
Effect of Variety and Harvesting Interval on Yield and Postharvest Quality of Frafra Potato (*Solenostemon rotundifolius* Poir)

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ABSTRACT

Frafra potato (*Solenostemon rotundifolius* Poir.) is a relatively underutilized root crop in Ghana. The crop is cultivated by smallholder farmers on less than 0.25 ha mainly in the Upper East and West Regions. Among the production constraints include the use of farmer-saved seed, low yield, high postharvest losses and little value addition technologies. This study assessed the yield, nutrient, sensory and shelf-life characteristics of 3 Frafra potato varieties and determined the optimum harvest maturity to maximize tuber yield. Three varieties (Maa-lana, Naachem-tiir, and Nutsugah piesa) and 5 harvest intervals (80, 90, 100, 110 and 120 days after planting) were assessed in relation to yield and shelf-life characteristics. Overall, tuber yield was comparable among the varieties, but Maa-lana (2.74 t/ha) recorded higher yield compared to Naachem-Tiir (2.54 t/ha) and Nutsugah piesa (2.43 t/ha). Naachem-tiir had a favorable sensory score for ease of peeling (3.7) compared to Nutsugah piesa (3.6) and Maa-lana (3.4) as well as a higher overall acceptability score of 4.4 for Naachem-tiir compared to 3.6 for Nutsugah piesa and 2.4 for Maa-lana. Simulating harvesting from 80 to 120 days provided reasonable tuber yield 1.12 (t/ha) - 3.22 (t/ha), with harvest interval of 100 days resulting in higher tuber yield. Optimizing storage at 6–8°C recorded decay losses of 5.7 to 6.8% and physiological weight loss of 4.6 to 5.7% during 16 weeks in storage. This study suggests utilizing vegetative propagules to increase seed security, and for scaling, Maa-lana and Naachem-tiir exude potential for higher productivity. The tuber yield of 1.12 t/ha recorded at the 80-day interval suggests that vegetative propagules can be used from late July to early August to obtain a reasonable yield, particularly when prolonged dry spells occur in early July.

Keywords: Plectranthus, underutilized tubers, vegetative propagules, productivity, early harvesting, shelf-life.

INTRODUCTION

Frafra potato (*Solenostemon rotundifolius* Poir.) is an underutilized tropical root crop cultivated in various parts of Africa and Asia (Abbiw, 1990; Alphonse et al., 2024; Nkansah, 2004). In Ghana, the crop is cultivated by smallholder farmers in districts mainly in the Upper East and West Regions. In these areas, it is produced on less than 0.25 ha of farmland per household (Ayambire et al., 2022; Callo-Concha et al., 2012). The commonly cultivated varieties have cream, black, red or dark-brown tubers (Alphonse et al., 2024; Sugri et al., 2013). Frafra potato grows about 15-30 cm high, with ascending or prostrate stem and thick leaves which have aromatic smell (Abbiw, 1990; Lukhoba et al., 2006; Nyawudzo et al., 2019). The tubers taste similar to Irish potato or trifoliolate yam, and can be eaten as a main starchy staple or in combination with legumes, rice, or with a vegetable sauce. It can be prepared into other cuisines either boiled, baked, or fried (Schippers, 2000). The tubers can also be processed into aromatic alcoholic beverages, and the leaves can be eaten as pot-herb (PROTA, 2013).

Some studies indicate that the tubers are rich in carbohydrates and fair amounts of vitamins, minerals and proteins (Anbuselvi and Balamurugan, 2013; Tortoe et al., 2020). Frafra potato contain higher protein content (4.1-6.2 g/100 g) compared to sweet potato (0.8 g/100 g), yam (1.8 g/100 g) and cassava (0.7 g/100 g) (PROTA, 2013). Other compositional characteristics include moisture (75.6%), energy (394 kJ or 94 kcal), protein (1.3 g), fat (0.2 g), carbohydrate (21.9 g), fibre (1.1g), Ca (17 mg), Fe (6 mg), thiamine (0.05 mg), riboflavin (0.02 mg), niacin (1 mg) and ascorbic acid (1 mg) (Anbuselvi and Balamurugan, 2013; Tortoe et al., 2020; Sugri et al., 2021). In the report of Anbuselvi and Balamurugan (2013), some tuber composition includes protein (14 g), calcium (29 mg), sodium (1.2 mg), potassium (0.1 mg), phosphorus (36 mg), magnesium (0.03 mg), vitamin A (13.6 mg) and Vitamin C 10.3 mg). Tortoe *et al.* (2020) profiled the nutrient composition as ash (4.4 g), fat (0.55 g), protein (5.1 g), carbohydrate (90 g), and energy (384.8 kcal).

Large scale cultivation and commercialization are confronted with several constraints such as lack of healthy planting materials, use of farmer-saved seed, pests and diseases damage, declining soil fertility, rapid tuber deterioration at storage and little value addition (Bennett-Lartey and Oteng-Yeboah, 2008; Sugri et al., 2013; Tetteh and Guo, 1997). Access to improved varieties and planting materials remains a dominant constraint in many communities (Romaric et al., 2018; Sugri et al., 2013; Tetteh and Guo, 1997). Another constraint relates to the breakdown of natural dormancy in about three months after harvest making the tuber fibrous. Other reports identified small tuber size as a constraint since most local cultivars produce tiny and/or branched tubers (Kwarteng et al., 2018; Murugesan et al., 2020; Sugri et al., 2021). These constraints result in poor tuber yield and low market value of the crop. So far, little research has been conducted towards improving the tuber size which is essential in increasing the production and commercial value of the crop. However, some research findings suggest the role of soil fertility, fertilizer application, plant spacing, planting time and bed size on tuber size (Yirzгла et al., 2022; Yirzгла et al., 2023). In addition to these pre-harvest constraints, the crop also experiences significant postharvest losses (30 to 60%) during storage beyond 2 months (Sugri et al., 2021).

The postharvest quality and shelf-life of Frafra potato (*Solenostemon rotundifolius*) has been noted to be significantly influenced by the timing of harvest. Several studies have demonstrated that delayed or premature harvesting can significantly affect traits such as nutrient content, sensory quality, storability, and resistance to decay pathogens (Abu et al., 2021; Atakora et al., 2020; Ile et al., 2006). Early harvesting results in immature tubers with underdeveloped periderm, making them more susceptible to water loss, mechanical damage and microbial infections during storage

(Nedunchezhiyan et al., 2008; Ile et al., 2006). The tubers are mainly stored in traditional storage vessels such as thatch mats, baskets and clay pots under ambient conditions which increases the severity of decay losses and shriveling (Ile et al., 2006; Abu et al., 2021). Low-cost options to minimize losses are therefore crucial to improving marketability, especially where refrigeration or controlled storage is absent in the producing areas. This study assessed the yield, nutrient, sensory and shelf-life characteristics of 3 varieties, and determined the optimum harvest maturity to maximize tuber yield and shelf-life.

MATERIALS AND METHODS

Description of study location

Field experiments were conducted at Manga Agricultural Experimental Station of the CSIR-Savanna Agricultural Research Institute in Bawku (10.8296101°N, 0.9414592°W) in the Upper East Region of Ghana, in 2022 to 2023. In terms of agroecology, the Upper East region is found in the Sudan savannah agroecology. The soils at Manga are Plinthic lixisols that are developed from granite and stones (IUSS Working Group WRB, 2007). The area has alternating wet and dry seasons with the wet season occurring between May and October; about 95% of rainfall occurs during this period. Maximum rainfall occurs from August to September, and severe dry conditions typically exist between November and April. Annual rainfall ranges from 800 to 1200 mm. There is wide fluctuation in relative humidity with as low values as 30 to 55% in the dry season (November to April) and above 75% in the wet season (Frimpong et al., 2014; Kanton et al., 2019). Some physical and chemical properties of surface soil (0 to 15 cm) in the area are presented in Table 1. The soils are mainly sandy and acidic, with high potassium.

Table 1: Weather conditions and physicochemical properties of surface (0 to 15 cm) soil at the experimental site at the Manga Agricultural Research Station

Soil physical and chemical properties	Manga, Binduri District	Physical and chemical properties	Upper East Region
Sand (%)	80.4	Mean Annual Rain (mm)	1000
Silt (%)	14	Relative humidity [%] (~Nov- April)	30
Clay (%)	5.6	Relative humidity [%] (~June to Oct.)	75
Soil texture	Loamy sand	Soil pH	4-7.4
Soil pH (H2O)	4.22	Soil Organic Matter (%)	0.54-6.74
Organic carbon (%)	0.47	Total Nitrogen (%)	0.0-0.14
Total nitrogen (%)	0.06	Available Phosphorus (mg kg ⁻¹)	0.0-3.62
Available P (mg kg ⁻¹)	20.25	Cation Exchange Capacity	0.0-7.72
Exchangeable cations cmol (+) kg ⁻¹			
Ca	0.08		
Mg	0.04		
K	27.30		
CEC [cmol (+) kg ⁻¹]	4.55		

Reference: Kanton et al. (2019).

Experimental design

The first experiment assessed the suitability of three frafra potato varieties (Nutsugah piesa, Naachem-tiir and Maa-lana) for production in the Upper East Region. The trial was laid as a single factor experiment in Randomized Complete Block Design (RCBD) with 3 replicates. The second experiment determined the optimum harvest maturity to maximize tuber yield and shelf-life of same varieties. The experimental set up was a 3 x 5 factorial in RCBD with 3 replicates. The factors were variety (Nutsugah piesa, Naachem-tiir and Maa-lana) (Described in Table 2) and harvest intervals (80, 90, 100, 110 and 120 days). Harvesting was staggered at intervals of 10 days from 80 to 120 days after transplanting. Experimental plots size of 20 m² were used, and planting was done on ridges using vegetative cuttings of 20 to 30 cm long with at least three internodes, and at plant spacing of 1 x 0.2 m. Alleys between replications and plots were 1 m and 0.5 m, respectively. Large ridges were used to ensure maximum utilization of available resources for good tuber formation as practiced in the area.

Table 2: Description of Frafra potato varieties utilized in this study

Variety	Colour of skin	Colour of flesh	Average tuber weight (g)	Days to physiological maturity	Average yield (t/ha)	Preferred Agroecology
Maa-lana	Brown	Cream	3.5	95	23	Guinea Savanna,
Naachem-tiir	Brown	Cream	3.4	95	22	Sudan Savanna,
Nutsugah piesa	Light brown	Cream	3.8	95	17	Coastal Savanna, and Forest zones

Source: Kusi et al. (2019)

Planting and agronomic practices

For the first experiment, planting was carried out on July 14, 2022 and harvesting was done by 100 days after planting (November 21, 2022). In the second experiment, planting was carried out on July 14, 2022 and harvesting was done on October 21, November 1, 11, 21 and December 1, 2022. Agronomic practices included timely weeding by hoeing, hand picking and fertilizer application at recommended dose (i.e., TSP at 300 kg/ha). Weeding was done in the 4th and 7th week after planting, followed by earthing-up to support the base of the plants for good tuber formation. Weeds were also occasionally pulled out by hand at the latter stage of growth and the plants were regularly inspected for incidence of pests and diseases but no pest control measure was undertaken.

Assessment of growth traits

Growth traits recorded were crop establishment at 4 weeks after planting (WAP), branches per plant at 12 WAP, canopy spread at 12 WAP, and plant height at 12 WAP. Flowering data collected included days to first flowering and days to 50% flowering (DFF).

Assessment of yield traits

The yield data collected at harvest were number of tubers as well as tuber and stover yields. Harvesting was done at 100 days after planting when the leaves had dried out and the stems had withered as practiced by the farmers. The tubers from the two central rows were harvested and weighed together using an electronic weighing scale from which tuber yield per hectare were

estimated. The tubers were also categorized into sizes: small tubers (<2.5 g); medium tubers (2.6-3.5 g) and large tubers (>3.5 g). The harvested tubers were further sorted into marketable (>2.5 g without injuries, insect wound and rots), non-marketable tubers (<2.5 g, tubers with injuries, insect wounds and rots).

Nutrient compositional analysis

After harvest, nutrient content analysis of the 3 varieties was conducted for dry matter, moisture, protein, crude fat, ash and vitamin C contents in the CSIR-Savanna Agricultural Research Institute Food Processing Laboratory, Nyankpala, Ghana. Wholesome tubers were sorted, cleaned and stored at room temperature (28-32°C) prior to processing. The selected nutrient contents were assessed based on the standard methods of the AOAC International (AOAC, 2005). Moisture content was determined using oven-air drying method. Using a pre-dried and aluminum can, 5 g fresh sample was weighed and transferred into an oven-air dryer (Memmert F110, Germany). The samples were dried to a constant weight and the percentage moisture content was estimated as loss in weight after drying. For crude protein, the micro-Kjeldahl method was used to determine total nitrogen content. Protein content was obtained by multiplying the percentage of total nitrogen by a factor of 6.25 as applicable to plant ingredients. For crude fat content, 2 g of the dried sample was weighed into extraction thimble and placed inside a Soxhlet apparatus (FOSS 255 Soxtec, China). A dried pre-weighed solvent flask containing 85 ml petroleum ether was connected beneath the apparatus and extracted for 65 min. On completion, the thimbles were removed, cooled in a desiccator and weighed, and crude fat expressed as a percentage. For total ash content, 2 g of sample was weighed into a dry, tared porcelain dish and placed in a muffle furnace (Carbolite GERO, CWF 1200) at 550°C for 4 h. After complete charring, the porcelain dish was removed and cooled in a desiccator and weighed, and the ash content was expressed as a percentage. The available carbohydrate content of samples was estimated by difference.

$$CHO\% = 100 - (Moisture\% + Ash\% + Protein\% + Fat\%)$$

Vitamin C content was determined using 2,6-Dichloro-phenol Indophenol dye reagent method as outlined by Abdelsamad et al. (2010). The dye was standardized so that 1 g of ascorbic acid was equivalent to 1 ml of the dye. Approximately, 30 ml of sample was blended in 100 ml of 0.4% oxalic acid for 2 min. and then filtered through Whatman filter paper (No. 1). The filtrate was made to 250 ml with 0.4% oxalic acid and ascorbic acid in 20 ml filtrate was titrated against standard 2,6-Dichlorophenol Indophenol.

Sensory analysis

Using the 3 varieties, descriptive sensory analysis was conducted on tubers using sensory panel comprising 100 regular consumers. The sensory attributes assessed included flavor, texture, mouthfeel, ease of peel and overall acceptability. The intensity of each attribute was evaluated in a 0 to 5 scale (where 1: not acceptable, 2: fair, 3: good, 4: very acceptable, and 5: most acceptable). The panel were engaged to measure the sensory attributes and overall preference of the varieties. The panel were not trained but were regular consumers selected at random from the Binduri District in the Upper East Region of Ghana, and varied in sex, age group, level of education and income levels. The tubers were washed and boiled with no additive nor salt for 15 minutes, and allowed to cool for 3 to 5 minutes, and then coded samples were presented in serving plates to the panel for assessment.

Determination of shelf-life

The postharvest shelf-life assessment was done immediately after harvest from November 2022 to April 2023. Using the 3 varieties, the first storage test simulates near optimal conditions (6 to 8 °C) if the farmers have access to cold chain storage facilities compared to storage in current farmer vessels. Uniform marketable grade tubers were selected to determine shelf-life stability up to 4 months after harvest. For each variety, 3 replicates of 200 tubers were wrapped in paper envelopes and stored in a refrigerator set to about 6 to 8 °C compared to farmers storage vessel in which the tubers were incorporated with millet husk and stored in open baskets. Shelf-life was evaluated in relation to weight loss and the incidence of decay at storage intervals of 4, 8, 12 and 16 weeks (Githieya, 2024; Sugri et al., 2021).

Total weight loss (TWL) was determined as a percentage of initial weight to the final weight during the storage period. Mean daily weight loss (%) was further calculated by dividing total weight loss by the number of days in storage. Decay incidence was assessed as the number of tubers showing overt decay symptoms expressed as a percentage of initial number stored at each storage period. In the second study, shelf-life qualities of tubers harvested at 5 intervals were assessed. Three replicates of 200 tubers were submerged in dry millet husk and stored in baskets at room temperature ($\sim 32 \pm 5$ °C, RH: 30 to 55%) for 16 weeks. Shelf-life assessment was same as described above.

Determination of pathogens associated with tuber rot

During the storage period, 3 replicates of 70 tubers showing intermediate decay symptoms were collected and processed for isolation and identification of pathogens at the Plant Pathology Laboratory of the Manga Agriculture Station. Tissues were excised from the infected tubers and sterilized in 3% sodium hypochlorite solution. The tissues were then washed in sterile distilled water and blotted dry on sterile tissue paper. The excised tissues were then placed on 9 cm Petri dishes containing freshly prepared potato dextrose agar amended with streptomycin sulphate. The cultures were incubated in a dark chamber for three days at 25 to 32°C, following which pure cultures were obtained through subcultures. The isolates were then identified by microscopy following descriptors suggested by Barnett and Hunter (2006).

Pathogenicity test was conducted using healthy tubers to evaluate the ability of the isolates to cause tuber rot following the protocol used by Ibrahim et al. (2014). Tubers were sterilised with 3% sodium hypochlorite solution, rinsed, and blotted dry. Rectangular grooves of 5 mm deep were created on the healthy tubers using sterile surgical blades. Mycelia pugs (5 mm in diameter) of five-day old cultures of the isolates were placed in the groove and sealed with paraffin. A control check in which the tuber grooves were inoculated with PDA pugs instead of the mycelia pugs were also conducted and sealed. The tubers were incubated in a growth chamber at 25 to 32°C for 5 to 14 days. After the inoculation period, visual examination of tubers for rot symptoms and re-isolation of pathogens from the tuber were done; fulfilling the Koch's postulates (Ibrahim et al., 2014; Agrios, 2005).

Data analysis

Data sets from both experiments were subjected to analysis of variance (ANOVA) procedure using the GenStat (14th Edition) software. Means that were significantly different were separated by Fischer Least Significant Difference at 5% significant level. The sensory data was analyzed using rated mean scores obtained for each sensory attribute.

RESULTS

Growth, yield, nutrient and sensory characteristics of three Frafra potato varieties

Growth characteristics

Table 3 presents some growth characteristics (canopy spread, leaf area, number of branches per plant and plant height) of the varieties. Comparing the varieties for growth habit, there were significant differences ($P \leq 0.05$) in leaf length, leaf area and number of branches. However, there were no significant differences for canopy spread and plant height. The mean canopy spread was 112.5 cm as well as leaf area (19.7 cm^2) and plant height (61.9 cm). Leaf area was 19.5 cm^2 for Nutsugah piesa, 20 cm^2 for Naachem-tiir (3.2 cm^2) and 19.5 cm^2 for Maa-lana. Canopy spread for Nutsugah piesa was 114.0 cm, Naachem-tiir (115.2 cm) and Maa-lana. Naachem-tiir was much taller (63.5 cm), followed by Nutsugah piesa (62.1 cm) and Maa-lana (60.1 cm) (Table 3).

Table 3: Some growth characteristics of three Frafra potato varieties assessed in the Upper East Region of Ghana

Variety	Canopy spread (cm)	Leaf area (cm^2)	Number of branches	Plant height (cm)
Maa-lana	108.2 ^a	19.8 ^a	57.4 ^b	60.1 ^a
Naachem-tiir	115.2 ^a	20.1 ^a	49.6 ^{ab}	63.5 ^a
Nutsugah piesa	114.0 ^a	19.5 ^a	41.8 ^a	62.1 ^a
Mean	112.5	19.7	49.6	61.9
CV (%)	12.2	13.6	34.3	17.5
Sig. level	ns	ns	0.05	ns
LSD($p < 0.05$)	2.4	5.7	12.7	8.1

ANOVA was conducted using mean of three replicates. CV: Coefficient of variation of three replicates of a treatment. LSD: represents the least significant difference between treatment means

Yield characteristics

There was no significant difference ($P \leq 0.05$) between the varieties for all the yield evaluated (Table 4). Nutsugah piesa had lower plant count (31.3), whilst Maa-lana (41) had higher plant count per plot. The number of non-commercial tubers per area (16 m^2) indicated that Nutsugah piesa had the most (573) number of non-commercial tubers, followed by Naachem-tiir (546) and Maa-lana (587). The number of commercial tubers was 240 for Nutsugah piesa, 250 for Naachem-tiir, and 253 for Maa-lana. Overall tuber yield was 2.43 t/ha for Nutsugah piesa, 2.54 kg/ha for Naachem-tiir and 2.74 t/ha for Maa-lana.

Table 4: Some yield characteristics of three Frafra potato varieties assessed in the Upper East Region of Ghana

Variety	Plant count	Number of non-commercial tubers	Weight of non-commercial (kg)	Number of commercial tubers	Weight of commercial tubers (kg)	Yield (t/ha)	Commercial tubers yield (t/ha)
Maa-lana	41.0 ^a	587 ^a	0.8 ^b	253 ^a	1.3 ^a	2.74 ^b	1.09 ^a
Naachem-tiir	38.0 ^a	546 ^a	0.8 ^b	250 ^a	1.1 ^a	2.54 ^a	0.93 ^a
Nutsugah piesa	31.3 ^a	573 ^a	0.7 ^a	240 ^a	1.3 ^a	2.43 ^a	1.06 ^a

Mean	36.8	568.7	0.8s	247.7	1.2	2.57	1.02
CV (%)	16.8	43.5	50.3	18.4	15.8	27.3	15.9
Sig. level	ns	ns	ns	ns	ns	ns	ns
LSD _(p<0.05)	14.0	527.7	0.9	103.1	0.4	1.59	0.37

ANOVA was conducted using mean of three replicates. CV: Coefficient of variation of three replicates of a treatment. LSD: represents the least significant difference between treatment means

Nutrient composition

Nutrient contents such as dry matter content, moisture content, total ash, protein content and crude fat content of the 3 varieties were profiled (Table 5). There were significant differences ($P \leq 0.05$) in dry matter, total ash, protein and crude fat contents. The dry matter content of Nutsugah piesa (20.9%) and Naachem-tiir (20.2%) were similar but Maa-lana recorded significantly lower dry matter content (18.1%). Maa-lana contain higher protein content (4.2%) compared to Naachem-tiir (3.4%) and Nutsugah piesa (3.1%). Similarly, Maa-lana (0.26%) and Naachem-tiir (0.31%) had higher crude fat content compared to Nutsugah piesa (0.06%). However, the total ash content ranged from 2.6 to 2.9%; in which Nutsugah piesa possessed higher total ash content (2.9%). Lastly, vitamin C content (1.9 to 2.3 mg/g) was not significantly different across the varieties.

Table 5: Nutrient composition of three Frafra potato varieties assessed in the Upper East Region

Variety	Dry matter (%)	Total ash content (g)	Protein content (%)	Crude fat (%)	Vitamin C mg/g
Maa-lana	18.1 ^a	2.8 ^b	4.2 ^b	0.26 ^b	1.9 ^a
Naachem-tiir	20.2 ^b	2.6 ^a	3.4 ^a	0.31 ^b	2.3 ^a
Nutsugah piesa	20.9 ^b	2.9 ^b	3.1 ^a	0.06 ^a	2.1 ^a
Mean	19.7	2.8	3.6	0.21	2.1
Sig. level	0.01	0.01	0.01	0.05	ns
CV (%)	2.6	3.1	6.0	29.7	17.6
LSD _(p<0.05)	1.0	0.17	0.43	0.12	0.74

ANOVA was conducted using mean of three replicates. CV: Coefficient of variation of three replicates of a treatment. LSD: represents the least significant difference between treatment means

Sensory characteristics

Comparing the varieties for sensory quality, Maa-lana recorded lower flavour score (2.7) followed by Naachem-tiir (2.8) and Nutsugah piesa (3.0) (Table 6). Same scoring was recorded for mouth-feel, namely, Maa-lana (2.3), Naachem-tiir (3.4) and Nutsugah piesa (3.4). But for texture, Maa-lana received higher score (2.9), followed by Naachem-tiir (2.8) and Nutsugah piesa (2.3). Also, Maa-lana had taste score of 2.4 lower than Naachem Tiir (3.4) and Nutsugah piesa (3.4). In general, Naachem-tiir and Nutsugah piesa were rated for most of the sensory traits, with Naachem-tiir possessing higher acceptability score of 4.4, followed by Nutsugah piesa (3.6) and Maa-lana (2.4).

Table 6: Description of sensory qualities of the varieties assessed in the Region

Variety	Flavour	Mouth feel	Texture	Taste	Ease of peeling	Overall acceptability
Maa-lana	2.7±1.1	2.3±1.1	2.9±1.2	2.4±1.0	3.4±1.3	2.4±1.1
Naachem-tiir	2.8±1.3	3.4±0.9	2.8±1.2	3.4±1.0	3.7±1.1	4.4±5.2
Nutsugah piesa	3.0±1.2	3.4±1.0	2.3±1.0	3.4±1.0	3.6±1.1	3.6±0.7

Shelf-life characteristics

The effect of optimum storage conditions (~6-8 °C) on the incidence of decay and weight loss was (Table 7) compared to ambient conditions (~30±5 °C, RH~35-55%). Across the varieties, storage at 6-8 °C recorded lower decay losses of 5.7 to 6.8% compared to ambient conditions (34.4 to 50%) during 16 weeks of storage. Also, storage at 6-8 °C recorded lower physiological weight loss (4.6 to 5.7%) compared to ambient conditions (32.9 to 42.2%) during 16 weeks of storage (Figure 1a-c). The trend of physiological weight loss in farmer storage vessels showed 6 to 15% in the first month in storage and up to 30 to 40% when stored for 4 months (Figure 2a). Under ambient conditions (~30±5 °C, RH~35-55%), the tubers suffer 0.2 to 0.5% daily weight loss during the initial period in storage and close to 0.3 to 0.4% in the latter stages (Figure 2b). Thus, by utilizing the farmers' storage vessels, the tubers will maintain premium quality for only 2 to 4 weeks after harvest, but the shelf-life can be extended up to 16 weeks if cold-chain packing houses are available.

Table 7: Decay incidence in 3 Frafra potato varieties stored at ambient (30±5 °C, RH~35-55%) and refrigerated (6-8 °C) conditions for 16 weeks

Variety	Storage Method	Decay loss from 4 to 16 weeks (%)			
		4	8	12	16
Maa-lana	Ambient	6.4(2.5) ^{bc}	14.9(3.8) ^b	26.6(5.2) ^c	50.0(7.1) ^c
	Refrigerated	0.8(0.9) ^a	2.7(1.6) ^a	3.8(1.9) ^a	5.7(2.4) ^a
Naachem-tiir	Ambient	2.5(1.6) ^a	14.9(3.7) ^b	26.6(5.9) ^c	50.0(7.1) ^c
	Refrigerated	1.3(1.1) ^a	2.8(1.3) ^a	5.0(2.1) ^a	6.8(2.6) ^a
Nutsugah piesa	Ambient	4.5(2.1) ^{ab}	6.9(2.6) ^a	13.0(3.6) ^b	34.4(5.9) ^b
	Refrigerated	1.5(1.1) ^a	3.0(1.7) ^a	4.5(2.1) ^a	6.3(2.5) ^a
Mean		2.9(1.5)	7.5(2.5)	13.3(3.3)	25.5(4.6)
Variety × storage method		ns(ns)	ns(ns)	0.01(0.05)	0.001(0.01)
CV (%)		61.4(30.9)	24.8(50.7)	20.8 (14.1)	8.5 (7.1)
LDS ($p<0.05$)		3.1 (0.85)	6.8 (1.1)	4.9 (0.8)	3.9 (0.6)

ANOVA was conducted using mean of three replicates. CV: Coefficient of variation of three replicates of a treatment. LSD: represents the least significant difference between treatment means

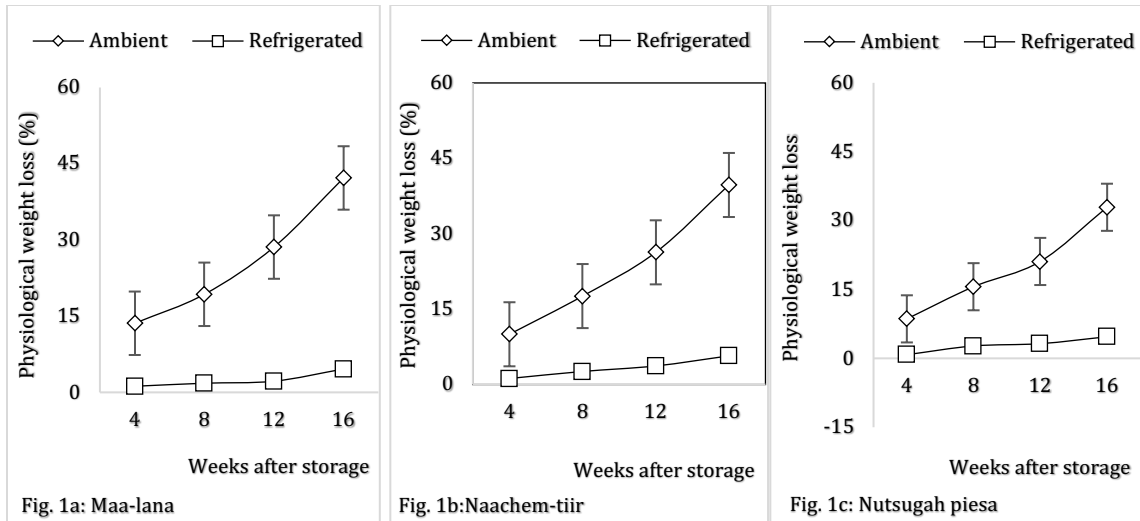


Figure 1a-c: Rate of physiological weight loss of Frafra potato varieties during 4 months storage in ambient (30±5 °C, RH~35-55%) and refrigerated (6-8 °C) conditions. Bars represent standard errors of the difference between means of three replications

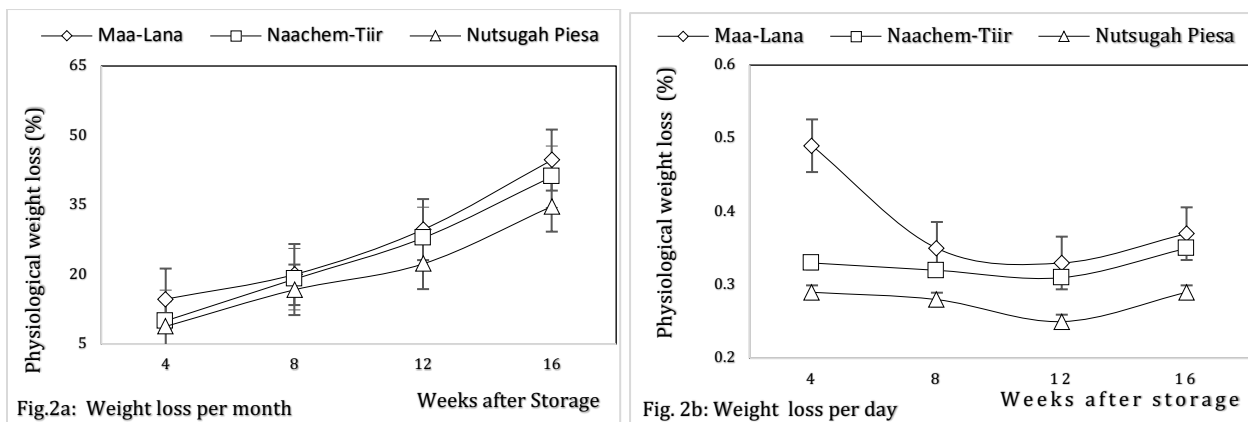


Figure 2a & b: Trend of monthly and daily physiological weight loss of Frafra potato varieties during 4 months in storage assessed in farmers storage vessels. Bars represent standard errors of the difference between means of three replications

Effect of harvest intervals on yield and shelf-life characteristics

Yield Characteristics

No significant differences ($P \leq 0.05$) were recorded for both variety and variety \times harvest interval on tuber yield characteristics (Table 8). However, harvesting interval significantly ($P \leq 0.05$) influenced tuber yield components. Early harvesting at 80 days produced the lower tuber yield (1.12 t/ha) compared to harvesting at 100 days (3.22 t/ha). Overall, harvesting at 100 days provided the highest tuber yield and a higher weight of commercial tubers (1.8 kg/plot).

Among the varieties, Maa-lana had higher number (238) and overall tuber yield (2.15 t/ha) compared to Naachem-tiir (2.12 t/ha) and Nutsugah pisa (1.9 t/ha). If early planting is feasible, the optimum harvest maturity for maximum commercial tuber yield was 100 days, with Maa-lana possessing higher yield potential among the varieties (Table 8).

Table 8: Effect of variety and harvesting intervals on the yield characteristics of Frafra potatoes

Treatment	Stand count	Number of commercial tubers	No. of non-commercial tubers	Weight of commercial tubers (Kg)	Weight of non-commercial tubers (Kg)	Tuber yield (t/ha)
Variety						
Maa-lana	34.1 ^b	238 ^a	623 ^a	1.6 ^b	1.6 ^b	2.15 ^a
Naachem-tiir	33.0 ^b	229 ^a	587 ^a	1.4 ^a	1.6 ^b	2.12 ^a
Nutsugah piesa	27.5 ^a	205 ^a	596 ^a	1.4 ^a	1.5 ^a	1.90 ^a
Sig. level	0.01	ns	ns	ns	ns	ns
LSD _(p<0.05)	4.3	65.3	123.1	0.3	0.3	0.96
Harvesting interval (days)						
80	33.7 ^a	172 ^a	669 ^a	0.9 ^a	0.9 ^a	1.12 ^a
90	30.9 ^a	292 ^b	595 ^a	1.4 ^b	1.0 ^a	1.49 ^a
100	30.3 ^a	222 ^{ab}	583 ^a	1.8 ^c	1.9 ^{bc}	3.22 ^b
110	33.2 ^a	222 ^{ab}	533 ^a	1.7 ^{bc}	1.8 ^b	2.17 ^{ab}
120	29.6 ^a	212 ^a	632 ^a	1.5 ^{bc}	2.2 ^c	2.29 ^{ab}
Sig. level	ns	ns	ns	0.01	0.01	0.05
LSD _(p<0.05)	5.6	84.3	158.9	0.4	0.4	1.24
Mean	31.5	224	602	1.5	1.6	2.06
CV	18.4	17.7	22.3	27.8	22.7	38.4

ANOVA was conducted using mean of three replicates. CV: Coefficient of variation of three replicates of a treatment. LSD: represents the least significant difference between treatment means.

Effect of harvest intervals on shelf-life characteristics

During the first 8 weeks of storage, Nutsugah piesa showed significantly ($P<0.01$) lower susceptibility (2.9–7.3%) to decay losses compared to Maa-lana (5–10.3%) and Naachem-tiir (4.9–12.3%) (Table 9). There were significant effects of variety ($P<0.01$) and harvest interval ($P<0.01$) on decay losses, but no effect ($P<0.05$) of variety \times harvesting interval was observed. Generally, Nutsugah piesa showed consistently lower susceptibility to decay losses, whilst Naachem-tiir was the most susceptible to decay losses. Although the large proportion of small to medium size tubers in Nutsugah piesa may account for this trend too.

The decay losses increased with prolong harvesting and extended storage duration. By 16 weeks after storage, differences between the varieties were negligible, in which decay losses ranged from 29.3 to 45.1% across the varieties. Similarly, physiological weight loss increased with prolong harvesting and storage period (Figures 3a-c). The weight loss ranged from 10.5 to 16.6% in the first 4 weeks after storage, and increased to 31.7 to 51.9% when stored up to 16 weeks. Late harvesting at 120 days resulted in higher (39.8–51.9%) weight loss among the harvest intervals and the varieties.

Table 9: Effects of variety and harvest intervals on the incidence of decay in three Frafra potato varieties

Treatment	4 weeks		8 weeks		12 weeks		16 weeks	
	Mean	CI (95%)	Mean	CI (95%)	Mean	CI (95%)	Mean	CI (95%)
Variety								
Maa-Lana	2.2 (5.0) ^b	3.9-7.7	3.2 (10.3) ^b	8.7-13.4	4.5 (20.0) ^b	18.2-23.4	6.1 (37.6) ^b	33.7-43.5
Naachem-tiir	2.2 (4.9) ^b	3.6-7.4	3.5 (12.3) ^b	10.2-15.6	5.0 (25.1) ^c	23.0-28.7	6.4 (41.4) ^b	36.8-47.5
Nutsugah piesa	1.8 (2.9) ^a	2.3-4.5	2.8 (7.3) ^a	6.8-9.0	4.2 (17.5) ^a	15.6-28.7	5.8 (33.7) ^a	30.7-38.1
Sig. level	0.01		0.01		0.01		0.01	
LSD(p<0.05)	0.3		0.3		0.2		0.4	
Harvest intervals (days)								
80	1.4 (1.6) ^a	1.6-2.5	2.6 (6.6) ^a	6.2-7.8	4.2 (17.6) ^a	16.2-20.1	5.4 (29.3) ^a	26.1-33.5
90	1.7 (2.4) ^a	2.3-3.4	2.8 (7.5) ^a	7.5-8.6	4.7 (22.2) ^c	18.9-26.7	5.9 (34.2) ^b	30.3-39.3
100	2.1 (4.1) ^b	2.9-6.3	3.2 (10.4) ^b	7.9-13.9	4.5	17.1-25.0	6.2 (37.8) ^{bc}	32.1-44.6
110	2.5 (6.2) ^c	4.4-9.1	3.4 (11.5) ^b	8.7-15.8	(20.5) ^{bc}	15.3-25.2	6.5 (42.2) ^c	36.8-48.7
120	2.8 (7.4) ^c	5.9-10.5	3.8 (14.3) ^c	11.6-18.3	4.4(19.7) ^{ab}	20.8-30.9	6.7 (45.1) ^{cd}	40.3-52.1
Sig. level	0.01		0.01		0.01		0.05	
CV (%)	18.2		11.8		6.5		8.9	
LSD(p<0.05)	0.4		0.4		0.3		0.5	

ANOVA was conducted using mean of three replicates. CV: Coefficient of variation of three replicates of a treatment. LSD: represents the least significant difference between treatment means. Percentage data on decay losses was managed by square root transformation. Mean values of non-transformed data are shown in parenthesis. CI: Confident interval at a probability of 95%.

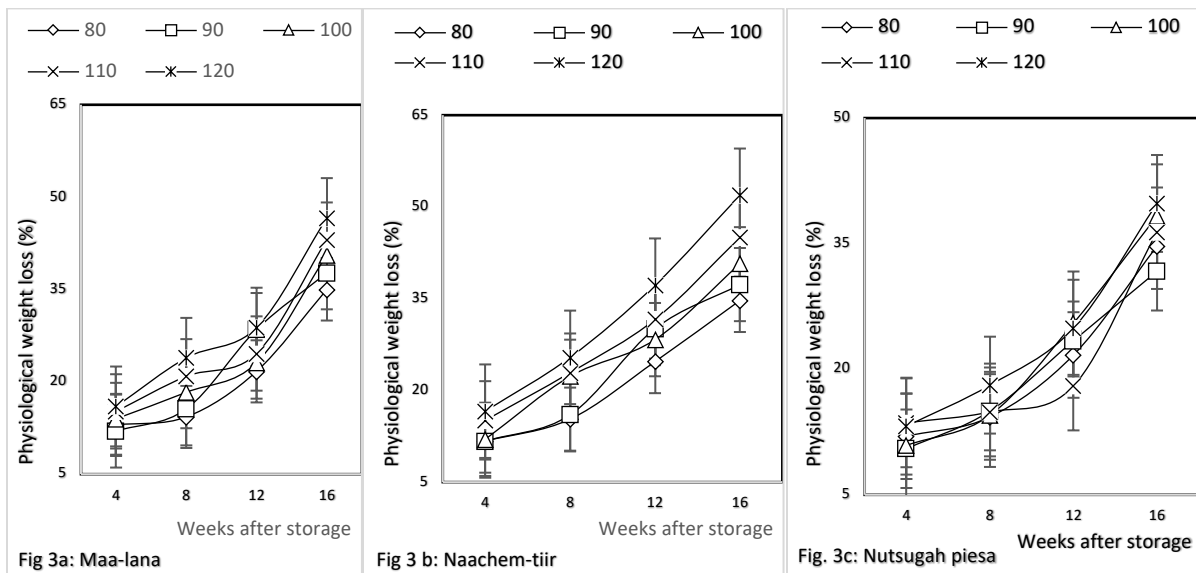


Figure 3a-c: Rate of physiological weight loss of Frafra potato varieties during 16 weeks in storage. Bars represent standard errors of the difference between means of three replications

Pathogens associated with tuber rot during storage

Significant differences (P<0.001) were recorded for tuber rot-causing pathogens (Table 10). The pathogenicity test revealed 5 isolates (Figure 4) to be associated with tuber rot. The dominant

pathogens were *Macrophomina phaseolina* (37%), *Rhizopus stolonifer* (29%) and *Aspergillus niger* (14%) but *Penicillium* spp. (10%) and *Fusarium* spp. (7%) were also recorded (Figure 4). During the initial period of storage, *Rhizopus stolonifer* (36.3%) was the dominant pathogen (Figure 5). Subsequently, four pathogens, namely, *Aspergillus niger* (22%), *Penicillium* spp. (18%), *Macrophomina phaseolina* (14.2%) and *Fusarium* spp. (19%) were recorded. At the latter period of storage, *Macrophomina phaseolina* (54.7%) and *Rhizopus stolonifer* (24.2%) were the dominant pathogens.

Table 10: Mean sum of squares from ANOVA of incidence of fungal pathogens associated with Frafra potato tuber rot

Source of Variation	DF	Percentage Incidence (Weeks after storage)				Total Incidence
		4	8	12	16	
Causal agent	5	6.22	2.61	9.13	22.07	10.01
Residual	12	0.14	0.27	0.21	0.18	0.2
Level of significance		0.01	0.01	0.01	0.01	0.01
CV (%)	10	13.1	12.1	13.2	12.1	12.1
Grand mean		3.7	4.0	3.8	3.2	3.67

Mean sum of squares was generated from values of transformed data. ANOVA was conducted using mean of three replicates. CV: coefficient of variation of three replicates of a treatment. Incidence data were transformed using square root transformation.

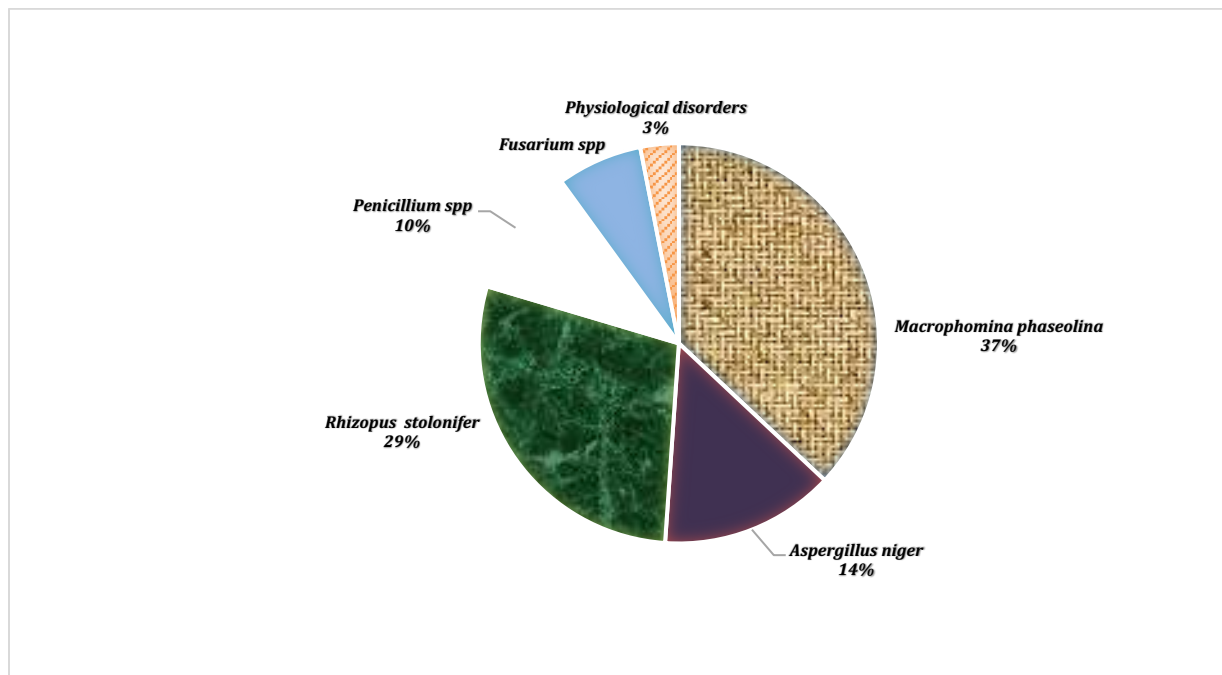


Figure 4: Proportion of fungal pathogens associated with Frafra potato tuber rot.

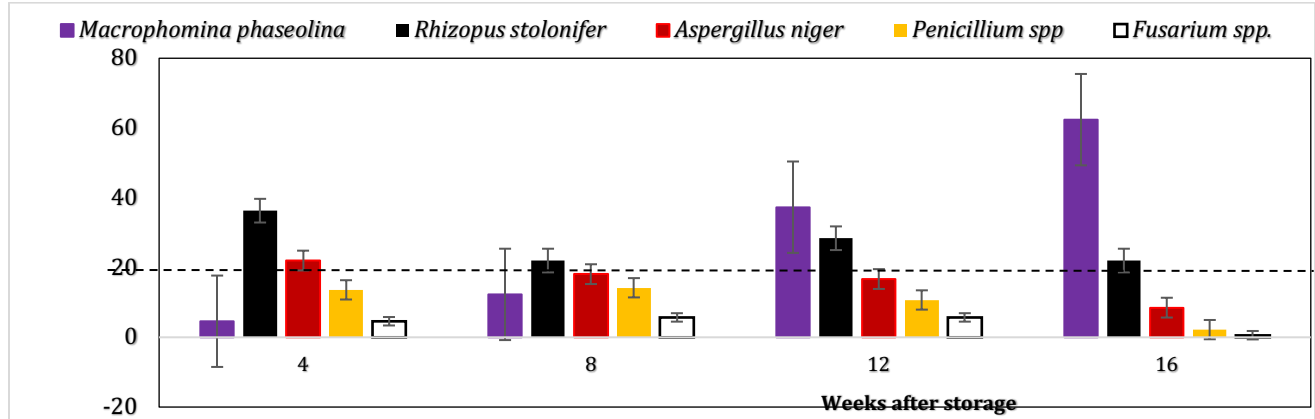


Figure 5: Incidence of fungal pathogens associated with Frafra potato tuber rot.

Percentage data on pathogen incidence was managed by square root transformation. Fungi incidence (%) in this figure was based on non-transformed data. ANOVA was conducted using mean of three replicates. Bars represent standard errors of the difference between means of three replications.

DISCUSSION

Enhancing yield and productivity

There is available information on good agronomic practices such as optimum spacing, planting time, fertilizer rate and use of vegetative propagules to increase yield (Bayorbor and Gumah, 2007; Ayimbire et al., 2022; Namo and Opaleye, 2019; Yirzagla et al., 2023). Bayorbor and Gumah (2007) evaluated the effects of ‘seed’ tuber weight and intra-row spacing on yield of Frafra potato in which the use of heavier ‘seed’ tubers increased the overall tuber. Generally, moderately heavy-sized ‘seed’ tubers (7-10 g) gave higher yield compared to heavy ‘seed’ tubers (>10 g) and slightly light ‘seed’ tubers (<7 g). Also, yield increased with decreasing intra-row spacing (20 cm>30 cm>40 cm). Additionally, the interaction of moderately heavy size ‘seed’ tubers (7-10 g) and intra-row spacing of 20 cm gave optimum yield. Yirzagla et al. (2022) reported that bed size significantly affected tuber size distribution with large beds (500 cm x 50 cm x18 cm) and inter-plant of 30 cm recording higher percentage of large tubers. Stem cuttings accounted for higher percentage of large tubers compared the use of ‘seed’ tubers.

Some studies characterized the yield components of Frafra potato to include seedling emergence, number of branches per plant, leaf area index, days to flowering, number of flowers per plant, relative growth rate, net assimilation rate, tuber length, tuber girth, root-top ratio, mean tuber weight, dry matter content and total tuber yield (Ayimbire et al., 2022; Namo et al., 2018; Yirzagla et al., 2022). In this study, the growth characteristics varied widely among the three Frafra potato varieties. Naachem-tiir had wider canopy spread (115.2 cm) compared to Nutsugah piesa (114.0 cm) and Maa-lana (108.2 cm). Similar growth characteristics were reported by Ayimbire et al. (2022) for plant height (26.4 cm) of Naachem-tiir compared with Nutsugah piesa (25.9 cm) and Maa-lana (25.4 cm). For leaf area, Nutsugah piesa recorded greater leaf area (3.5 cm²) compared to 3.2 cm² leaf area in both Naachem-tiir and Maa-lana. In general, higher leaf area increases the photosynthetic efficiency of crops which has effect on vegetative growth and the ultimate tuber

yield. However, Ayimbire et al. (2022) found that Frafra potato varieties with high vegetative growth resulted into relatively lower tuber yields. In this case, photo-assimilates are diverted into vegetative biomass growth to the detriment of reproductive development. They reported that the choice of variety (Naacheem-tiir and Nutsugah piesa) alongside good agronomic practices and moderate rainfall especially during the reproductive phase of the crop contribute significantly to higher tuber yield.

Comparing the varieties for tuber yield, Maa-lana had the highest overall yield and commercial tuber yield compared to Nutsugah piesa and Naachem-tiir. The yield potentials were similar to the report of Sugri et al. (2021) in which the tuber yields were 23 t/ha for Maa-lana, 19 t/ha for Nutsugah piesa and 22 t/ha for Naachem-tiir. The salient contributing factor to the yield was the higher number of commercial tubers observed for Maa-lana per unit area. According to Namu et al. (2018) and Ayimbire et al. (2022), any increase in the number of tubers per plant has a positive effect on root yield of sweet potato. Yield potential of Naachem-tiir might be adversely affected by the higher vegetative growth compared to Maa-lana. In the studies of Namu et al. (2018) and Kuhlase et al. (2009), positive correlations exist for number of branches and number of flowers and mean tuber yield; root-top ratio and tuber yield; relative growth rate and net assimilation rate; tuber length and harvest index; relative growth rate and harvest index; tuber length and tuber yield as well as harvest index. The relative growth rate and net assimilation rate were also positively correlated in report of Kuhlase et al. (2009). The implication is that such growth and yield attributes could make significant contribution to increasing tuber yield.

Nutrient composition and utilization

Commenting on the nutrient content of the varieties, Maa-lana and Naachem-tiir possessed higher protein and crude fat contents compared to Nutsugah piesa. This range is consistent with Tortoe *et al.* (2020) in which higher protein contents in Maa-lana (5.2 g/100g) and Naachem-tiir (4.9 g/100g) were found compared to Nutsugah piesa (4.1 g/100g). Some studies suggest positive correlation between the protein and crude fat contents of Frafra potato accessions (Namu et al., 2018). Although the tubers have not been extensively explored in industrial applications, it's potential to act as a source of flour and starch is huge (Nkansah, 2004; Osei-Tutu et al., 2019; Tortoe *et al.*, 2020). The major biomolecule of the tubers is starch, which accounts for about 80% of the edible root's dry mass. The crystalline structure, granular characteristics, among other starch qualities, play an important role in the quality and end-user experience of starchy food products (Osei Tutu et al., 2024; Peroni et al., 2006). Osei-Tutu et al. (2024) classified Frafra potato starch as A-type, with similar amylose content and degree of crystallization. Starch granules from ten cultivars were mainly spherical or oval-shaped, with smooth surfaces. Their study grouped starches in Frafra potato into two clusters; defined by their thermal properties and paste clarity. This classification provides essential information for practical applications of the starches, which may influence advance selection of breeding lines of interest for developing suitable varieties for commercial starch and other sensory qualities. Starches with excellent clarity, for example, can be utilized as a thickening or coating in culinary and medicinal applications, whilst those with low peak viscosity can be utilized in producing weaning meals. Those with high amylose and/or low digestibility are ideal for food applications targeted at people with health conditions such as celiac sprue and/or diabetes.

Harvest maturity and shelf-life

The response of perishables and their capacity to acclimate and withstand abiotic stresses is dependent on several factors such as the stress type and characteristics (e.g., severity, number of exposures, duration) and the characteristics of the commodity (e.g., genotype, maturity stage, organ type) (Ferguson et al., 1999; Pedreschi and Lurie, 2015). Genetic background, pre-harvest factors (e.g., growing conditions and crop management) and stage of development can largely influence the response of commodities to specific abiotic stresses. Pre-harvest abiotic stresses, including drought, light, and field temperature, may influence the outcomes of commodities exposed to different levels of postharvest stresses. In root and tuber crops, harvesting intervals that either precede or exceed the crop's physiological maturity can adversely affect its storage potential and market quality. Studies on related tuber crops such as Iris potato, yam and sweet potato suggest that early harvesting often results in immature tubers with underdeveloped periderm, making them more susceptible to water loss, mechanical damage, and microbial infections during storage (Ferguson et al., 1999; Nedunchezhiyan et al., 2008; Ile et al., 2006). In this study, harvesting at 80 days produced the lowest tuber yield (1.12 t/ha) while harvesting at 100 days provided the highest tuber yield (3.22 t/ha) and a higher weight of commercial tubers (1.8 kg). This is consistent with Lebot (2009) who found that harvesting at 100–120 days after planting yielded optimal postharvest quality of sweet potato while harvesting in <90 days produced underdeveloped tubers with high respiration rates. However, over delay in harvest is noted to affect the postharvest quality and shelf-life of tubers, due to stresses from field heat, water stress, sprouting, and pest/pathogen infestations (Abu et al., 2021; Ile et al., 2006). In this study, decay and physiological weight losses of tubers increased with prolong harvesting and extended storage duration. Prompt harvesting is most suitable for full development of the periderm to reduce shriveling and decay in storage (Nedunchezhiyan et al., 2008).

CONCLUSION AND RECOMMENDATION

Frafra potato is a resilient root tuber crop with significant prospects to improve household food security in parts of northern Ghana. The production ecology, mainly in the dry savanna areas, may relate to its tolerance to drier weather conditions and other abiotic stresses such as drought and low soil fertility. Frafra potato production does not require much external inputs compared to other root crops. Its production is, however, low in terms of fresh tuber yield and area under cultivation due to poor access to seed and limited market for the fresh tubers which constricts its commercialization potential. This research addresses some gaps in best production practices to increase yield and prolong the shelf-life. If early planting is feasible, the optimum harvest maturity for maximum commercial tuber yield was 100 to 110 days. The cropping calendar suggests that Frafra potato is harvested from 100 to 130 days if planting occurs in May to June. However, due to climate variability and threat from animal pests, planting is now delayed to July. The tuber yield obtained at 80 days interval indicates that farmers may utilize vegetative propagules from late July to early August to obtain reasonable yield; particular if prolong dry spells occur in early-to-mid-July. Comparing the varieties, Maa-lana provided higher tuber yield (2.15 t/ha) while Naachem-tiir possessed higher sensory qualities and overall consumer acceptance level (46%). The study suggests the potential of utilizing vegetative propagules to increase seed security, and for scaling, Maa-lana and Naachem-tiir exude potential for higher productivity.

ACKNOWLEDGMENTS: The authors wish to acknowledge the support of the technical staff of Manga Agricultural Station of CSIR-Savanna Agricultural Research Institute for their role in data collection.

Funding: There are no sources of funding to declare.

Conflict of interest: The author(s) declare no conflict of interest.

Data availability statement: Data supporting these findings are available within the article or upon request.

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