from the crater (eruption center) (Alima *et al*., 2020). The sampling locations were divided into three distances from the crater (eruption center): near, moderate, and far. The distance of sampling locations was taken into sampling variable because of diverse distribution patterns of volcanic materials, that affected soil characteristics and plant regrowth (Sivarajan *et al*., 2017). The coarse particle falls near the eruption center, and the finer particles dispersed by wind and fall far away the center, depending on the height of the eruption column, air temperature, and the direction and speed of wind (Hamdan *et al*., 2008; Wilson *et al*., 2012). Samples were taken randomly at five sampling points at each distance location using a quadrant plate meter of 0.5 x 0.5 m^2. Those plants were cut 5-10 cm above ground level and placed in labeled plastic bags. The fresh samples were weighed, separated into different species, and calculated botanical composition and identify predominant species. Botanical composition was calculated in percent by dividing the fresh weight of individual species by the total weight of individual sam-

Table 1. Geological and agricultural characteristics of five active volcanoes in Indonesia

	Name of volcanic mountains				
	Agung	Gamalama	Lokon	Merapi	Sinabung
Location [(2)]	Karangasem district, Bali province.	Ternate city, North Maluku province.	Tomohon city, North Sulawesi province.	Magelang, Sleman, Yoyakarta, Boyolali, Klaten districts, Central Java province	Karo district, North Sumatra province.
Geographical coordinate [(1)]	8.3429°S 115.5072°E	0°48′ North Latitude, 127°20′ East Longitude	1°21′29″N 124°47′31″E / 1. 358°N 124.792°E	7°32′30″NL 110°26′e0″EL	3.17°10'NL 98°22.5'EL
Height above sea level (m) [(1)]	3.142	1.715	1.580	2.968	2.460
Rainfall (mm) [(2)]	17.5	13.1	44.7	111.0	175.5
Major farming activities	Livestock and agriculture farming	Perennial agricultural farming	Horticultural farming	Horticultural farming	Perennial and horticultural farming
Main farming commodities	Beef cattle, vegetable	Nutmeg, cloves, and coconut	Vegetables and flowers	Vegetables	Coffee, vegetables, flowers, and fruits
Eruption history [(1)]	November 2017 March 2018 June 2019	December 2011 September 2012 October 2018	July 2011 August 2015	May 2018 June 2020 November 2020	June 2019 August 2020 March 2021
Eruption types	Strato			Effusive eruption	
Eruption-Impacted areas [(1)]	Ban, Sebudi, Besakih, Buana Giri, Jungutan, and Dukuh villages.	Togafo, Lot, and Takome villlages	Pineleng subdistrict, Tateli, and Tanawangko villages	Srumbung and Dukun subdistricts	Berastagi, Merdeka, and Dolat Rakyat subdistricts

[(1)] Source: https://id.wikipedia.org/wiki/ (cited: August 31, 2023).
[(2)] Center for Database Online from the National Board for Meteorology and Climatology (BMKG): https://dataonline.bmkg.go.id/ (cited: August 31, 2023).

ples and then multiplying with 100%. Plant species that had a proportion of a minimum of 5% were then identified as predominant species (Yuherman *et al*., 2017).

The samples were then chopped and mixed at the same sampling point. Representative samples of about 150 g were taken and dried in an oven at 60ºC for 48 hours and ground in meal form before analysis for dry matter (DM) and crude nutrient (crude ash, crude protein, and crude fiber), and fiber fraction (neutral detergent fiber, acid detergent fiber, and hemicellulose) content. DM content was used for the estimation of biomass production and carrying capacity. The DM and nutrient content were analyzed by following the procedures described by AOAC (2006). Biomass production was calculated by using the formulas of Infitria and Khalil (2014).

Table 2. The study sites and background of selected respondents in the eruption-impacted areas in the five active volcanic mountains in Indonesia

I t e m	Agung	Gamalama	Lokon	Merapi	Sinabung
Study site (village, subdistrict, district, province)	Basakeh, Rendang, Karang Asem, Bali	Takome, West Ternate, Ternate city, North Maluku	Wakilan, North Tomohon, Tomohon city, North Sulawesi	Krinjing, Dukun, Magelang, Central Java	Sigarang-garang, Naman Teran, Karo, North Sumatra
Age of respondent (year) (range)	50.7 (25-80)	53.9 (39-75)	47.1 (26-70)	39.7 (19-60)	41.4 (22-73)
Family number (person) (range)	4.1 (2-6)	4.5 (3-6)	3.8 (1-6)	3.3 (1-5)	4.1 (2-7)

Biomass production (tons DM/ha/year) = {(fresh sample weight x 4) x 10000 m^2 x 365/60}x% DM. Daily biomass production is calculated by dividing the total biomass production by 365 days. Carrying capacity in animal unit per ha (AU/ha) = {(biomass production/365)/{(2.8/100) x 450 kg}. The carrying capacity was estimated based on. An animal unit is equivalent to a 1000 pound cow (450 kg) with a DM requirement of 2.8% (Infitria and Khalil (2014).

Samples of soil were obtained using a stainless-steel sampling auger to a depth of 10-15 cm (topsoil). Soil samples were taken from the same sampling points of which the forage samples were taken (Khalil *et al*., 2016). The fresh samples were freed from plant roots and other foreign contaminants and dried under the sun. The air-dried samples were reduced and uniformed the particle sizes by manual grinding using a glass bottle and then sieved through a 2-mm sieve. The samples were analyzed for DM and minerals (calcium, phosphorus, magnesium, potassium, and sulfur). The total calcium, magnesium, and sulfur were analyzed using a flame photometer according to the procedures described by Eviati and Sulaeman (2012). The potential potassium was measured using an atomic absorption spectrophotometer (Eviati and Sulaeman, 2012). The potential phosphorus was analyzed using the Bray method (ISRIC, 2022).

Data Analyze

Data on DM and proximate composition, biomass production, carrying capacity of forages, and mineral composition of soil were statistically analyzed in one-way variance analysis using the SPSS software version 18. The variance analysis was followed by Duncan post hoc multiple comparisons to estimate significance at the level 5%. The results were expressed as mean ± SD.

RESULTS AND DISCUSSION

Livestock Rearing and Feeding Practices

Table 3 shows the population number, cattle breed, rearing, and feeding practices of farm animals. There were five ruminant animals: beef cattle, buffalo, horse, goat, and sheep. Farmers in the Sinabung mountain had the most diverse types of livestock, followed by the Lokon mountain with three types of animals. The animals are raised in small flock sizes with a mean population of less than seven animals per farm. The animal types and population reduced post-eruption due to being sold, dying, or disappearing. The farmers want to increase their livestock numbers post-eruption. However, the eruption disaster damaged their properties, crops, and other economic sources, preventing the small farm holders from restocking due to the poor financial state of farmers post-eruption. Other reasons for limited flock size were due to limited labor (Lokon mountains) and forage shortage (Agung mountains).

Beef cattle were the most popular farm animals in the volcanic areas, followed by goats, presumably due to better adaptation to mountain agroclimatic conditions and more resistance to eruption disasters than other types of ruminant animals. Priyanti and Ilham (2011) reported that the mortality rate of beef cattle was only 1.2% which was significantly lower than the mortality of dairy cattle of 8.3% from the eruption disaster in the Merapi mountain in 2010. Beef cattle might also be more likely to be involved in farm productions as dough and traction powers due to better heat resistance than buffalo (Winarto *et al*., 2000).

Moreover, there were differences in cattle and goat breeds, rearing, and feeding practices. Farmers in the Agung and Gamalama mountains had the same local breed of Bali cattle but were raised differently. Beef cattle in the Agung Mountain were kept by tying in simple open-air shades for 24 hours with a cut-and-carry feeding system. Forages composed of exotic elephant grass and wild vegetation were collected around farmyards and forest areas. Feces were used to fertilize crops and forage plants. In the Gamalama mountain, cattle were kept in simple paddocks at night and freed during the day to graze and utilize wild vegetation grown around the house yard or plantation areas (nutmeg, coconut, banana).

Beef cattle in the Lokon mountain was dominated by Ongole crossbreed, characterized by a big hum in the back body part of male cattle. They had higher body sizes than Bali cattle. Cattle and horses were involved in farming activities as a source of dough power for land preparation and transportation. The animals were fed by a tethering system. They were equipped with long ropes and by tying the rope's end to a tree or other firm object. They were fed using agricultural byproducts and tethered around house yards, harvested crop plantation areas, idle lands, roadsides, or riverbanks.

In the Merapi and the Sinabung mountains, Simental and Limousine were dominant cattle breeds. Cattle in the Merapi were kept for 24 hours in closed stalls made from concrete walls. They were fed using agricultural byproducts and forages collected around the horticultural farm. Feces were used for crops and forage plant fertilizer. In the Sinabung mountains, cattle were kept in simple shelters at night, free grazing in forest or communal grazing areas near the eruption center. They used buffalo for traction and transportation power in crop production.

Table 3. Type and number of animals, cattle raising, and feeding practice in the eruption-impacted areas in Indonesia's five active volcanic mountains.

Parameters	Name of volcanic mountains				
	Agung	Gamalama	Lokon	Merapi	Sinabung
Species and number of ruminants (range) (heads/farm):					
• Beef cattle	5.9 (2-20)	6.4 (0-10)	4.8 (1-30)	2.3 (1-4)	4.4 (0-40)
• Buffalo	-	-	-	-	4.4 (0-13)
• Horse	-	-	0.6 (0-6)	-	0.1 (0-1)
• Goat	0.4 (0-6)	1.4 (0-17)	0.3 (0-5)	-	2.1 (0-9)
• Sheep	-	-	-	-	1.1 (0-15)
Cattle breed	Bali cattle	Bali cattle	Ongole crossbreed	Simental and Limousine	Simental and Limousine
Cattle rearing and feeding system	Open-air stall, cut and carry feeding	Free grazing	Tethering system	Closed stall, cut and carry feeding	Free grazing

There were two breeds of goats reared by some respondent with diverse flock size ranging from 5 to 17 heads/farm: : Kacang and Peranakan Etawa PE). The exotic PE goats were kept in wood-made simple houses. They were fed grass, shrubs, broadleaves, and tree leaves. On the other hand, the local breed of Kacang goats were kept semi extensively by free grazing or tethering systems to utilize various wild vegetation growing under tree crop plantation, roadsides and idle lands located around the farm and owner houses.

The present results indicated that beef cattle and goats have diverse breeds and production purposes compatible with different agroclimatic conditions and farming systems (Sutarno and Setyawan, 2016). Bali cattle and goats are suitable for intensive and semi-intensive rearing practice in warm climatic conditions with limited forage availability and quality, like in the Gamalama and Agung mountains (Sutarno and Setyawan, 2016; Hariyono and Endrawati, 2023). The Ongole crossbreeds and horses are well-known working farm animals due to their strong and big body size, tame and quiet, heat-tolerant, and easy to adapt to the environment (Sutarno and Setyawan, 2016; Mischka, 1992). The robust cattle and horses were, therefore, suitable for supporting farm production in the horticultural farming region, like Lokon Mountain.

Moreover, the exotic cattle and goats might be less suitable to develop in the volcanic-high-risk zones. They are reared intensively and need more feed with better quality than the local breed due to higher body sizes and better growth rates. However, due to limited feed supply and abandonment, they might be more sensitive than the local breeds during eruption disasters. Consequently, exotic breeds have more problems in health, production, and reproduction, resulting in more economic loss. Khalil *et al*. (2019) found that the Simental heifers reared by traditional small farm holders faced reproductive disorders due to malnutrition and poor shelter conditions. Farmers in the Merapi and Sinabung mountains are suggested to local beef breeds such as Ongole or Brahman crossbreeds.

Impact of Eruption on Farm Animals and Forages

The impacts of eruptions on farm animals and forages are summarized in Table 4. Volcanic eruptions had direct and different impacts on farmers, farm animals, and forages, depending on the type of animals, rearing, and feeding systems. The common harmful effects of volcanic eruptions on farm animals kept in stalls with cut and carry or tethered feeding systems in the Merapi, Agung, and Lokon mountains were animal death and injuries, body weight loss, reproduction disorder, health problems. It was due to hot ash and cloud hits, abandonment, and inadequate feed and water intake. The free-grazed beef cattle and goats in the Gamalama and Sinabung mountains had body injuries and eye irritation, leading to health problems, eye infections, and severe vision problems. It was because of small particles of ash in the air and exposure to toxic volcanic materials. Farm animal death and loss cases were reported in the Sinabung and Gamalama mountains, respectively. The case of cattle death in Sinabung Mountain was due to gastrointestinal complications from ash consumption. Beef cattle were freely grazed in a forest area located close to the eruption center. Cattle death due to starvation and gastrointestinal complications from ash consumption were also reported as the primary cause of livestock mortality (Rubin *et al*. 1994). The case of losing cattle and goats during a volcanic eruption occurred in the Gamalama mountain, where the free-grazed animals fled and escaped and did not come back to the yard, presumably due to panic and loss of grazing areas.

Volcanic eruptions significantly impacted forage plants and feed supply for farm animals in all study sites. Ashfall blanketed the farmland and covered the forage plants. Pyroclastic flows and explosive blasts of hot gases and solids caused the complete destruction of forage and other vegetation in impacted areas. As shown in Table 4, there were two major serious impacts of volcanic materials on forage plants. These forage damage and contamination, reducing feed supply

Table 4. Impact of eruption on livestock and forages in the five active volcanoes in Indonesia.

Parameter	Agung	Gamalama	Lokon	Merapi	Sinabung
Farm animal	Cattle were sold far under normal price to minimize economic loss	Body injuries and cattle loss due to escape from the yard.	Cattle loss due to death. The animals were left on the farm, and the owner stayed refugee camp.	Body weight loss due to abandonment and inadequate feed and water intake.	Animal death due to ingesting volcanic ash and exposure to toxic gases
	Cattle suffer from eye irritation due to exposure to volcanic ash and gases.	Cattle suffer from eye irritation due to exposure to volcanic ash and gases.		Delayed reproduction due to mall nutrition.	Body injuries due to ashfall and accident
Forages	Plants were severely damaged and contaminated due to ashfall.	Loss of grazing areas due to farmyards covered by volcanic ash.	Plants were severely damaged and contaminated due to ashfall.	Plants were severely damaged and contaminated due to ashfall.	Loss of grazing areas due to farmyards covered by volcanic ash.
	Poor palatability due to contamination with ash and gases.	Poor palatability due to contamination with ash and gases.	Poor palatability due to contamination with ash and gases.	Poor palatability due to contamination with ash and gases.	Poor palatability due to contamination with ash and gases.

Table 6. The biomass production, carrying capacity, dry matter, and crude nutrient content of forages derived from the five active volcanoes in Indonesia.

Parameter	Name of volcanic mountains				
	Agung	Gamalama	Lokon	Merapi	Sinabung
Biomass production in DM:					
- ton/ha/year	$11.2^{bc}\pm1.9$	$5.1^{c}\pm2.7$	$17.7^{ab}\pm3.5$	$11.7^{b}\pm2.9$	$18.9^{a}\pm4.9$
- kg/ha/day	$32.0^{bc}\pm4.0$	$15.2^{c}\pm6.7$	$49.6^{ab}\pm9.2$	$30.0^{b}\pm6.3$	$54.6^{a}\pm11.5$
Carrying capacity					
-AU/ha	$2.6^{bc}\pm0.5$	$1.2^{c}\pm0.6$	$4.1^{ab}\pm 0.8$	$2.7^{b}\pm0.7$	$4.4^{a}\pm1.1$
DM content (% FW)	$15.9^{c}\pm1.0$	$27{,}4^{b}\pm5.1$	$34.7^{a}\pm5.0$	$19.1^{c}\pm0.4$	$20.3^{c}\pm2.0$
Crude nutrient content (% DM)					
- Crude ash	$13.5^{ab}\pm2.5$	$12.2^{b}\pm2.1$	$14.2^{ab}\pm1.0$	$16.1^{a}\pm0.5$	$13.0^{ab}\pm0.5$
- Crude protein	15.7±2.4	10.2±2.1	13.8±1.2	14.9±4.8	10.5±1.4
- Crude fat	2.3±0.3	1.6±0.73	1.8±0.2	1.8±0.1	1.8±0.2
- Crude fiber	$32.6^{ab}\pm5.6$	$34.2^{ab}\pm3.3$	$24.8^{b}\pm5.5$	$39.0^{a}\pm3.4$	$34.4^{ab}\pm11.4$
- Nitrogen free extract (NfE)	$35.9^{ab}\pm6.4$	$41.8^{ab}\pm3.0$	$45.4^{a}\pm7.3$	$28.3^{b}\pm7.5$	$40.3^{ab}\pm12.5$

[a,b,c;] Means within a raw with different superscripts differ significantly ($P<0.05$)

Table 5. The diversity and botanical composition of forages grown in the five active volcanoes in Indonesia

Group	Agung		Gamalama		Lokon		Merapi		Sinabung	
	Species name	%	Species name	%	Species name	%	Species name	%	Species name	%
Grass	***Pennisetum purpureum****	**64.3**	***Chrysopogon zizanioides***	**49.7**	***Panicum maximum***	**42.7**	***Pennisetum purpureum***	**62.8**	***Axonopus compressus***	**58.3**
	Axonopus compressus	2.2	***Axonopus compressus***	**29.9**	***Axonopus compressus***	**14.0**	***Axonopus compressus***	**5.8**	***Leersia hexandra Sw***	**10.2**
	Panicum maximum	1.7	***Cyperus rotundus***	**12.1**	***Setaria barbata***	**9.4**	*Panicum maximum*	3.9	*Imperata cylindrica*	3.4
	Imperata cylindrica	1.3	*Japanese stiltgrass*	0.4	*Imperata cylindrica*	1.2			*Cyperus rotundus*	0.2
			Chrysopogon aciculatus Retz	0.4						
		69.5		**92.5**		**67.3**		**72.5**		**72.3**
Herb	***Justicia gendarusa***	**13.9**	*Melampodium divaricatum*	4.6	***Alliaria petiolata (6.1)***	**6.1**	***Justicia gendarusa***	**8.6**	***Justicia gendarusa***	**7.2**
	Ageratum conyzoides	1.5			***Crassocephalum crepidioides***	**5.4**	***Ageratum conyzoides***	**7.5**	*Ageratum conyzoides*	4.7
	Alliaria petiolata	1.1			***Ageratum conyzoides***	**5.0**	***Alliaria petiolata***	**5.7**	*Crassocephalum crepidioides*	4.1
	Asystasia gangetica	0.1			*Sonchus arvensis*	4.2	*Elephantopus Scaber Linn*	1.2	*Alliaria petiolata*	3.7
					Wedelia trilobata L	3.2	*Impatiens balsamina L*	1.1		
					Spilanthes paniculata	0.6				
		16.6		**4.6**		**29.8**		**24.1**		**19.7**
Schrub	*Calliandra calothyrsus*	10.3	*Mimosa Pudica (2.1)*	2.1	*Mimosa pudica*	1.1	*Commelina communis*	2.8	-	0.0
			Syzygium australe	0.5	*Commelina communis*	1.1				
		10.3		**2.6**		**2.2**		**2.8**		**0.0**
Fern	*Polypodiophyta sp*	3.6					*Polypodiophyta sp*	0.6	*Polypodiophyta sp*	8.2
		3.6						**0.6**		**8.2**
Legumes			*Desmodium triflorum*	0.4	*Drymaria cordata*	0.8				
		0.0		**0.4**		**0.8**		**0.0**		**0.0**
		100.0		**100.0**		**100.0**		**100.0**		**100.0**
Species number		**10**		**9**		**14**		**10**		**9**

*) bold letter: predominant species with botanical composition of ≥5%.

and making it unpalatable. Rough and hot volcanic materials which composed of ash, sand, gravel, or stones covered and killed the plants, resulting in forage damage and being unavailable for animals. Moreover, volcanic eruptions released fine ash and gases like sulfur oxide and hydrogen sulfide. The fine particle-size ash and smell of volcanic gas stuck to the plants and gave a sulfur-like odor. The animals rejected the sulfur -like odor forages. Farmers in the Gamalama used banana stems as emergency feed for cattle during and post-eruption, while in the Merapi mountain, they used self-mixed concentrate using commercial cattle concentrate mixed with locally available ingredients, such as tofu waste, cassava root wastes, and rice bran.

Farmers in the Agung mountain admitted that they had no alternatives to minimize economic loss and had to sell their livestock to middlemen at considerably low prices, far below the normal price. Livestock were already in poor condition and suffered from starvation and other health problems due to abandonment on farms or the poor condition of the evacuation shelter. Farmers could not care for their animals since they were evacuated and stayed in refugee camps during the eruption. Farmers were also not allowed to visit their farmland and take care of their animals until the eruption had stopped and was declared safe.

The evacuation of livestock was a secondary priority to human evacuation. Except for Agung Mountain, there were no significant efforts made by either farm owners or the government to evacuate farm animals before, during, and after eruptions, although there were gradual disaster warnings from the Center for Volcanology and Geological Hazard Mitigation about the development of the threat of eruption disasters, starting from "siaga" (stand-by) and followed by "awas" (Beware) if there is a significant increase of volcanic activity. The eruption disaster level is categorized into four levels: "Normal" (Normal, Level 1), "Waspada" (Alert, Level 2), "Siaga" (Standby, Level 3), and "Awas" (Beware, Level 4) (National Board for Disaster Management, 2021). The farming families generally left within hours or days of the eruption onset in "awas" status, while livestock was left and abandoned on farms. Several studies have reported that evacuation efforts of livestock from the volcanic eruption-impacted area are impractical and not economically justifiable. It was because of poor access to impacted areas (Wilson *et al*., 2009; Wilson *et al.,* 2012; Wild *et al*., 2019; FAO, 2020). Efficient livestock evacuation during eruptions in Indonesia requires significant planning and standard operational procedure because of scattered small farm locations, limited transport infrastructure and detailed data on livestock populations and locations. Evacuation decisions also require farmers' understanding of how volcanic disasters may impact their farms, as most farmers have a close bond with their livestock and are unlikely to want to lose them (Wilson *et al*., 2009). Instead of impractical evacuation, livestock farmers in the high-risk volcanic zones could also be directed to keep their animals in a semi-intensive rearing system, like in the Gamalama or Lokon mountains, to allow livestock freely to find their own way to survive during moderate or heavy eruptions.

The Forage Diversity, Availability, Quality and Recovery Post-eruption

Table 5 shows the diversity, botanical composition, and predominant forages grown in the eruption-impacted areas. There were, in total, 29 palatable plant species, which were mainly composed of grasses and herbs (75.9%), followed by shrubs (13.8%), ferns (3.4%), and legumes (6.9%). Forage plants were dominated by native wild vegetation. The data showed that ruminant livestock relied on mixed wild forages, which was inherent with Umami *et al*. (2015) who reported grazing land in the post-eruption area of Kali Kuning and Krasak River of Merapi mount are included in the mixed native vegation.

Lokon Mountain had the most diverse species of forage plants, with a total number of 14 species compared to the other four mountains of 9-10 species (Table 5). The forages were underutilized due to low ruminant population (Table 3).

As shown in Table 5, the predominant species that counted botanical composition of ≥ 5% was composed of grasses and herbs. They presumably had better survival rates and regrowth, leading to recovery earlier post-eruption than the other species. The predominant species are therefore the most potential forage plant species to be developed in the future to increase the feed supply in volcanic-prone areas. The types and number of dominant species varied among the study sites. The Lokon mountain had the most diverse dominant species, followed by the Merapi and Sinabung mountains. There was only one dominant species of *P. purpureum*, in the Agung mountain. The predominant grass species with the highest percentage were *P. purpureum, A. compressus*, *Chrysopogon zizanoides*, and *P. maximum*. *P. purpureum* was the most dominant forage in the mountains of Agung and Merapi, *A. compressus* of Sinabanung, and *P. maximum* of Lokon mountain. In the Gamalama mountain, the predominant species of *A. compressus* and *C. zizanoides* were shade-tolerant plants. They were grown under the java plum tree (local name: "jamlang" tree) (*Syzygium cumini* L), which is useful for cattle shading to protect animals from high air temperatures during the day.

Table 6 shows biomass production, carrying capacity, and crude nutrient content of forages. Forage feed post-eruption production capacity and quality varied among the study sites. The mountains of Sinabung had the highest biomass production and carrying capacity, followed by the Lokon, Merapi, and Agung mountains. The Gamalama mountain had significantly the lowest forage capacity. It was noted that the exotic species of *P. purpureum*, which was the predominant species in the Agung and Merapi mountains increased significantly forage productivity and carrying capacity.

DM content ranged from 16-35% of fresh weight. Forages grown in the Lokon mountain had significantly the highest DM content, followed by the Gamalama. The lowest DM had forages derived from the mountain Agung, but there was no significant difference with those from the Sinabung and Merapi mountains. Crude protein and crude fat ranged from 10.2-15.7% and 1.6-2.3% DM. There was no significant difference in crude protein and fat content, presumably due to high data variation. Forage grown in the Merapi mountain had the highest crude ash, but there was no significant difference with those from the Agung, Lokon, and Sinabung mountains. Forages grown in the Merapi also had the highest crude fiber but lowest NfE content, but there was a significant difference with those from Agung, Gamalama, and Sinabung mountains. On the other hand, forages grown in the Lokon mountain had the lowest crude fiber and highest NfE.

The results showed that the production and nutrient content of forages is largely determined by the diversity and predominant species. Forage supply become a crucial factor for sustainable livestock farming in volcanic disaster-prone areas. The Sinabung and the Lokon had the highest biomass production and animal capacity. The data revealed that forages in these areas were better regrown, presumably due to being dominated by *P. maximum* and *A. compressus*. These native grass species had a good survival rate under volcanic material pressure and could be, therefore, considered to be developed in volcanic -prone disaster areas. Another reason for high production, forages could be underutilized in these areas due to a limited number of farm animals (Table 3), characterized by broader plant size and yellowish green color of leaves, low protein, but high crude ash and crude fiber content (Table 6). This has a negative effect on nutritive values. The farmers in the Lokon mountain limited their flock due to limited labor and time. They allocated farm resources more for horticultural rather than livestock farming. In the Sinabung mountains, the farmers have not been able to recover stocks due to financial limitations since the Sinabung erupted repeatedly and over a long period until 2019-2020. Muzayyanah *et al.* (2013) reported that the cattle population in Sleman regency declined 96.7% due to either death or sales post-eruption of the Merapi mountains in 2010. Therefore, livestock farmers in the Lokon and Sinabung need support and help to increase the number of livestock populations post -eruption.

On the other hand, the forage production in the Agung and Merapi mountains is limited, while the grazing lands in the Gamalama were overgrazed, preventing the farmers from increasing flock size. In the Agung and Merapi mountains, forages were dominated by Napier grass (*P. purpureun*), which is well known as a highly productive exotic grass because of its ability to produce large amounts of biomass. This grass is also remarkably drought-tolerant and tolerant of different soil conditions (FAO, 2016). However, this exotic plant had a slow regrowth rate in erupted-impacted land, presumably due to undesirable soil conditions and poor essential nutrients. Baillie *et al*. (2018) indicated that topsoil was acidified, which has a negative impact on mineral uptake, due to volcanic materials and gases. Acidification was accompanied by an accumulation of sulfur in the soil with a high portion of sulfate, consequently depleted of magnesium and potassium. Forages in the Agung and Merapi mountains had significantly low dry matter content (Table 6). Species with lower dry matter possess a lower effective content protection against extreme sulfur accumulation (Baillie *et al*., 2018). Forage production post-eruption could be improved by soil rehabilitation using organic fertilizer and the introduction of acid-tolerant plant species. In the Gamalama mountain, forages were grown under different tree plantations of java plum, nutmeg, and coconut. The shade-tolerant and fibrous species of *C. zizanoides* should be replaced with invasive exotic grass species, such as *Brachiaria decumbens* to improve forage capacity and quality. The low economic value tree of java plum should be replaced with a legume or non-legume-nitrogen-fixing tree, such as *Calliandra spp*, *Leucaena leucocephala*, and *Paraponia rigida*, to enhance soil fertility and forage recovery post-eruption (Ishaq *et al*., 2020).

Farm animals thrived in post-eruption might recover quickly when forages recover quickly. Farmers stated that forage plants would be regrown and recovered about one to six months after the eruption. The rate of recovery and regrowth of forage plants varies among the volcanoes, depending on factors such as rainfall, the plant species, proximity to the eruption center, and the extent of damage (Smather and Dombois, 1974).

CONCLUSION

Livestock farming in the high-risk zones was dominated by small farmholders. Five types of ruminant animals were reared in small flock size (< 7 heads/farm): beef cattle, buffalo, horses, goats, and sheep. Beef cattle were the most popular farm animals raised in different breeds, rearing, and feeding systems. The volcanic eruption caused animal loss and health problems due to exposure to volcanic materials, forage damages, and animal mitigation constraints, resulting in flock size decrease and economic loss. The impact of the eruption on farm animals and forage plants varied among the volcanoes due to diverse eruptive characteristics, stock breed, rearing, and feeding practices. Livestock farming recovery post-eruption depended largely on the survival of the flock and the regrowth of forage plants. It is suggested that sustainable livestock farming in volcanic hazard-prone areas might be realized by effective livestock mitigation efforts, selection of appropriate types of animal and rearing/feeding systems based on agroecological conditions, and improvement of forage capacity and survival rate during and post-eruption.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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