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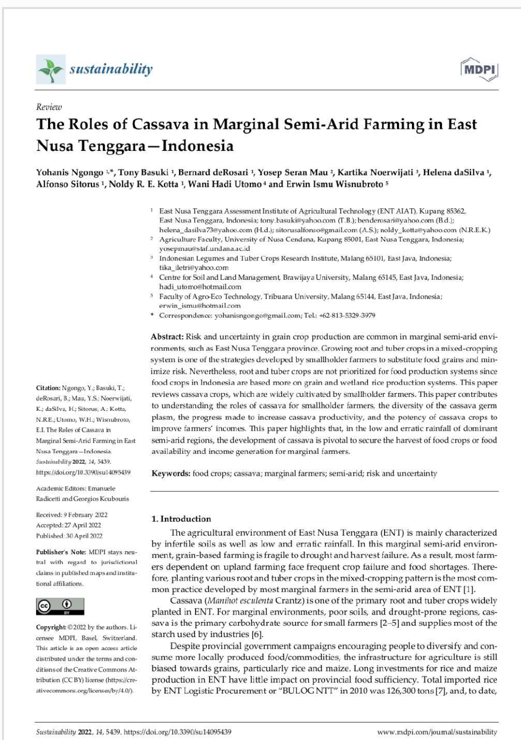
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Review

The Roles of Cassava in Marginal Semi-Arid Farming in East Nusa Tenggara—Indonesia

Yohanis Ngongo [1,*], Tony Basuki [1], Bernard deRosari [1], Yosep Seran Mau [2], Kartika Noerwijati [3], Helena daSilva [1], Alfonso Sitorus [1], Noldy R. E. Kotta [1], Wani Hadi Utomo [4] and Erwin Ismu Wisnubroto [5]

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Abstract: Risk and uncertainty in grain crop production are common in marginal semi-arid environments, such as East Nusa Tenggara province. Growing root and tuber crops in a mixed-cropping system is one of the strategies developed by smallholder farmers to substitute food grains and minimize risk. Nevertheless, root and tuber crops are not prioritized for food production systems since food crops in Indonesia are based more on grain and wetland rice production systems. This paper reviews cassava crops, which are widely cultivated by smallholder farmers. This paper contributes to understanding the roles of cassava for smallholder farmers, the diversity of the cassava germ plasm, the progress made to increase cassava productivity, and the potency of cassava crops to improve farmers' incomes. This paper highlights that, in the low and erratic rainfall of dominant semi-arid regions, the development of cassava is pivotal to secure the harvest of food crops or food availability and income generation for marginal farmers.

Keywords: food crops; cassava; marginal farmers; semi-arid; risk and uncertainty

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1. Introduction

The agricultural environment of East Nusa Tenggara (ENT) is mainly characterized by infertile soils as well as low and erratic rainfall. In this marginal semi-arid environment, grain-based farming is fragile to drought and harvest failure. As a result, most farmers dependent on upland farming face frequent crop failure and food shortages. Therefore, planting various root and tuber crops in the mixed-cropping pattern is the most common practice developed by most marginal farmers in the semi-arid area of ENT [1].

Cassava (*Manihot esculenta* Crantz) is one of the primary root and tuber crops widely planted in ENT. For marginal environments, poor soils, and drought-prone regions, cassava is the primary carbohydrate source for small farmers [2–5] and supplies most of the starch used by industries [6].

Despite provincial government campaigns encouraging people to diversify and consume more locally produced food/commodities, the infrastructure for agriculture is still biased towards grains, particularly rice and maize. Long investments for rice and maize production in ENT have little impact on provincial food sufficiency. Total imported rice by ENT Logistic Procurement or "BULOG NTT" in 2010 was 126,300 tons [7], and, to date,

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Despite provincial government campaigns encouraging people to diversify and consume more locally produced food/commodities, the infrastructure for agriculture is still biased towards grains, particularly rice and maize. Long investments for rice and maize production in ENT have little impact on provincial food sufficiency. Total imported rice by ENT Logistic Procurement or "BULOG NTT" in 2010 was 126,300 tons [7], and, to date, this number has not significantly changed. Similar to maize, the productivity and production of rice are volatile according to the climate, particularly rainfall.

Cultivating cassava is a strategy developed by upland farmers to minimize risk and uncertainty in upland farming. Cassava is an important crop for marginal semi-arid environments as a substitute for grain crops and as a source of cash income. Traditional cassava farming is cultivated with no external input used. Small farmers grow cassava as an integral part of the conventional farming system [8,9]. In terms of various root and tuber crops spread in different agroecological zones (AEZs), only cassava and sweet potatoes are planted in large areas and recorded officially [10] as well as having been studied more comprehensively [11–13].

This paper reviews cassava crops, which smallholder farmers widely cultivate in the dominant semi-arid environment of ENT—Indonesia. This paper aims to understand the roles of cassava for smallholder semi-arid farmers and how they manage to improve cassava farming, productivity, and income generation. It highlights that in the low and erratic rainfall of the dominant semi-arid region, the development of cassava is pivotal to secure the harvesting of food crops or food availability and income generation for marginal farmers.

2. Land and Soil Suitability for Cassava in ENT Province

In Indonesia, cassava plants are found in vast growing environments, in dryland agroecosystems with dry climates and drylands with wet climates, especially on Inceptisol, Ultisol, and Alfisol soils, as well as in areas with varied agroecological conditions, such as areas with dry climates, marginal lands, and optimal lands [14].

Based on the land suitability direction for this commodity, the S1 (very suitable) land suitability class requires rainfall between 1000 and 2000 mm·year^{-1}; temperature 22–28 °C; soil texture, slightly fine and medium; and rocks on the surface and rock outcrops, <5% and not threatened by flood hazard. In the conditions of land slope between 8 and 15%, this plant still grows with limited conditions, and at a sulfidic depth of 40 to 75 cm this plant is also still growing, although the level of productivity is not optimal. Cassava can grow under moderate soil moisture conditions and avoid extremes of inundation or dryness [15].

Furthermore, from the perspective of nutrient availability, cassava plants will still grow optimally if the availability of nitrogen, P_2O_5, and K_2O is in the medium category, namely for total nitrogen, >2%, P_2O_5, >21 mg·100 g^{-1} soil, and K_2O, 21 mg·100 g^{-1} soil [15]. Furthermore, this plant grows well on Rendzina soil (black soil) with a pH of six and Kambisol soil (red soil) with a pH of five in Southeast Maluku [16]. Although cassava can be grown in a wide range of soil textures and fertility, cassava grows well and produces a high yield of tubers in light sandy loam, fertile, and deep soils [17,18]. Depending on the variety and crop management, in a favorable soil environment cassava crops can produce fresh tubers around 31–45 tons·ha^{-1} in Indonesia [19] and up to 67 tons·ha^{-1} in Thailand by applying an additional 100 kg N fertilizer [20]. A summary of land suitability criteria for cassava is presented in Table 1.

Table 1. Land characteristics for cassava.

Land Characteristics	**Land Suitability Class**			
	S1	**S2**	**S3**	**N**
Average temperature (°C)	22–28	>28–30	18–20>30–35	<18 >35
Annual rainfall (mm)	>1000–2000	>600–1000 >2000–3000	500–600 >3000–4000	<400 >4000
Drainage	Good, fairly good	Rapid, imperfect	Poor	Very poor, rapid
Texture	Moderately fine, moderate	Fine, moderately coarse	Very fine	Coarse
Soil depth (cm)	>100	>75–100	50–75	<50
CEC (cmol (+)·kg^{-1})	>16	5–16	<5	-
Base saturation (%)	20	<20	<20	-
pH (H2O)	>5.2–7.0	4.8–5.2 >7.0–7.6	<4.8 >7.6	-
C-organic (%)	>1.2	0.8–1.2	<0.8	-
N total (%)	Medium	Low	Very low	-
P2O5 (mg·100 g^{-1})	Medium	Low	Very low	-
K2O (mg·100 g^{-1})	Medium	Low	Very low	-
Sulfidic depth(cm)	>100	>75–100	40–75	<40
Slope (%)	<3	>3–8	8–15	>15
Flood height (cm)	-	25	>25–50	>50
Long of flood (day)	-	<7	7–14	>14
Rocks on the surface (%)	<5	5–15	>15–40	>40
Rock outcrop (%)	<5	5–15	>15–25	>25

Note: S1: very suitable; S2: suitable; S3: marginal suitable; and N: unsuitable. Source: [15].

In East Nusa Tenggara, the land potential available for cassava plants, based on the agroecological zone (AEZ) map scale of 1:250,000, was 595,530 ha or 13.19% of the land area of ENT. This land includes flat to undulating land with a slope of >3 to 25%. This land includes soil types *Typic haplustalfs*, *Typic ustropepts*, *Typic haplustolls*, *Typic hapludolls*, and *Eutric haplustands*. The potential of this land is spread over the islands of Flores, Sumba, Timor, and Alor, and has not considered nutrient retention conditions [21] (Figure 1). The methodology and detailed land availability distribution for cassava in ENT can be obtain from the Table S1.

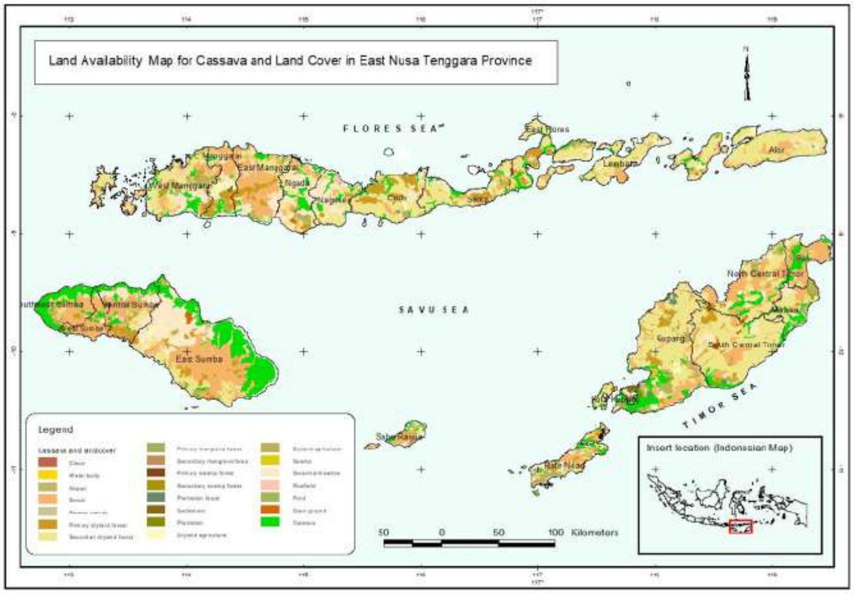

Figure 1. Map of land availability for cassava and land cover in East Nusa Tenggara Province.

Climatologically, the East Nusa Tenggara region is included in the semi-arid area [22,23], with altitudes ranging from lowlands less than 700 m asl covering 74% to highlands above 700 m asl [1]. In terms of soil development, it is dominated by underdeveloped soils, such as Entisol and Inceptisols, and more developed soils, such as Vertisols, Mollisols, Alfisols, and Andosols. These soils develop from basic materials, such as limestone, calcareous sediments, and volcanic materials [21]. Regarding nutrient retention and soil nutrient availability, the value of soil chemical parameters varies, but is generally in the low to high categories.

In West Timor, part of East Nusa Tenggara, the degree of acidity (pH H_2O) generally varies in the neutral to slightly alkaline categories, with values ranging from 7.3 to 8.2, for all the districts in the island [24–29]. C-organic in West Timor varies between locations [30]. Research by [28] showed that the soils overgrown with Sandalwood (*Satalum album*) contained 1.18% (low) organic C-organic located in North Central Timor district and 4.39% (high). Meanwhile, as reported by [31], from each type of Vertisol and Alfisol soil in Kupang, the C-organic values were 1.26 and 1.05% (low), respectively, including for rice fields in Malaka [27]. Similar soil conditions occurred in other locations in Kupang[25] and the medium category, 2.85% [32].

Cation exchange capacity (CEC) is generally classified as medium to high [33], and ranges from 19.84 to 31.67 cmol (+)·kg^{-1} [24,25]. The existence of a good CEC value is closely related to areas dominated by montmorillonite clay type 2:1 [15]. The nutrient retention characteristics, such as pH acidity (H_2O), organic C, and CEC, mentioned above are not much different from the observations at 16 observation points in Sumba island and 16 observation points on soils in Ende, Flores, as presented in Table 2.

Table 2. Soil parameter values in Sumba island and in Ende, Flores.

Soil Chemical Parameters	Sumba		Ende (Flores)	
	Average	Category *	Average	Category *
pH (H_2O)	7.83	Slightly alkaline	6.40	Neutral
C (%)	1.46	Low	2.20	Medium
N (%)	0.09	Very low	0.14	Low
P-potential (P_2O_5 HCl 25%) ($mg \cdot 100\ g^{-1}$)	76.44	Very high	19.44	Low
K potential (K_2O HCl 25%) ($mg \cdot 100\ g^{-1}$)	34.22	Medium	95.49	Very high
P-available (P_2O_5 Olsen) (ppm)	16.17	Higher	42.46	Very high
CEC($cmol(+) \cdot kg^{-1}$)	17.29	Medium	17.80	Medium

Noted: * Based on [33]. Source: Primary data.

Based on climatic consideration, cassava crop suitability in ENT ranges from highly suitable to marginally suitable [34]. A detailed analysis of the land in East Sumba district on the island of Sumba, especially in the Ngaha Ori Angu subdistrict, conducted by [35] showed that the land suitability class for this plant was S1: 539.48 ha (1.24%, based on the area of the subdistrict), S2: 39,214.70 ha (90.74%), and S3: 3,462.80 ha (8.01%). Conditions in this area are rainfall of 760 to 1600 mm $year^{-1}$, average temperature between 21.1–27.7 °C, soil with poor drainage and fine to slightly fine texture, very little to medium coarse material, soil depth from 20 cm to >75 cm, CEC: 25–64.19 cmol $(+) \cdot kg^{-1}$, soil reaction conditions (pH) slightly acidic to alkaline (4.85–8.11), and C-organic soil ranging from 0.25 to 5.1%.Another analysis showed that cassava is very suitable in Central Sumba, covering 186,916 ha [36].

Based on the potential of soil quality and the current condition of the cassava farming system in ENT, the opportunities for developing farming are still wide open, both from planting expansion and aspects of increasing farming from a subsistence orientation to a commercial orientation. To increase the productivity of cassava which is currently still low, it is necessary to improve the quality of the soil through the application of Nitrogen and phosphate with the amount given based on the plant's needs and soil fertility status.

3. Cassava Potency, Productivity, and Constraints

3.1. Germplasm Evaluation in Indonesia

The cassava germplasm, as a source of genetic diversity, is indispensable for assembling new high-yielding varieties [37,38]. Although the cassava plant is not native to Indonesia, Indonesia has an extensive collection of cassava germplasms, around 954 accessions of cassava in gene bank collections, including local cassava, crossbreeding clones, and introductions [20], and the Indonesian Legumes and Tuber Crops Research Institute has a collection of about 325 accessions of cassava [39].

In 2015, [40] evaluated the deterioration rate of 239 cassava germplasm collections from the Center for Research and Development of Biotechnology and Agricultural Genetic Resources. The results showed that, in observations made on an eight-month harvest age group, as many as seven accessions had a resistant reaction to root rot (deterioration), with a damage range of 19.14 to 31.31%, and there was one accession from a nine-month harvest age group, with a high level of 32% damage. Additionally, it is known that the thickness of the tuber skin (tuber cortex) has no effect on tuber damage.

An evaluation carried out on 75 accessions of cassava germplasms with good taste obtained data that showed that 10 accessions had high yield potential, with yields of fresh tubers ranging from 36.61 $tons \cdot ha^{-1}$ to 61.64 $tons \cdot ha^{-1}$ [41]. In 15 accessions, physicochemical analysis of fresh tubers was performed, and the results showed that the average HCN content was 9.40 ppm and water content was 59.5%, while the starch and amylase levels were 28.8% (wb) and 11.0% (wb), respectively. In bitter cassava, the HCN content and water content were relatively higher, namely 82.88 ppm and 74.8%, respectively, while the starch and amylose contents were relatively lower, namely 15.8% (wb) and 5.5% (wb), respectively [41].

A total of 100 accessions of cassava were observed for tuber yields at the age of seven MAP, and data obtained showed that tuber yields ranged from 6.8 to 50.6 tons·ha^{-1}, with an average of 28.8 tons·ha^{-1}, while at a harvest age of 10 MAP it ranged from 8.0 to 68.4 tons·ha^{-1}, with an average of 38.1 tons·ha^{-1} [37]. Cluster analysis using the K-mean method from eight selected accessions showed that the yield of fresh tubers ranged from 39.6 to 50.6 tons·ha^{-1} at seven MAP and from 46.20 to 67.20 tons·ha^{-1} at 10 MAP.

The evaluation results obtained for the cassava germplasm are very useful in assembling new high-yielding varieties of high-yielding cassava with other advantages, such as early maturity, low HCN, and other characteristics.

3.2. *Cassava Diversity*

Indonesia in general, and ENT province in particular, is rich in cassava genetic biodiversity, derived from a long history of cultivating this crop in various agroecological zones. At the national level, many varieties, either nationally released or locally adapted varieties, have been recorded in the Indonesian cassava genetic database [42–45]. This wide genetic diversity is induced not only by the wide range of environmental conditions but also by artificial genetic recombination through breeding efforts carried out by both government research institutions, such as the Indonesian Legumes and Tuber Crops Research Institute (ILETRI) and state universities, and by nongovernmental/private research institutions.

The well-known nationally released superior cassava varieties include Adira 1, Adira 2, Adira 4, Malang 1, Malang 2, Malang 4, Malang 6, DarulHidayah, UJ 3, UJ 5, UK 1 Agritan, Litbang UK 2, Vati 1, Vati 2, Vamas 1, etc. [46], with the superior traits being high tuber yield, good eating quality, resistance/tolerance to biotic (pests and diseases) and abiotic (drought, salinity, etc.) factors, and suitable traits for industrial purposes [46]. Meanwhile, considerable cassava genetic diversity exists in almost all provinces in Indonesia, each with unique characteristics that can be used to select preferable traits for superior variety assembly. West Sumatra, North Sumatra, Maluku, North Maluku, and East Nusa Tenggara provinces are the provinces in Indonesia that have recorded their local cassava genetic diversity in the Indonesian cassava database.

Local cassava genotypes from West Sumatra province were recorded with narrow to wide variability based on leaf, stem, and tuber characteristics [47]. A study on another collection of the cassava germplasm from West Sumatra province revealed that the germplasm was highly diverse and distinguishable based on leaf morphological characteristics, tuber morphology (tuber color and shape), and tuber chemical composition (carbohydrate content and protein content) [48]. More recently, a high-yielding local cassava cultivar from West Sumatra has also been identified [49] with a potential tuber yield of up to 80 tons·ha^{-1}, much higher than the average of nationally released varieties (22–42 tons·ha^{-1}) [46].

In North Sumatra province, various local cassava germplasms from different districts have been identified and found to be highly diverse. These cassava germplasms play a vital role in supporting food security in the region [50]. High local cassava biodiversity also occurs in Maluku province [51] and in North Maluku [52], where the cassava genotypes were highly diverse based on morphological and agronomical characteristics. In ENT province, there was high cassava genetic diversity distributed in the districts within the island of West Timor, each with unique characteristics and local adaptability [53]. Among the local cassava germplasms in ENT province is the *Ubi Nuabosi* from Ende District, registered as a superior local variety for its taste and preferred eating quality. This local variety is well-known by consumers in ENT province, and hence has the potential to be developed and more widely distributed in terms of planting location.

All of the aforementioned cassava varieties are precious genetic assets that can be used to develop cassava in East Nusa Tenggara province, either as genetic resources for superior variety assembly or directly employed by farmers as both food and income sources. Furthermore, the nationally released cassava varieties and local cassava varieties from other provinces can also be incorporated into the farming system in ENT province based on their suitability and superiority. The superior high-yielding variety from West Sumatra [49] and nationally released varieties [46], for instance, can be evaluated for their adaptability to the agroecological zone of ENT or may be directly adopted into the cassava farming system in ENT. The same is true for other superior varieties with high tolerance/resistance to abiotic and abiotic stresses, which can also be adopted for cassava cultivation in ENT province. Combining all the likely strategies of utilizing cassava biodiversity from Indonesia would be of great assistance for the development of cassava in the marginal and drought-prone agricultural land of ENT province.

3.3. National and ENT Provincial Cassava Production

Based on the Agricultural Ministry of Indonesia, in 2018 cassava productivity in ENT was 12.2 tons·ha^{-1}, but still below national productivity (23.12 tons·ha^{-1}) [54]. Based on trade map data in 2020, Indonesia exported 16.529 tons of frozen cassava (HS 71410) with a total value of USD 9.7 million, an increase from 4.829 tons in 2019 with a value of USD 4.1 million.

Dominant cultivated land with dry climatic conditions in East Nusa Tenggara (ENT) does not support rice growth. However, cassava is one of the plants that can survive in dry conditions and develop in ENT [18,55]. Therefore, cassava is used as a primary food source [56–58]. Because of the tolerance of cassava to the dry climate, cultivating cassava in ENT is very promising. Currently, the agricultural land used for cassava cultivation in ENT is about 60,557 ha of the total dry land available (527,397.2 ha). Therefore, the opportunity for cassava development is still widely open [59].

The total cassava production in ENT in 2015 was 637,315 tons and the average productivity was 10.52 tons·ha^{-1} [60], while the average yield of superior varieties can reach 40 tons·ha^{-1}.The productivity of national cassava varieties ranges from 20 tons·ha^{-1} to 102 tons·ha^{-1} [61]. One of the causes of low productivity in ENT is using local varieties that have low productivity. In line with [62,63], who stated that local varieties are one of the causes of low root yields, there should be efforts to increase production by introducing new varieties that have a high yield potential. It is expected that farmers can choose one variety to be developed in East Nusa Tenggara. According to [64–66], one of the efforts needed to increase agricultural productivity is to adopt new technologies, such as high-yielding cassava varieties.

In ENT, cassava is mainly used as a staple food (in the dry season), substituting a small amount of cassava chips for snacks [67]. Some constraints for developing cassava in ENT were low yield (5–10 tons·ha^{-1}), dominant local varieties (sweet cassava for consumption, low yield and low starch), and it being cultivated as an intercropping plant with maize. As a result, farmers grew the 'Yellow-flesh' variety as the most common variety, followed by the 'White-flesh' variety, with only a handful of farmers still planting the local variety [19,68].

In ENT province, cassava is widely cultivated in mixed farming, especially in mountainous areas with a minimum altitude of ~300 m above sea level. Most cassava production is utilized by villagers in hilly areas (60%), and the remaining amount (40%) is consumed by urban residents in coastal areas, which are urban areas, such as the city of Maumere [19,69,70].

Farmers do not use fertilizer or manure, and they are worried about increasing the yield because there is no market; however, they are keen to apply fertilizer and increase production when there is a market for cassava. The application of fertilizer is still relatively low and based on reports from farmers who have used fertilizer on cassava, on average around 21% stated that they used organic fertilizers, while the use of inorganic fertilizers was higher, at 50%. In cultivating their cassava fields, most farmers use two- or four-wheel tractors, especially for farmers in the lowlands. Farmers in NTT tend to use more manual tools for land cultivation, especially in upland areas, and not many farmers make mounds to plant cassava [19].

Due to low rainfall, varietal trials in Flores—ENT showed that cassava growth was not good (about one-third of the plant in one plot) (Figure 2), and that the plants were attacked by mealybugs. Based on individual plant measurements, high-yielding varieties of cassava planted in the research area had fresh root yields in the range of 3120 to 4570 quintal·ha^{-1}. The tuber yield was higher than the local varieties commonly grown by farmers (Table 3) [19].

Table 3. Fresh root yield and infestation of mealybugs from various varieties in experimental fields and farmers' fields in Sikka, ENT.

Varieties	Experimental Fields		Farmers' Fields	
	Mealybugs (%)	Yield (tons·ha^{-1})	Mealybugs (%)	Yield (tons·ha^{-1})
Sika Putih	20	25.7	-	-
Sika Kuning	25	26.6	-	-
Adira1	41	31.2	100	29.4
TambakUdang	65	32.5	100	28.2
Faroka	50	36.8	100	34.7
UB ½	52	34.8	100	34.2
UB 4472	39	33.6	100	35.7
Gajah	35	45.7	-	-
Malang 6	54	38.5	100	35.2

Source: [19].

In general, cassava plants in ENT province were never fertilized. Farmers, especially in Sikka Regency, only apply fertilizer to their corn plants. Based on these facts, research activity on fertilization treatment was carried out on cassava plants, and the results show that cassava yields increased with the use of inorganic fertilizers. The problem is that subsidized fertilizers are prioritized for corn rather than cassava, so it is necessary to coordinate efforts with field officers to allocate nonsubsidized fertilizers to cassava after the harvesting of corn. Most farmers (more than 60%) apply NPK fertilizer to their crops [71].

(A) (B)

Figure 2. Varieties trial at 3.5 months (**A**) and nine months (**B**) at Sikka district—ENT, 2017. Source: [72].

Combined fertilizer (urea + superphosphate + potassium chloride) and two planting space (1 × 1 m and 2 × 1 m) treatments caused no significant maize yield under a higher density of cassava planting. However, the fresh tuber yield increased up to 5–7 tons·ha^{-1} in combining138 kg N + 36 kg P_2O_5 and 45 kg K_2Oper hectare compared to the application of solely urea practiced by farmers [71].

The intercropping of cassava was compared with monoculture cassava cropping in ENT to increase farm income, following treatment that included maize (local practice), maize (improved practice), peanut, and peanut mungbean. Table 4 shows that the practice of monocultures produced the highest root yield (3320 quintal·ha^{-1}). On the other hand, the yield of cassava in all intercropping systems was lower (in the range of 1004 to 2704 quintal·ha^{-1}) due to the low plant population. However, when viewed from the value of the land equivalent ratio (LER) in all treatments, the intercropping of cassava with maize with higher density had the highest LER, 1.78 [73].

Table 4. Yield and land equivalent ratio value (LER) of four intercropping cassava systems in ENT.

Treatment	Yield (quintal·ha^{-1})			LER Cassava	LER Intercrop	Total LER
	Cassava	Intercrop	Monoculture			
Cassava monoculture	3319	0	0	1.00	0.00	1.00
Cassava intercropping with maize (local practice)	1004	405	417	0.30	0.97	1.27
Cassava intercropping with maize (improved practice)	2478	432	417	0.75	1.04	1.78
Cassava intercropping with peanut	2708	126	200	0.82	0.63	1.45
Cassava intercropping with mungbean	2628	63	145	0.79	0.43	1.23

Source: [73].

Based on the AEZ data and the Cassava research conducted in ENT, there is a possibility to increase cassava productivity and production in ENT. The research showed that the introduced cassava variety increased cassava productivity up to 75% compared to the local white and yellow Sikka varieties, and even for Gajah variety has significantly increased up to 350% compared to average local cassava productivity in ENT.

3.4. Constraints in Cassava Production

Substantially, cassava production constraints are influenced by biotic and abiotic factors. Four factors considered contributed to the low productivity of cassava in the dry climate of ENT, namely drought conditions, pests and diseases, local varieties, and resistant varieties. Several developing countries with dry climates have also reported that limited cassava production is affected by pest and disease problems which are influenced by favorable climatic conditions [66,74–76]. Some pests can reproduce and migrate optimally in dry conditions [74].

This section discussed the main pests of cassava in ENT which are affected by a dry climate that causes low production. In ENT, endemic pests on cassava are mealybugs and red mites, which are elaborated on below. Data on the percentage of mealybugs infestation and cassava production were the results of the experimental research at Sikka Regency, while the influence of climate on pests and diseases is more of a literature study.

3.4.1. Mealybugs

Under controlled environmental conditions, cassava cultivated under water stress or water shortage intensifies *Phenacoccus manihoti* performance [77,78]. The long drought that limits crop production in the tropics is exacerbated by the existence of *P. manihoti* [79], which reduces yield significantly [80,81].

P. manihoti was first detected in Thailand [82,83] and then spread rapidly through Thailand and neighboring countries, including Indonesia [83–85], where it was first detected in Bogor in 2010 [85,86]. It is reported that there are 27 species of *P.manihoti* affecting *Manihot* spp. in general and 24 species affecting *M. esculenta* in particular [82]. Mealybugs are commonly found on the underside of leaves, especially around the main veins [77]. The first-instar nymph is quite mobile, while there is limited movement in the remaining instars. Mealybugs associated with cassava may reproduce by parthenogenesis (e.g., *P. manihoti*) or by sexual reproduction (e.g., *P. herreni*) [66].

The mealybug pest is a new pest on cassava plants in Indonesia that began to attack in 2009 [87]; the Indonesian environment is climatically suitable for the vast invasion of *P. Manihoti* [88–91], which has led to this pest being discovered in all areas of cassava farming (Table 3) [19].

Figure 3. Cassava plants in ENT attacked by *P. manihoti*. (Photo: Jonathan Newby, 2017).

A study was conducted to observe the effect of the number of mealybugs on the intensity of attacks with direct observation and sampling in three areas (Figure 3): Ende, Sikka, and Nagekeo districts. The results showed that Sikka district had the highest intensity of damage (43.3%), followed by Nagekeo district (22%), and Ende district with the lowest intensity, at 20% [92]. The development of the mealybug population is strongly supported by weather conditions with high temperatures and low humidity [93,94]. It is known that Sikka Regency has a drier climate than that of Nagekeo and Ende, so cassava plantations in Sikka are more sensitive to mealybug attacks. Dry season conditions with high temperatures, dryness, and low humidity cause cassava plants to experience stress and trigger an increase in mealybug populations [77].

In experimental fields and farmers' fields in ENT, cassava plants suffered from mealybugs. Still, the severity of infestation in the experimental fields was lower than that in farmers' fields (Table 3) [19]. Furthermore, according to ACIAR, the mealybug infestation percentage did not affect the root yield [95], presumably because the mealybug attack occurred in the final phase of cassava growth, when the cassava tuber had already developed.

To prevent mealybug attacks, integrated treatment and a combination of various methods are needed [96]. Some recommended management methods include the conservation of natural enemies, continuous monitoring of cassava plants, destruction of infected plants, and preventing the spread of pests through exchanging planting materials to other areas [20].

Research aiming to determine the geographical distribution of mealybugs has been carried out in seven provinces, namely Lampung, Banten, West Java, Central Java, East Java (representing a relatively wet climate area), West Nusa Tenggara (WNT), and East Nusa Tenggara (representing a dry climate area) [97]. The results showed that the incidence of mealybugs ranged from 35.5% to 74.18%. The highest mealybugs incidence occurred in Lampung province, and the lowest was in Central Java province. The highest incidence of mealybugs occurred in Lampung, presumably because cassava cultivation in Lampung was the most extensive compared to other areas. Meanwhile, the abundance of mealybugs was lowest in Lampung. This is because Lampung is a wet area, so the development of mealybugs is lowest, as is the severity of attacks, as supported by [98,99]. Meanwhile, in WNT and ENT, the level of crop damage (44.05% and 36.57%, respectively) and the abundance of the mealybug population (37.33 and 43.89 insect/tip, respectively) were high. This is because both areas have a dry climate that is very suitable for the development of mealybugs [89,90,97,99–101].

In the semi-arid climatic conditions in ENT province, mealybug attacks often occur in the dry season of August–November [102,103]. Farmers reportedly understand the effect of mealybugs on lowering their cassava yields. The main recommendation for dealing with mealybug attacks in ENT is to set the planting time. The recommended growing season for cassava in Sikka is early December or early January. This will help cassava grow throughout the wet season (December–March), and during the dry season the cassava will be 7–8 months old. Therefore, mealybug infestation is expected to have less impact on yields. The following recommendation is to increase the capacity of farmers to carry out integrated pest management, including the release of natural predators for mealybugs [71].

3.4.2. Red Mites

Red mites (*Tetranychusurticae)* are the main pests in the world that attack many plants. A severe attack during the early growth phase of a plant can lead to yield loss and significant economic decline [104–106]. The red mite has a stylet it uses to attack plants by damaging the leaves, thereby forming green and yellow spots [107,108]. A severe infestation of red mites can cause plant growth to stop and yield losses of around 50–70% [109].

There are about 50 species of pest mites associated with cassava plants; among them are spider mites (*T. urticae, T. cinnabarinus, Mononychellus caribbeanae, M. tanajoa, and M. progressives*). These mite species can cause a high intensity of damage, yield reductions of up to 87%, and stem cuttings losses for planting materials of up to 82% [110]. In Asia, mites cause significant yield reductions of 2–10% for minor damage and up to 60% for severe damage [111,112].

The population of red mites declines at the beginning of the rainy season and remains at a very low level in winter. The temperatures, mainly maximum and minimum temperatures, have a significant positive correlation with mite attacks [113]. Low humidity and high temperature will cause an increase in mite populations and reduce the biodiversity of predatory mites [114]. Dry and hot weather supports the reproduction and survival of red mites, because in such conditions biological control by entomopathogenic fungi is almost nonexistent [115]. Moreover, the spider mite population (*T. urticae*) is more resistant to climate change, including global warming, than its predatory mites [116].

So far, farmers have not carried out the optimal control of mite pests, which may be related to the low price of cassava compared to the price of pesticides (Acarisida), which are considered expensive for most farmers. Therefore, a control system consisting of a combination of two or more control methods in an integrated control system is needed so that yields and farmers' incomes can be increased in addition to environmental sustainability and health being maintained. The control of mites can be carried out through several methods, such as cultural practices, the use of resistant varieties, farm sanitation, proper time of planting, mechanical control methods, and biological control as well as chemical control using pesticides [117]. Biological control can employ potential predators, such as *Oligotaminuta* and several predators from the family Coccinellidae, as well as pathogenic fungal pathogens from the genera Neozygites (Zygomycetes: Enthomophthora) and Hirsuta (Hyphomycetes: Monilia) [118]. Thus, the impact of red mites on cassava in ENT is evident, since drought-prone areas dominate the region.

4. Trends in Cassava Production and Consumption

In this section, we used data on food commodities (rice, cassava, and sweet potatoes) gathered from the food commodity balance data or *data Neraca Bahan Pangan* released by the Food Institute—Ministry of Agriculture [119]. We included rice and sweet potatoes here as a comparison in positioning cassava's outlook. Twenty-five years of time series data, from 1993 to 2017, were used. The trend analysis of rice, cassava, and sweet potato consumption uses regression analysis through estimation curve analysis (R-square, ANOVA, and t-test). In addition, a t-test was employed to analyze the per capita consumption. The analysis was performed using IBM SPSS 26.

We grouped the use of the above commodities based on the food, nonfood, feed, and loss. Rice consumption in Indonesia tended to increase in the last 24 years (1993–2016). Fluctuation in the use of rice is parallel for consumption and other uses. However, the use of commodities for feed and nonfood have different fluctuation patterns. For example, 2002–2005 was when rice used for nonfood increased (Figure 4).

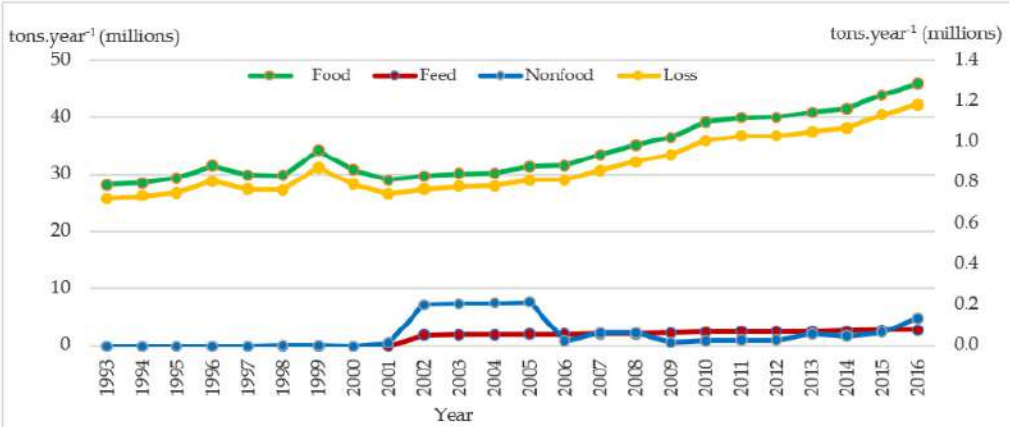

Figure 4. Use of rice in Indonesia, 1993-2016. Source: [119]. Primary axis: food; secondary axis: feed, nonfood, and loss.

Rice consumption tends to increase significantly (t < 0.00; ANOVA F < 000; and R = 0.84 and R^2 = 0.70). This implies that rice consumption increased as food or main source of carbohydrate, nonfood, feed, and loss. The constant point for rice was 27,066,930 tons and increased by 619,258 tons annually. Besides increases in human population, increases in rice consumption in Indonesia have also been related to the mainstream food policy in Indonesia to provide subsidies for rice production and maintain affordable rice prices [120].

The use of cassava has positive trends; however, it fluctuated more than rice [121,122]. The use of cassava for food follows the total use trend, which means that cassava for food is dominant compared to other uses. The use of cassava for feed was considered low, with stable trends. The use of cassava for nonfood purposes significantly increased in 2002–2005 (Figure 5).

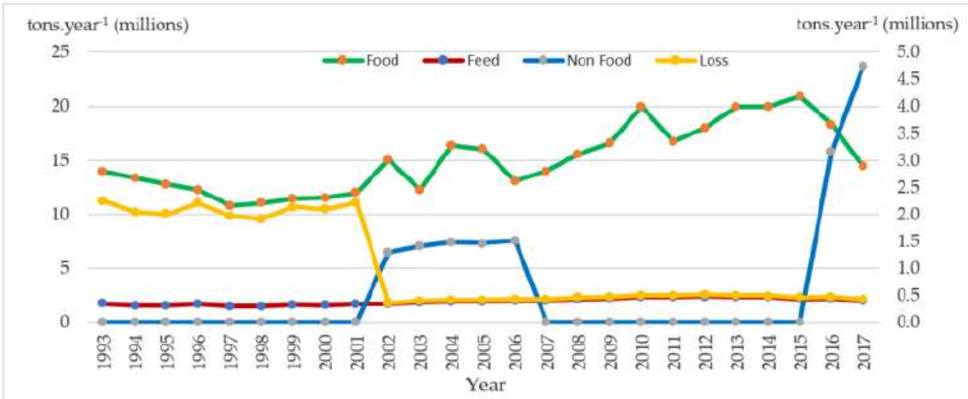

Figure 5. Use of cassava in Indonesia, 1993-2017. Source: [119]. Primary axis: food; secondary axis: feed, nonfood, and loss.

The total use of cassava has shown a significant increase (t < 0.00 and ANOVA F < 0,00; $R^2 = 0.65$). This implies that the use of cassava for all purposes increased significantly at a constant of 13,045,170 tons and increased by 312,144 tons annually.

The use of sweet potatoes is quite different from that of rice and cassava. The trends in the use of sweet potatoes are more stable and slightly fluctuate. The use for feed was also stable over the 25 years (Figure 6).

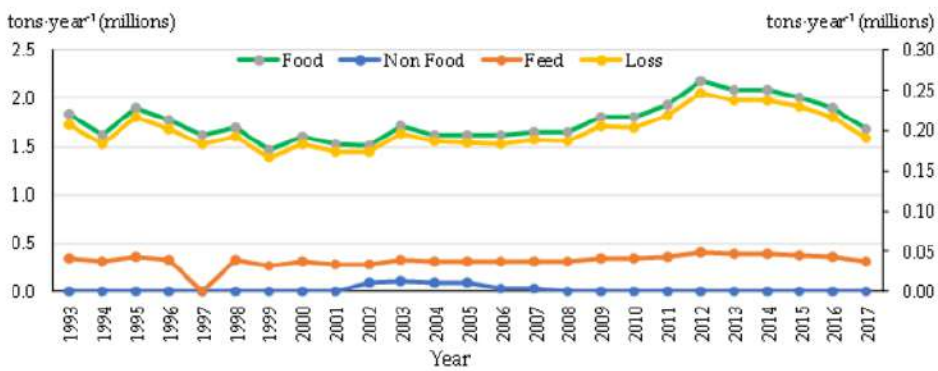

Figure 6. Use of sweet potato in Indonesia, 1993-2017. Source: [119]. Primary axis: food; secondary axis: feed, nonfood, and loss.

4.1. Consumption Behavior of Foodstuff

Foodstuffs from cassava, sweet potatoes and rice in Indonesia allocated for food, nonfood, feed and loss. In the last 25 years' data (1993–2017), those three crops have positive consumption trend, although they have different fluctuations trends. Among them, rice has the highest per capita consumption. Rice and cassava consumption increased yearly, while that of sweet potato was slightly stagnant. This implies that rice is the primary food source, followed by cassava and sweet potatoes (Figure 7). Rice is complementary to cassava and sweet potatoes, while tubers are more for substitution.

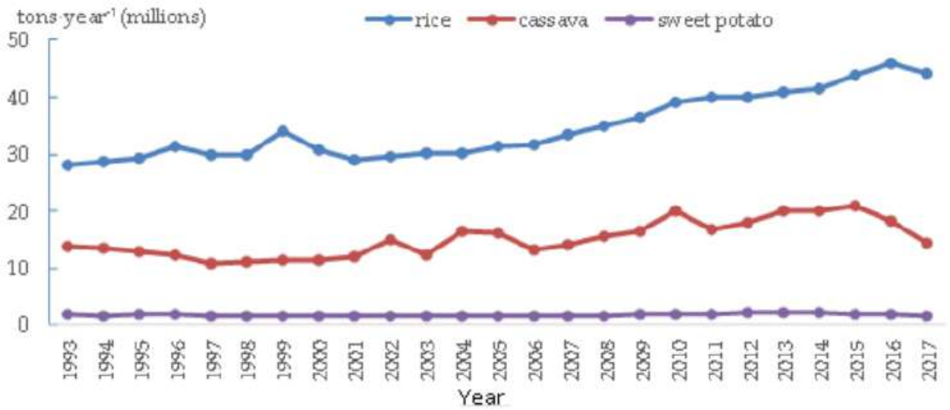

Figure 7. Per capita consumption of rice, cassava, and sweet potato in Indonesia, 1993-2017. Source: [21,123,124].

Consumption consistency analysis of rice, cassava, and sweet crops in the period of 1993–2017 showed significant consistency for these three crops ($t < 0.00$). Per capita consumption level interval between the lowest and the highest confidence at 95%: The highest per capita consumption for cassava was 57.2 kg·capita^{-1}·year^{-1},and the lowest was 45.5 kg·capita^{-1}·year^{-1}; for sweet potatoes, it was 8.2 kg·capita^{-1}·year^{-1} (highest) and 7.53 kg·capita^{-1}·year^{-1} (lowest); and for rice, the highest was 158 kg·capita^{-1}·year^{-1} and the lowest was 148.2 kg·capita^{-1}·year^{-1} (Figure 7) [122,125].

The decision for food consumption showed that households consume cassava and sweet potatoes as complementary to the rice. Rice is the first option that combines with cassava and sweet potatoes in overall household carbohydrate-based consumption. Cassava and sweet potatoes have a substitution relation (Table 5).

Table 5. Consumption rate and relation between foodstuffs.

Food Stuffs	Mean Value (Millions Tons)	Correlation			Consumption (kg·capita·year^{-1})	
		Cassava	Sweet Potato	Rice	Lowest	Highest
Cassava	15,065	-	substitution	complementary	45.50	57.20
Sweet potato	1756	Substitution	-	complementary	7.53	8.20
Rice	34,172	Complementary	Complementary	-	148.20	158.00

Source: Analyzed from [119].

The increase in rice and cassava consumption in 1993–2017 was mainly due to the fact that demand for rice and cassava increased. It was also due to the human population increasing, enough rice stock being available at an affordable price, and being supported by the government through "rice for poor" [126]. The demand for cassava increased due to an increased number of processed products being cassava-based, health reasons, and complimentary food diversification. Cassava contains a low glycemic index (GI), which is recommended as an alternative food source for diabetic people for rice substitution [127].

The use of sweet potatoes was indicated to be more stable and slightly fluctuate. This showed that the demand for sweet potatoes does not change much due to the increased human population, complementarity and substitution of other foodstuffs. Sweet potatoes in recent years have been more processed for snacks and health food. Therefore, some potential crops need to be developed for food diversification [128,129] through crop diversification and food processing [130,131].

4.2. Cassava and Food Preference in ENT

In terms of the food preferences of people in ENT, cassava is ranked third, after rice and maize; however, in some marginal coastal areas, it is the main staple, followed by maize and rice [132]. During the course of a year, rice and maize are the main food sources after the first season's harvest, while cassava becomes a main staple in the second and third quarters (September–December) (Figure 8).

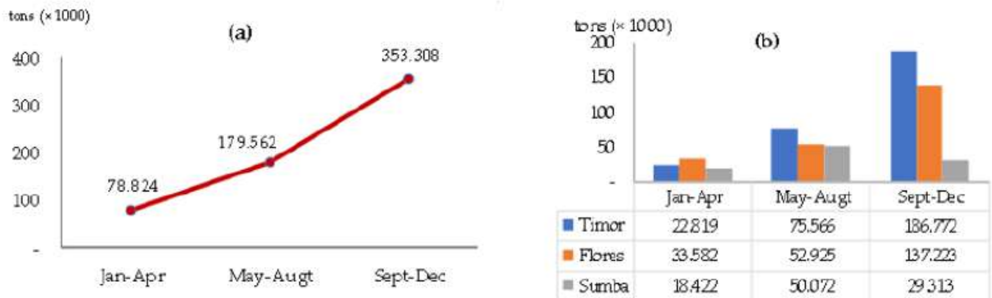

Figure 8. Cassava production by quarter (**a**) and zone (**b**) in ENT Province, 2018. Source: [123].

The production pattern of the cassava crop provides positive impacts for household food security, such as (a) maintaining food security/availability for the whole year, (b) being a source of cash income, and (c) being an available "food bank" in the cropland, with little impact from climate change and harvested only when it needed, which is the food sector mitigation strategy for smallholder farmers against climate change.

The Timor zone gave the highest contribution of the three production zones, followed by the Flores and Sumba zones, with figures of 286,157 tons, 223,730 tons, and 97,807 tons, respectively [59] (Figure 8).

In the upland farming in ENT, almost half of the household farmers (43%) plant cassava, most of which (90%) is planted in mixed-crop farming systems. The productivity of existing cassava farming was low (10–12 tons·ha^{-1}), and the cultivated area was lower than the potential area. However, if introduced high-yield cultivars are used, cassava productivity increases by up to 23 tons·ha^{-1} or more. As a result, the contributions of cassava to households were relatively high, both for consumption (70%) and income generation (30%). For household consumption, 45% was allocated to food and 55% to feed (mainly for pigs) (Table 6). The contributions of cassava to household income generation increase if (a) there are increases in cultivated land close to the potential area, (b) HY cultivars are cultivated and cassava innovations are applied, and (c) if the value added through cassava processing increases. There should be an improvement in the cassava value chain in order to improve the market and realize the potential of cassava production.

Table 6. Actual and potential figures of cassava production and consumption in ENT.

No	Item	Actual	Potential
1	Planting area (ha)	51,693	119,294
2	Harvested area (ha)	51,180	118,101
3	Productivity (tons·ha^{-1})	11.87	23.12
4	Production (tons)	607,694	2,730,489
5	Farmer household (unit)	818,853	818,853
6	Cassava farmer household (43%) (unit)	352,107	352,107

7	Price (IDR kg^{-1})	1000	1000
8	Consumption (70%) (tons)	425,386	425,386
9	Consumption/household (tons)	1.21	1.21
10	Allocation for food (45%) (tons)	0.54	0.54
11	Allocation for feed (55%) (tons)	0.66	0.66
12	Consumption value (IDR)	425,385,800	425,385,800
13	Sold (tons)	182,308	2,305,103
14	Sold value (IDR)	182,308,200	2,305,102,742
15	Total value of cassava (IDR)	607,694,000	2,730,488,542

Source: Analyzed from [123,124].

4.3. Cassava in the Farming System Context of Marginal Semi-Arid Areas

This section is based more on the first author's experiences in conducting farming system research and disseminating agricultural innovations in various places across islands in the semi-arid areas of East Nusa Tenggara province. Altitude, soil, and climate, particularly rainfall, determine cassava farming in semi-arid regions. Farmers plant more cassava in general at lower altitudes with less rain. In porous and unfertile soils, farmers grow more cassava and beans than grain crops.

Cassava is planted in various agroecosystem zones with different cropping patterns. Cassava is commonly grown in a mixed-cropping system. However, this practice depends on farmers' indigenous knowledge about the specific characteristics of their cropland. In certain places, such as North Central Timor district, farmers plant monoculture cassava for the first plow of cultivated land or after it has long been fallowed [133]. The reason for this practice is that cassava is considered the most successful crop to be harvested, while other crops, including maize, cannot grow well in very porous soils and with low rainfall. Therefore, in the second year of cultivated land, maize dominated the crops, while cassava was a minor crop, commonly planted in buds and around the cropland.

In undulated and hilly landscapes, cassava is generally cultivated in mixed-crop farming or part of the local agroforestry. Cassava is mainly grown in dry flatland areas as mixed-food-crop farming. The most commonly mixed food crops in Timor island are maize, beans, cassava, and pumpkins. Cassava is harvested later, after other food crops are harvested, and sometimes cassava remains in the field until the next year. In Timor island, local varieties are harvested by taking out only their fresh tubers, while cassava trunks are kept standing and produce new fresh tubers until 2–3 years.

In the small and dry islands that are limited for growing grain crops, cassava and other root crops of Dioscorea sp. are the main staples of local inhabitants. In the islands of Lembata, Adonara, and Alor, root crops, particularly cassava, became dominant staple food crops. In the coastal lines of Sikka, East Flores, and Lembata districts, cassava is planted as part of mixed-food-crop farming with maize and beans.

From the 1960s to the 1970s, cassava was the second most important food crop after upland rice in Sumba island. During that time, the fresh tuber of cassava was harvested and dried (Wewewa local term: *Killu*) and became the main staple during the monsoon. However, as innovations in grain crops, particularly rice and maize, were introduced, changes occurred in the image of dry cassava as a "monsoon or famine staple"; cassava in Sumba Island has recently been considered a minor crop for fresh tubers harvested for household consumption for feed.

Rote Ndao district is the district of the southern part of Timor island. The consumption pattern of the indigenous people of Rote Island in the 1960s–1980s was maize, sorghum, sesame, foxtail, rice bean, and pigeon pea. Although not a staple food, cassava (*Ufihau/Ufi ai* in the local language) was one of the intercropping plants. Cassava was cooked and usually consumed with brown sugar (from toddy palm tree). In the 1980s, they began to switch to rain-fed lowland rice, thus shifting the position of local foods.

5. Conclusions and Future Cassava Development

With the diverse agroecosystem zones of a dominant semi-arid area, ENT province is one of the provinces rich in cassava biodiversity. Most of the local cassava germplasms are cultivated for food purposes and become pivotal crops in food resilience for people in marginal environments.

As cassava can grow in a wide range of soil conditions, and with the present land use in ENT, cassava can still be developed in ENT. According to the agroecological zone (AEZ) scale of 1:250,000, the land potential for cassava was 596,468 ha or close to 20% of the land area of ENT. This is because cassava is the most "successful" crop in marginal semi-arid regions and the last food crop harvested from croplands; cassava should be considered to strengthen food security in rural areas. Moreover, the demand for cassava has had a positive trend over the previous 20 years, indicating that cassava can be cultivated widely to increase smallholder farmers' incomes.

Although it is a minor crop in the carbohydrate diet of people in ENT, cassava plays a vital role as a buffer stock of food for marginal smallholder farmers in marginal semi-arid areas. In traditional farming practices, farmers have managed mixed-cropping systems to maintain reasonably fresh root cassava production without the use of external inputs. Besides acting as a food source, cassava is also the main feed for traditional pig growth in rural areas.

The local cassava germplasm in existing ENT cassava farming is considered as having low productivity. However, ACIAR's collaboration research on cassava in Sikka district indicated that cassava productivity could be increased by more than double compared to the conventional one by introducing high-yield cultivars and improving farming management. This showed that, if cassava-related innovations can be widely implemented, ENT will have potency as one of the major contributors of cassava production at the national level, as well as help promote rural cassava-based business.

Cassava is considered as being more tolerant of semi-arid dry climate conditions than other food crops. Based on this characteristic, farmers cultivate more cassava in low-rainfall or drought-prone areas and have them become the main staple, particularly during the long dry season of June–December. Recent unpredictable climate changes, particularly rainfall in semi-arid regions, assert that cassava remains cultivated as a strategy to minimize risk in the food resilience of marginal farmers.

As cassava suits a wide range of agroecosystems, is resistant to more minor pests and diseases, and requires less care or less use of external inputs, cassava farming suits marginal farmers' circumstances. Nevertheless, cassava-related innovations need to be delivered to increase cassava productivity, markets, and rural cassava-based industries; later on, it will increase smallholder farmers' incomes.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/article/10.3390/su14095439/s1, Table S1: Land availability distribution for cassava in ENT.

Author Contributions: Y.N. led and oversaw the review. Y.S.M. drafted the cassava diversity in Indonesia aspects, particularly in semi-arid areas of ENT. K.N., E.I.W., and N.R.E.K. drafted the overview of cassava research in Indonesia aspects, particularly of research conducted in ENT in addition to pests and diseases encountered in cassava farming. T.B. and A.S. drafted the land suitability and soils for cassava in ENT aspects. B.d. and H.d. drafted the socioeconomic aspects of cassava. W.H.U. contributed to the institutions and cassava development policy aspects. All authors have read and agreed to the published version of the manuscript.

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