2022-02-07

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Elsevier B.V.

https://doi.org/10.1016/j.tfp.2022.100216

Trees, Forests and People 7 (2022) 100216

Contents lists available at ScienceDirect

Trees, Forests and People

journal homepage: www.sciencedirect.com/journal/trees-forests-and-people

Growth performance of the neglected crop *Telfairia pedata* across elevation and climate gradients in Northern Tanzania

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ARTICLE INFO

Keywords:
Environmental stress
Vines
Rainfall
Orphan crop
Agro-biodiversity
Small-holder farms

ABSTRACT

Herbaceous vines, including the neglected crop *Telfairia pedata,* play a key role in small-holder livelihoods of Eastern Africa. Despite this species' importance in enhancing agro-biodiversity, little is known about its distribution and growth performance in relation to environmental variables. We collected biophysical and environmental data, i.e., on climate and elevation, for 346 *T. pedata* vines across four districts of Northern Tanzania from September, 2019, to February, 2020. The four sites included Same, Lushoto, Muheza and Arumeru districts. We found that plants of *T. pedata* were mainly grown in elevations ranging between 900 to 1800 m above sea level with annual rainfall regimes of 1000 to 1400 mm. We recorded large abundance of *T. pedata* in Lushoto (46%) and Arumeru (28%) and observed that the number of fruits and fruit diameter were both positively correlated with elevation across the study districts. There was a significant effect of elevation on number of seeds, with Same district having more seeds across the studied districts. Rainfall had a significant effect on fruit diameter and number of seeds in the study districts. Furthermore, the tree species *Albizia schimperiana* was most commonly (in 40% of the cases) associated with *T. pedata*, followed by *Persea americana* (14%), and *Croton macrostachyus* (9%). We highlight that mountainous regions are ideal for this highly nutritious crop, and that native trees are of high importance for enriching this vine to current agro-ecosystems. Our findings will increase awareness on the importance of raising *T. pedata* crop, livelihood diversification, and increasing biodiversity through production of this orphan crop in small-holder farms.

1. Introduction

Telfairia pedata (Smiths ex Sim) Hook or oyster nut belongs to Cucurbitaceae family, which includes over 700 species and approximately 90 genera (Okoli and Mgbeogu, 1983; Odiaka et al., 2008; Chiamaka et al., 2020). It is a herbaceous woody vine and dioecious that bears squash-like fruits with large and nutritious oily seeds, is perennial and can withstand drought to some extent (Onovo et al., 2010; Ifeanyi-Obi et al., 2013), (Fig. 1). *Telfairia pedata* is mostly grown for its oilseeds in Tanzania including Zanzibar Island, and other African countries including Angola, Mozambique, coast of Kenya, Uganda and Nigeria (Schippers, 2000; Odiaka et al., 2008; Odiaka and Odiaka, 2011; Aregheore, 2012). The nuts are highly valued by East Africa natives and are in great demand by breastfeeding mothers (Fubara-Manuel et al., 2012; Nwonuala and Obiefuna, 2015). These oilseeds are related to pumpkin seeds (*Cucurbita moschata*) which are also highly important for their therapeutic and functional (nutraceutical) values (Dotto & Chacha, 2020). *Telfairia pedata* nuts are mostly eaten raw or boiled, roasted for confectionery or grounded into a thick paste for use in staple meals such as soup thickening (Odiaka et al., 2008; Alegbejo, 2012). It contain protein, fat, carbohydrates, oleic acid, linoleic acid, stearic acid, palmitic acid, minerals including phosphorus (P), magnesium (Mg), potassium (K), iron (Fe) and calcium (Ca) (Aregheore, 2007; Mwakasege et al., 2021).

In some cases, *Telfairia* species provide substantial cash income to small rural farm families and for biodiversity conservation (Akoroda, 1990; Alegbejo, 2012; Chukwurah et al., 2015). However, despite its household income generation, nutritional and environmental value, the cultivation of this crop in Tanzania has been neglected, and little is known about its distribution, growth performance and constraints. The climber grows well in presence of hard wood trees or wooden made structures, and it is regarded as an important component of the rich

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https://doi.org/10.1016/j.tfp.2022.100216
Received 30 August 2021; Received in revised form 25 January 2022; Accepted 3 February 2022
Available online 7 February 2022

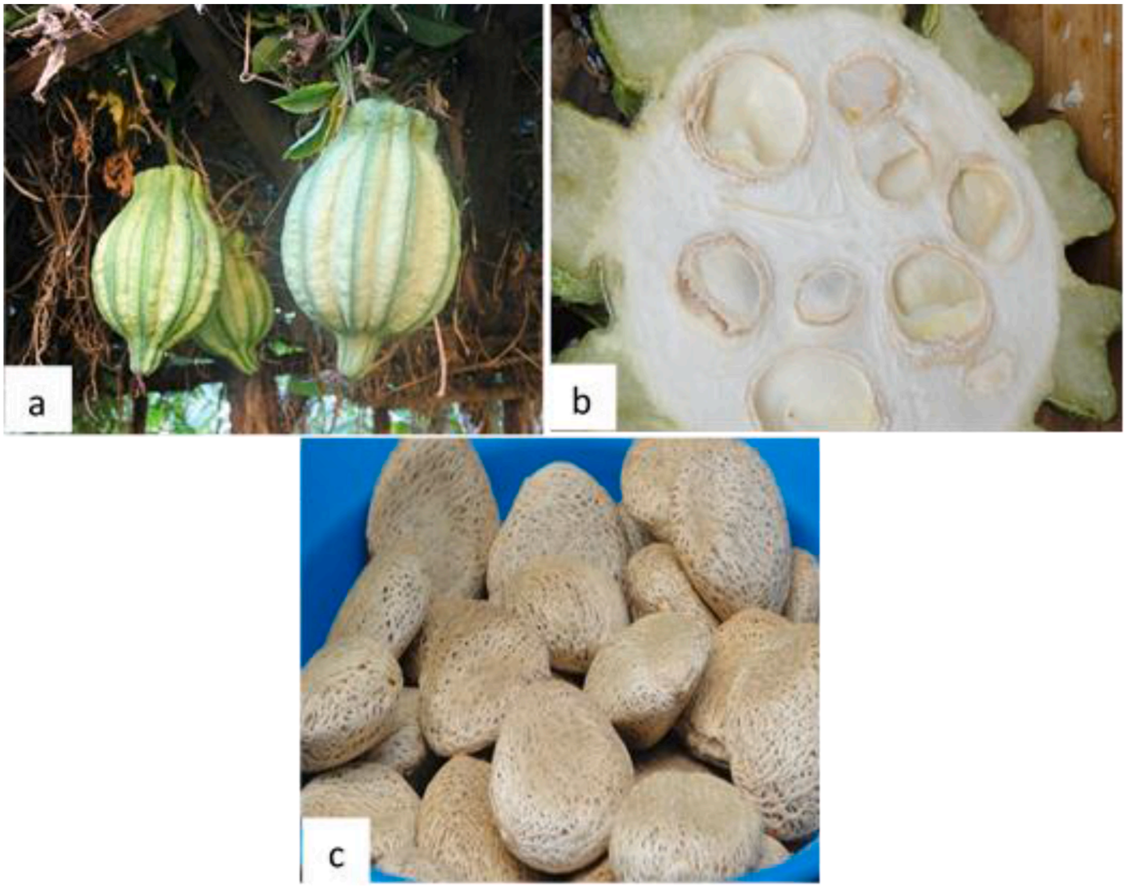

Fig. 1. *Telfairia pedata* (a) Dangling whole fruits (b) Cross section of fruit approx. 15 cm diameter (d) nuts from samples collected during survey period in Tanzania. Photo by © Philipina Shayo, 2020.

agroforestry systems of Mountains of Kilimanjaro and Meru in Tanzania, where it is grown in combination with banana (*Musa species*) and coffee (*Coffea* species) (Garrity, 2004). In order to understand the performance of the various plant species that can be incorporated in an agro-ecosystem, environmental factors must be assessed (Joshi et al., 2002; Vodouhe et al., 2007).

Along with the economic gain of *T. pedata,* the ecological advantages have also been a benefit of safeguarding and protecting (i.e. conserving) the saplings, trees, and forests of the ecosystems they are grown in Ajayi et al. (2004). Additionally, similar herbaceous and woody vines stabilize the microclimate beneath trees, subsidizes canopy closure when trees fall, enables simple movement of arboreal animals while navigating tree tops and provide food for animals during fruit and flowers shortage seasons (Schnitzer and Bongers, 2002; Addo-Fordjour et al., 2008). Moreover, they are perennial crops that are drought resistant, less affected to weeds, pests and diseases and protects the soil surface from direct impact from rainfall (Akoroda, 1990; Chukwurah et al., 2015). Their fruits vary in size and productivity, and their distribution outside of the Kilimanjaro mountain system is unknown. Despite its high fat, carbohydrate, protein, and necessary amino acid content, the species has been forgotten by younger generations. Similarly, Luoga et al. (2000), Whitney et al. (2018), Mutaqin et al. (2020) stated that there is a need to capture traditional knowledge that has been held by the elderly, and which is being transmitted to younger generations in very few cases. This might have a significant impact on future food security and livelihood income, as well as sustainable land management and biodiversity conservation.

Our study focused on effects of climate and elevation on growth performance of *T. pedata* in Northern Tanzania. Our objectives were to (1) map the distribution of *T. pedata* across multiple districts along an elevation and rainfall gradient and (2) analyze the influence of elevation and rainfall on fruit and diameter growth, as well as the number of fruits and seeds. We hypothesized that: (i) more *T. pedata* are grown at higher elevations (> 1500 masl) similar to other vines, herbs and lianas richness found in Mt. Kilimanjaro increased with elevation (Hemp, 2006; Cirimwami et al., 2019); (ii) areas of higher rainfall will promote heavier fruits with more seeds of *T pedata* similar to *T. occidentalis,* which also performs well in areas with heavy rainfall (iii) farmers tend to grow more than one stem of *T. pedata* vines around the host tree in order to have more fruit yield; and (iii) tall native tree species will be the dominant host plant across all elevation levels. As it has been described by Schnitzer and Bongers (2002) that lianas and vines (*T. pedata* inclusive) share a common growth strategy of ascending to the tree canopies using their climbing mechanism while they remain rooted to the ground throughout their life cycle.

Our study combined observational data with participatory assessment and interviews in four separate districts of northern Tanzania. Our findings will help in the promotion of a largely underutilized but highly nutritious crop that can be grown in the current agro-ecosystems without any additional management, so as to diversify livelihoods for future food consumption by the small-holder farmers.

2. Material and methods

2.1. Study area

We selected public and cultivated lands in 57 villages across four districts, i.e., Arumeru, Lushoto (Bumbuli inclusive), Muheza, and Same districts in 3–5°S and 37–39°E in Northern Tanzania, i.e., in areas, where *T. pedata* had been recorded previously (Fig. 2). The study sites

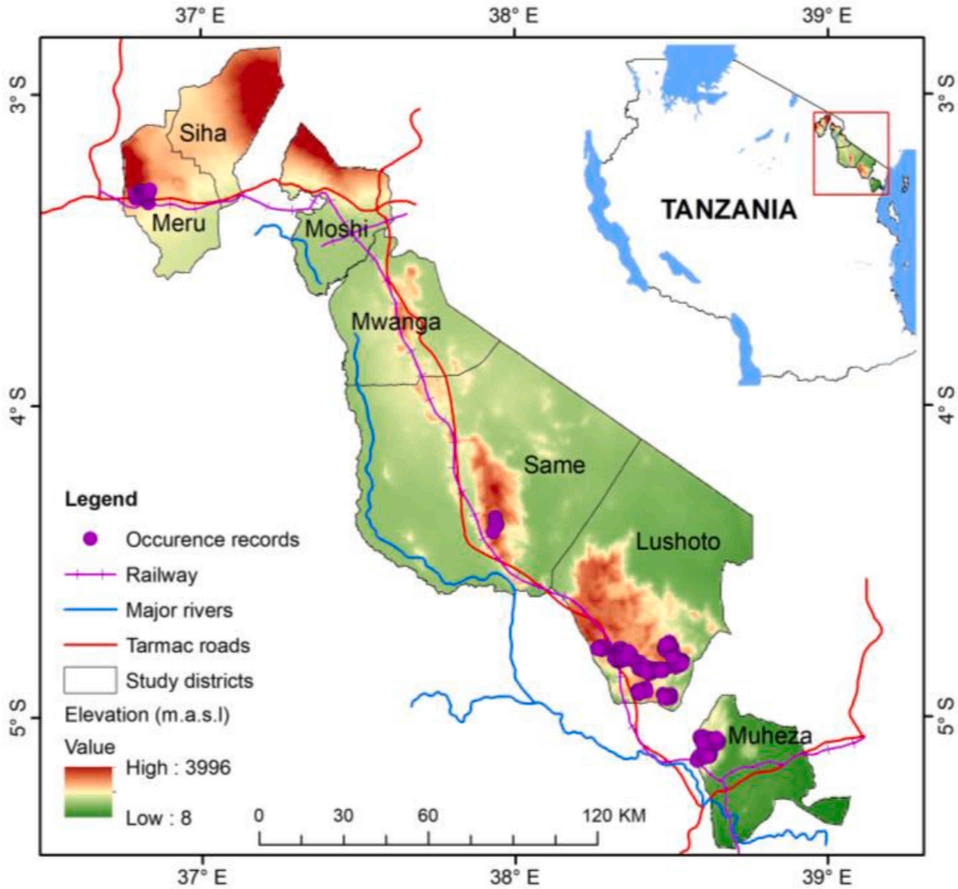

Fig. 2. Location of study sites across districts in Northern Tanzania, where we assessed the use, management, as well as ambient climate and rainfall parameters of *T. pedata*. Sites covered four districts (Arumeru, Muheza, Lushoto and Same) and were visited from September, 2019, to February 2020; N =346.

were selected based on the varying environmental factors (rainfall and elevation), covering elevations between 900 masl and 1900 masl, and a range of annual rainfall between 600–1400 mm and annual average temperatures of 10 °C to 29 °C (NBS, 2013).

2.2. Data collection

We purposely surveyed a total of 346 *T. pedata* plants for this study, with the number of surveyed plots in each district being determined by the availability of *T. pedata* vines around the homesteads and on agroforestry farms. Out of the 346, 144 (42%) *T. pedata* vines had mature fruits, 60 of which were found in Lushoto district, 39 in Arumeru district, 33 in Muheza district, and 12 in Same district. Recorded data included location (GPS, Garmin 64 s), *T. pedata* diameter at breast height (1.3 m above the ground surface: hereafter DBH) was measured using calipers, fruit diameter using a ruler, and the number of fruits and seeds as well as number of vines per tree. Rainfall layers with a spatial resolution of ~1 km^2 were downloaded from WorldClim data archive (https://www.worldclim.org) while the elevation layer (also with a spatial resolution of ~1 km^2) was acquired from Shuttle Radar Topography Mission dataset (http://srtm.csi.cgiar.org). We further identified and measured all tree species associated with *T. pedata* with the help of a field guide book (Yineger et al., 2007) and locals to understand which tree species preferably hosted the vines. We visited both agroforestry systems (trees mixed with annual crops) and trees in lines (live fence, boundary planting), which potentially hosted *T. pedata* vines (pers. obs.).

Table 1
Average *Telfairia pedata* individual plant abundance across different districts, elevation and rainfall gradients in northern Tanzania during the assessment from September 2019 to February 2020, N = 346.

Districts	Abundance	Elevation range (masl)	Rainfall range (mm)
Arumeru	107	1160–1740	1000–1400
Lushoto	170	1100–1730	1000–1400
Muheza	87	900–1720	1100–1500
Same	22	1300–1600	1150–1350

2.3. Data analysis

Pearson's correlation analysis was used to explore the relationship between environmental variables (elevation, rainfall) and vine parameters (fruit diameters, number of seeds, number of fruits and diameter of vines). Also, linear regression in R (Core Team 2020) was used to determine the effects of environmental variables on fruits diameter, number of seeds, number of fruits, and diameter of vines. Frequencies of host tree species associated with *T. pedata* were descriptively analyzed and expressed as percentages. The GPS locations for each vine were overlaid with an elevation and rainfall layers derived from (https://www.worldclim.org) using ArcMap 10.6.

3. Results and discussion

3.1. Distribution and abundance of T. pedata

The distribution of *T. pedata* along the elevation and rainfall gradient ranged from 900 – 1800 masl and 1000–1400 mm, respectively

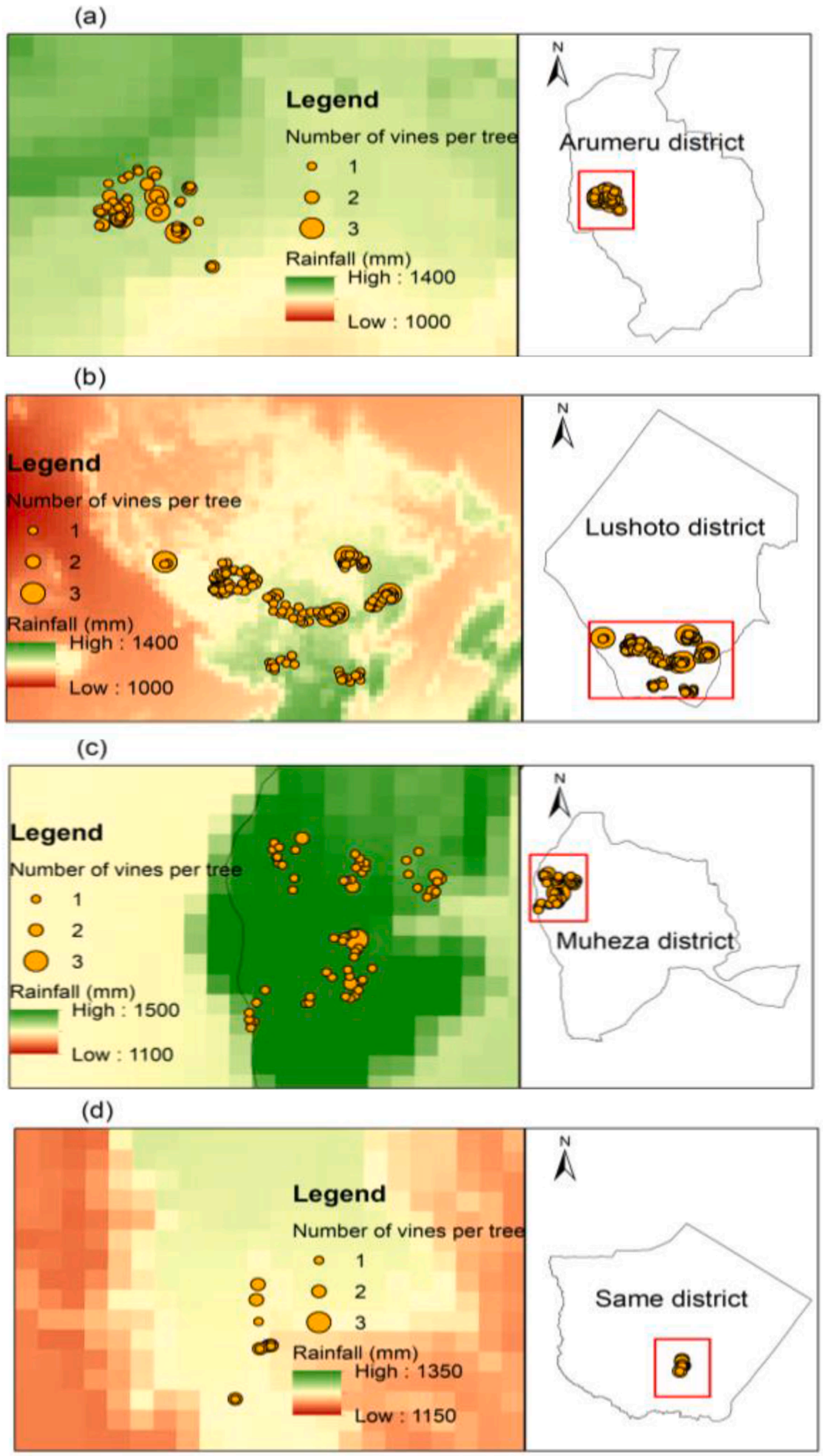

Fig. 3. (a–d). Maps showing the distribution of *T. pedata* populations across the four districts surveyed from September, 2019, to February, 2020, in Northern Tanzania. Larger circles represent higher numbers of vines stems per tree.

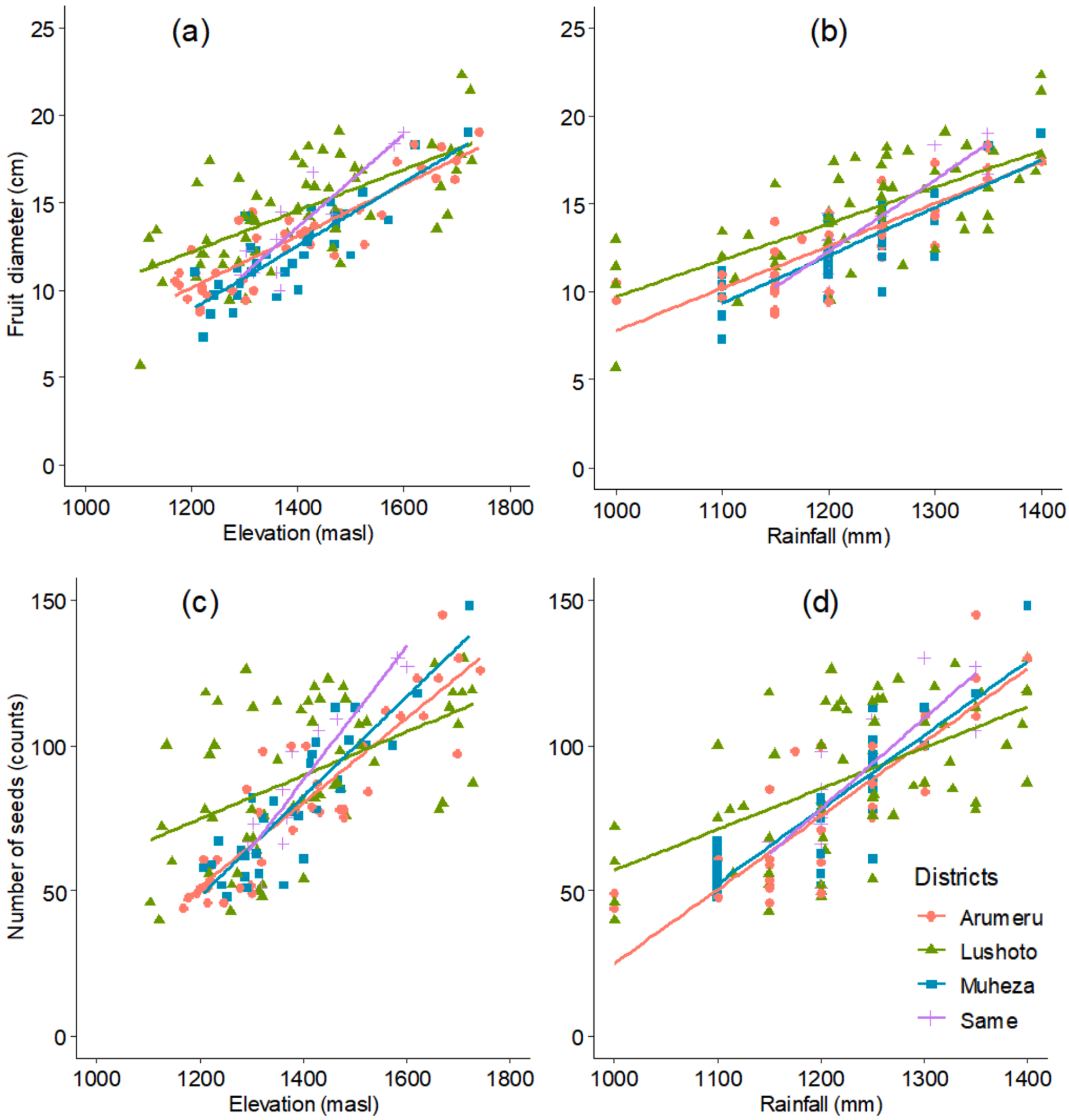

Fig. 4. (a–d). Relationship between *T. pedata* fruit diameter with elevation (a) and rainfall (b) as well as between number of seeds with elevation (c) and rainfall (d) during our survey in Arumeru, Lushoto, Muheza and Same districts, from September 2019 until February 2020. N = 346.

(Table 1). We recorded a higher abundance (79%) of *T. pedata* at >1500 masl while only 21% were found in lower altitudes (< 900 masl). Also, *T. pedata* was more abundantly found to the eastern part of Arumeru district 28%, southern part of Lushoto district 44%, southern part of Same district 6% and western part of Muheza district 23% (Fig. 3a-d). We also recorded large abundance of *T. pedata* in Lushoto (46%) and Arumeru (28%) (Table 1). The majority of farmers (88%) grew one vine per host tree but a maximum of three vines per tree were recorded across all districts (Table 1, Fig. 3). In addition, *T. pedata* and the host trees were mainly planted, particularly in agroforestry farmlands, where other crops where grown such as maize *(Zea mays* L.*)*, banana (*Mussa* species) and coffee (*Coffea* sp), intercropped with cauliflower (*Brassica oleracea* var. *botrytis*), carrots (*Daucus carota* subsp. *sativus*), common beans (*Phaseolus vulgaris*), potatoes (*Solanum tuberosum*) and onions (*Allium cepa L.*). Most (81%) of the *T. pedata* vines were planted near the homesteads, at the middle of the farm and on farm boundaries while the rest (20%) were planted more than 200 m away from the farm lands.

As expected, we found more *T. pedata* plants growing in higher elevations up to 2000 masl and in areas of higher rainfall. This was similar to *T. occidentalis* which is grown in the Niger Delta region, particularly in areas with abundant rainfall throughout the year (Fubara-Manuel et al., 2012). Even for lianas, it has been documented that its abundance strongly increases with mean annual precipitation (Bruy et al., 2018; Birhane et al., 2020). Moreover, in Lushoto, the average number of three vines per tree were slightly more than in the other districts. This was also shown by species richness for climbers tends to increase with elevation up to 2760 masl (Cirimwami et al., 2019). Even Hemp (2006) revealed the same trend to similar species in Mt. Kilimanjaro. In contrast, Schnitzer, (2005) reported that the diversity and abundance of climbers tend to decrease with decreasing temperature and rainfall in tropical forests. But our study revealed that there is higher abundance of *T. pedata* at higher elevations with higher rainfall.

We further found that the fruit diameter of *T. pedata* increased with increasing elevation (>900 masl) as did the number of seeds and the number of fruits. Even Parciak (2002) also described that the seed of *P. virginiana* size and numbers varied with environmental conditions and annual resource availability e.g. rainfall availability and soils properties. While we found similar trends for the three districts Lushoto, Muheza and Lushoto while Same showed a slightly opposite trend due to low rainfall availability of < 1300 mm per annum. Even Sivirihauma et al.

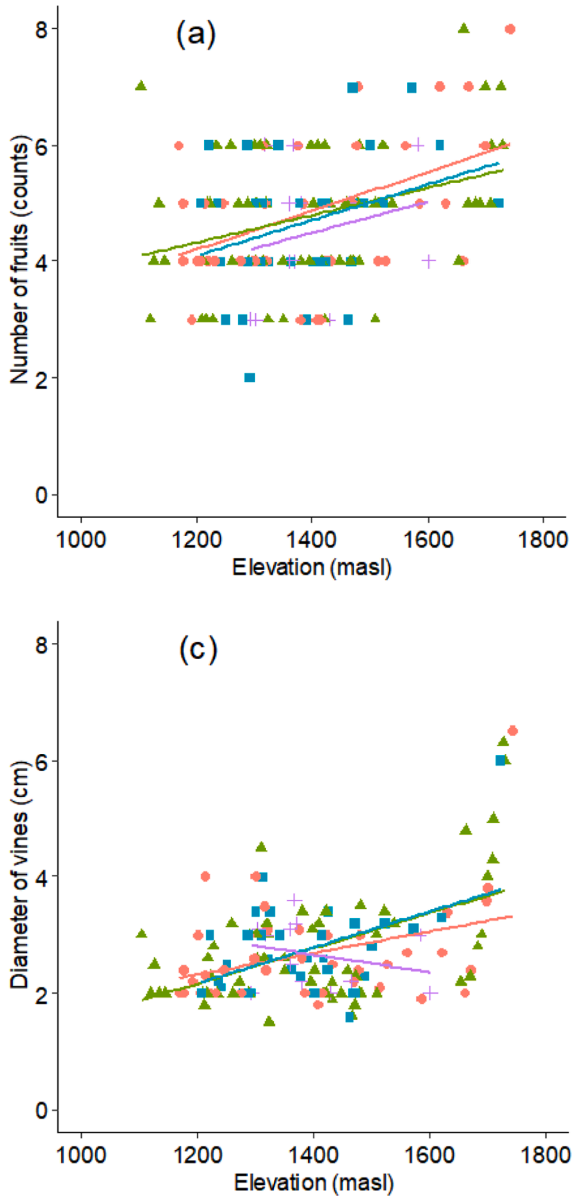

Fig. 5. (a–d). Relationship between number of fruits with elevation (a) and rainfall (b) as well as between diameter of vines with elevation (c) and rainfall (d) during our survey in Arumeru, Lushoto, Muheza and Same districts, from September 2019 until February 2020. N = 346.

(2016) explained the growth and yield of banana (*Mussa* spp) plantain cultivars performed well at higher elevation of 1815 masl.

3.2. Fruit diameter, number of seeds and environmental factors

Our study observed a significant positive relationship between fruit diameter and elevation for Arumeru district (r = 0.90 p <0.001), Muheza district (r = 0.84, p <0.001), Same district (r = 0.89, p = 0.001), and Lushoto district (r = 0.67, p <0.001) (Fig. 4a). Similarly, we found a significant positive relationship between fruit diameter and rainfall in Arumeru (r = 0.83 p <0.001), Muheza (r = 0.84, p <0.001), Same (r = 0.88, p = 0.001), and Lushoto districts (r = 0.71, p <0.001) (Fig. 4b). Further, we observed a significant positive relationship between the number of seeds and elevation for Arumeru (r = 0.90 p <0.001), Muheza (r = 0.88, p <0.001), Same (r = 0.92, p < 0.001), and Lushoto districts (r = 0.5, p <0.001) (Fig. 4c) as well as for number of seeds and rainfall for Arumeru (r = 0.87 p <0.001), Muheza (r = 0.87, p <0.001), Same (r = 0.80, p = 0.002), and Lushoto districts (r = 0.57, p <0.001) (Fig. 4d).

The effect of rainfall also had an effect on number of seeds in a fruit, as the number of seeds within a fruit increased with increasing rainfall across the study sites (Fig. 4). Similarly, larger sizes and number of *P. virginiana* seeds have commonly been associated with increased water availability (Parciak, 2002). Therefore, *T. pedata* which is an agroforestry crop can be grown at higher elevation not more that 1800 masl fpr environmental purposes and commercial scale due to its oilseed potential.

3.3. Number of fruits, diameter of vines and environmental factors

We observed a significant positive relationship between number of fruits and elevation in Arumeru (r = 0.47 p = 0.002) and Lushoto (r = 0.35, p <0.007), Muheza (r = 0.32, p = 0.03) and Same districts (r = 0.23, p = 0.04) (Fig. 5a). Likewise, a significant positive relationship between number of fruits and rainfall for Arumeru (r = 0.40 p = 0.011), Lushoto (r = 0.28, p = 0.03) and Muheza districts (r = 0.35, p <0.001) (Fig. 5b). Further, vines had larger diameter at higher elevation for Arumeru (r = 0.37 p = 0.019), Lushoto (r = 0.52, p <0.001), and Muheza districts (r = 0.46, p = 0.007) (Fig. 5c). The diameter of vines

Table 2
Names, frequency, and average diameter at breast height (DBH) of host tree species preferred by farmers for growing *T. pedata* vines as found during our study in Northern Tanzania from 2019 to 2020.

Tree species	Family	Frequency	Relative frequency (%)	Mean DBH (cm)
Albizia schimperiana	Fabaceae	110	39	40
Persea americana	Lauraceae	40	14	36
Croton macrostaychs	Euphorbiaceae	24	9	38
Artocarpus heterophyllus	Moraceae	23	8	38
Cordia africana	Boraginaceae	23	8	37
Terminalia superba	Combretaceae	16	6	19
Ficus sur	Moraceae	14	5	62
Rauvolfia caffra	Apocynaceae	12	4	35
Ficus thonningii	Moraceae	11	4	60
Mangifera indica	Anacardiaceae	7	3	52
Total		280	100	

was also higher with higher rainfall for Arumeru ($r = 0.38$ $p = 0.016$), Lushoto ($r = 0.42, p = 0.001$) and Muheza districts ($r = 0.51, p = 0.002$) (Fig. 5d). This study concurrently agrees with (Nwangburuka et al., 2014) that, once we understanding vegetative traits including vine length and width, number of fruits, and fruit size for a plant specie across different environmental factors, we will be able to effectively predict *T. pedata* in the future. This might help farmers deciding whether to include this highly nutritious specie (Mwakasege et al., 2021) in their agricultural cultivations to enrich both biodiversity and livelihood incomes.

3.4. Variation of fruit diameter, number of seeds with environmental factors

We recorded larger average fruit diameter at higher elevations across the study districts ($F_{1,\ 136} = 217.9$, $p < 0.001$) as well as with higher rainfall ($F_{1,\ 136} = 228.2$, $p < 0.001$). In addition, a significant district × elevation interaction was observed on fruit diameter ($F_{3,\ 136} = 3.57$, $p = 0.015$), with Lushoto and Same showing higher positive slopes than the other two districts, highlighting that elevation played a stronger role at these two districts.

The number of seeds increased at higher elevations across the study districts ($F_{1,\ 136} = 166.9$, $p < 0.001$). Likewise, the number of seeds increased with increasing rainfall across all the study districts ($F_{1,\ 136} = 171.9$, $p < 0.001$). We also observed a significant district × elevation interaction on fruit diameter ($F_{3,\ 136} = 7.9$, $p = <0.001$) with Muheza and Same showing higher positive slopes than the other two district. In addition, we found a significant rainfall × districts interaction on number of seeds ($F_{3,\ 136} = 4.9$, $p = 0.003$), with Arumeru, Muheza and Same showing higher positive slopes than Lushoto district. Lawes et al., (1990) explained that the relationship between the fruit size and content of seeds is complex and varies quantitatively and qualitatively between vines. Our study is in line with Chukwudi and Agbo (2014), they found out that large sized fruit gave bigger seed size in *Benincasea hispida* (ash guard) similar to *T. pedata* both members of Cucurbitaceae family. Even with *T. occidentalis,* large sized fruits gave higher marketable leaves and fruit yield than small sized fruits. Hence, this highlights that achieving larger fruit sizes might generally be more beneficial for small-scale farrmers.

3.5. Variations of number of fruits, diameter of vines across districts

We observed that on averge more that five fruits per plant were found significantly more often at higher elevations across the study districts ($F_{1,\ 136} = 21.7$, $p < 0.001$) with. Similarly, rainfall significantly increased the number of fruits across the study districts ($F_{1,\ 136} = 14.3$, $p < 0.001$). Interactions of districts × elevation ($F_{3,\ 136} = 0.18$, $p = 0.90$) and districts × rainfall ($F_{3,\ 136} = 0.5$, $p = 0.63$) were not significantly influencing number of fruits across study districts.

We found larger vine diameter at higher elevations across the study districts ($F_{1,\ 136} = 33.25$, $p < 0.001$) as well as higher rainfall ($F_{1,\ 136} = 26.44$, $p < 0.001$. Fruit numbers were positively influenced by vine diameter ($r = 0.55$, $p <0.001$). However, other studies revealed that, vine size, fruit size and numbers are traits which are vital information used to distinguish *T. occidentalis* and used for conservation of genetic materials (Chukwudi and Agbo, 2016). Therefore, having many large fruits could eventually affect the profitability of *T. pedata* hence increase fruit production and economic returns.

3.6. Availability of host tree species in different land use systems

We found a total of 280 individual trees representing seven families as hosts for *T. pedata* vines across the surveyed districts (Table 2). Most of the time, *T. pedata* was associated with *Albizia schimperiana* (in 39% of the cases), followed by *Persea americana* 14%, and least common was *Mangifera indica* with three percent. We also expected that tall native tree species will be the dominant host plant across all elevation levels due to the nature of the crop self-support from their climbing ways. This will be in-line with Gianoli (2015), who found that climbing plants which grow vertically, require external support such as trees for greater performance, enhancing light attainment and survival mechanism. Tree structure seems to be an important factor in determining the association of the climber to the tree (Rahman et al., 2020). We found trees with an average DBH of approximately 41 cm as the main supporters of *T. pedata*. Local climber species diversity and abundance are affected by the availability of structural support and vegetation attributes such as tree diameter, crown canopy, tree density, and crown features (Bruy et al., 2018). Also Yang et al. (2018) claimed that vines prefer host trees which have been growing for a long period of time resulting into larger DBH. Hence, promoting the growth of tall trees in agro-ecosystems is another advantage in ehhancing agro-biodiveristy vines, additionally to provision of shade, nutrient input etc. (Paul and Yavitt, 2011).

4. Conclusion

We found that elevation and average annuall rainfall clearly affected fruit sizes, number of seeds in fruits, as well as distribution and abundance of *T. pedata.* We showed that particularly in higher elevations and higher rainfall regions, *T. pedata* vines and bigger fruits were more common. This indicates that higher yields under favourable environmental condisitons will help increase agro-biodiversity across the various districts, where the crop is cultivated. We further highlighted that theassociated tree species beneficial for this vine will contribute to biodiversity conservation and might also influence *T. pedata* distribution, abundance, number of fruits and seeds, size of fruits and vines. We suggest that studies on growth performance of *T. pedata* in relation to soil nutrients and temperature should be conducted to enhance growth performance. Our study highlights the significance of *T. pedata* as a nutritious food and oilseed crop (Mwakasege et al., 2021) in order to also diversify small-holder farmers' income and agro-biodiversity.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We are thankful to the people of Lushoto, Muheza, Bumbuli, Same and Arumeru and Lushoto districts who generously shared their knowledge and experience. The authors also extend their gratitude to the centre for Research, Agricultural Advancement, Teaching Excellence and Sustainability in Food and Nutrition Security (CREATES-FNS) at the Nelson Mandela African Institution of Science and Technology (NM-AIST) for funding this research. We also thank IDEA Wild Inc. for assistance with field equipment as well as the Mbeya University of Science and Technology (MUST), for granting PFS a study leave for PhD studies. We are greatly indebted to all people who supported data collection and provided constructive comments on the manuscript.

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