Agronomic performance and farmer preferences for biofortified orange-fleshed sweetpotato varieties in Zimbabwe

JAN 2021

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ISBN: 978-92-9060-566-9
DOI: 10.4160/ 9789290605669

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Citation:
Jogo W., Kudita S., Munda E., Chiduwa M., Pinkson S., Gwaze T. (2021). *Agronomic performance and farmer preferences for biofortified orange-fleshed sweetpotato varieties in Zimbabwe*. International Potato Center: Lima, Peru.

Design and Layout:
Communications Department

January 2021

CIP also thanks all donors and organizations that globally support its work through their contributions to the CGIAR Trust Fund: www.cgiar.org/funders

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Acknowledgements

This study was undertaken by the Livelihood and Food security Program (LFSP) under the technical leadership of a tripartite arrangement between HarvestPlus, the International Potato center (CIP) and the Department of Research and Specialist Services (DR&SS). The LFSP is a FAO managed program that is funded by the Government of the United Kingdom through its Foreign, Commonwealth & Development Office (FCDO). The program is implemented by a consortium of local and international non-governmental organisations (NGOs) led by Practical Action in Manicaland, Welt Hunger Hilfe (WHH) in Midlands and World Vision in Mashonaland Central Provinces, with HarvestPlus being the program's technical partner on biofortification. Complementary funding support for the study was provided by FCDO through the International Potato Center (CIP) under the *Development and Delivery of Biofortified Crops at Scale program* (Code 300649).

The technical team would like to acknowledge the support of the LFSP partner organizations, and the Department of Agriculture Technical and Extension Services (Agritex) in implementing this evaluation. The time and effort that farmers spent in monitoring the trials and participating in the evaluation is greatly appreciated.

The views expressed in this report are those of the individual authors and do not necessarily reflect the views of the donor, the authors' institutions and other partners. The authors are responsible for any remaining errors and inferences.

Acronyms and abbreviations

CIP	International Potato Center
DR&SS	Department of Research and Specialist Services
FAO	Food and Agricultural Organisation
FCDO	Foreign Commonwealth and Development Office
FNSP	Food and Nutrition Security Policy
GoZ	Government of Zimbabwe
HIB	High Iron Beans
OFSP	Vitamin A Orange-fleshed Sweetpotato
RCBD	Randomized Complete Block Design
VAD	Vitamin A Deficiency
VAM	Vitamin A orange maize
WHH	Welt Hunger Hilfe
AGRITEX	Department of Agriculture Technical and Extension Services

Executive Summary

This report summarizes the findings of a study carried out to evaluate the agronomic performance and sensory acceptance by small holder farmers of six biofortified orange-fleshed sweetpotato (OFSP) varieties that were first introduced from CIP's sweetpotato breeding hub for Southern Africa in Mozambique. The study was participatory and carried out under different agroecological environments in Zimbabwe. The six OFSP varieties, namely Alisha, Victoria, Delvia, Sumaia, Namanga and Irene were planted in the 2019/20 agricultural season along with two non-biofortified white-fleshed local varieties, namely Chingova and German II, at seven DR&SS research stations (Kadoma, Marondera, Harare, Henderson, Gwebi, Makoholi and Panmure) and 120 farmer managed on-farm trial sites in 12 LFSP districts of Bindura, Gokwe North, Gokwe South, Guruve, Kwekwe, Makoni, Mazowe, Mount Darwin, Mutasa, Mutare, Shurugwi and Zvimba. At all but one of the research stations, two trials were set up, one under irrigation and the other under rain-fed conditions. On-farm trials were established following the Mother-Baby Trial approach with 2 mother trials and 8 baby trials per district. In each of the districts, one mother trial was planted under irrigation while the other was rain-fed. All the baby trials were rain-fed.

At harvest, field days were held during which 1,763 (59% female) farmers participated in collecting quantitative data for the number of roots per plant, total storage root yield and commercial root yield for each variety. In addition to the agronomic data, a structured questionnaire was used to collect information from the participating farmers on the most important traits that they consider when selecting sweetpotato varieties. These were, root yield, earliness of maturity, drought tolerance, weevil resistance, taste and dry matter content. Then, using a six-point Likert scale ranging from 1 (very poor) to 6 (excellent), farmers scored each variety against the identified individual traits and ranked the varieties in the order of their preferences. The questionnaire also captured general information on farmers' perceptions on potential future production and consumption of OFSP varieties and constraints to sweetpotato production.

The agronomic data was analysed using analysis of variance (ANOVA) on treatment means using Genstat 18th Edition statistical package. Socio-economic data was analysed using mean score analysis, descriptive means and frequencies using Statistical Package for Social Sciences (SPSS), STATA and Microsoft Excel.

According to the trial results, all the sweetpotato varieties had significantly higher root yield under irrigation than under rain-fed conditions, while the on-station trials had significantly higher root yields than the on-farm trials. Of the six OFSP varieties, Alisha had the highest commercial root yield under irrigation (19.9MT/ha on-station and 12.2 MT/ha on-farm). In the dryland trials, there was no significant difference between the yields of Alisha (10.9MT/ha on-station; 4.3MT/ha on-farm), Sumaia (10.1 MT/ha on-station and 4.1MT/ha on farm) and Delvia (11.1MT/ha on-station and 3.7Mt/ha on-farm). However from the sensory evaluations, Alisha was the most preferred by farmers in terms of taste followed by Delvia while most farmers did not like the taste of Sumaia. The two local varieties generally performed better than the OFSP varieties under both irrigated (22.2 – 23.4 tons/ha) and rain-fed conditions (14.4 – 15.6 tons/ha). Although the local checks yielded more than the 6 OFSP varieties, the yield performance for Alisha, Sumaia and Delvia were comparable to that of the local varieties. In fact, the results from on-farm trials show that Alisha and Sumaia slightly edged Chingova under irrigation and these two varieties were comparable to the top performing local variety, German II.

The most preferred varieties by farmers both in terms of agronomic performance and taste were Chingova, German II and Alisha, each of which were ranked first by about 30% of participating farmers. Despite having good yield and taste, the rating by farmers for Delvia was low, due to its cracked roots, especially under irrigation.

When results from both the agronomic and sensory evaluation are considered together, the conclusion drawn is that, the performance of the OFSP variety Alisha was comparable to that of the two local varieties. Of the six OFSP varieties evaluated, Alisha is the most promising and should therefore be considered for wider promotion among farmers for its agronomic performance, taste, dry mater content and most importantly, its nutritional value. The study also showed that farmers were willing to buy OFSP vines to grow and consume these sweetpotato varieties.

The main limitations of the study are that the results are based on one season evaluation, and the trials were planted late, in a season where rains were abnormally sporadic. Accordingly, we recommend that the evaluation be repeated for another season to validate these results.

1 INTRODUCTION

1.1 Background and motivation

Micronutrient malnutrition is a major public health problem in Zimbabwe. According to the Zimbabwe 2018 National Nutrition Survey Report, one in four children aged 6 – 59 months are stunted and approximately 25% and 72% suffer from vitamin A deficiency (VAD) and iron deficiency respectively (Food and Nutrition Council, 2018). According to the same report, one in four women of childbearing age (15 – 49 years old) are vitamin A deficient and six in ten are iron deficient. Vitamin A deficiency (VAD) is the leading cause of preventable blindness in children, and is also associated with impaired growth and development, weakened immune systems, increased severity of illnesses and mortality from common childhood illnesses, xerophthalmia and night blindness (Low et al., 2007). Iron deficiency on the other hand is linked to impaired brain development, reduced cognitive abilities, unfavorable pregnancy outcomes, and is the leading cause of anemia.

While improving food security remains the top priority for the Government of Zimbabwe (GoZ), addressing malnutrition, especially stunting and micronutrient malnutrition has gained significant policy attention in the last ten years. The enactment of the Food and Nutrition Security Policy (FNSP) in 2013 and establishment of the Food and Nutrition Council attest to the government's commitment to addressing malnutrition at scale. To this end, several strategies have been adopted, including supplementation, industrial food fortification, promoting dietary diversification and biofortification. Although supplementation and industrial food fortification programs can be effective in combating micronutrient deficiencies, their sustainability is an issue in some contexts, not least in developing countries. As the rural poor produce most of what they require for consumption, an integrated approach that includes food-based approaches such as dietary diversification and biofortification may be optimal.

1.2 Biofortification and current status on use of biofortified crops in Zimbabwe

Biofortification is the conventional breeding of staple crops for increased concentrations of key micronutrients such as Vitamin A, iron and Zinc in their edible parts. The biofortified crop varieties currently grown in Zimbabwe are Vitamin A enriched orange maize (VAM) and iron rich common beans (*Phaseolus vulgaris*) (HIB), all of which were bred and released by the Department of Research and Specialist Services under the Ministry of Lands, Agriculture, Water, Climate and Rural Resettlement with support from HarvestPlus through CIMMYT and CIAT, respectively. DR&SS then licensed these varieties to private seed companies to produce and market their seed. Other biofortified crops that could potentially be grown in Zimbabwe include Zinc maize, Iron pearl millet and Vitamin A orange-fleshed sweetpotatoes (OFSP).

1.3 Why orange-fleshed sweetpotato?

Sweetpotato is a key food security crop grown in many parts of the country. Over the last 15 years, national sweetpotato production has increased sharply from less than 10,000 tons per year to current levels in excess of 200,000 tons per year (Neurashe, 2019).

The sweetpotato varieties grown in Zimbabwe are mostly white fleshed, although a few farmers, mostly large-scale commercial ones, also grow the yellow and orange-fleshed varieties. The International Potato Center (CIP) and partners have developed new and improved OFSP varieties that have many characteristics desired by smallholder farmers, which include high yield potential, drought tolerance, early maturity and high dry matter content. More importantly, these varieties have high concentrations of beta carotenes, so high that a 125-gram root can supply the daily vitamin A needs of a child under the age of five (Low et al., 2009). In addition to Vitamin A, OFSP varieties are a major source of dietary energy and have good levels of several other micronutrients, including potassium, phosphorus, magnesium, iron, zinc, vitamins C, K, E, and several B vitamins.

The effectiveness of OFSP in combating VAD among children and women of reproductive age and reducing the incidence and severity of diarrhea among children is scientifically well established (Low et al., 2007; Hotz et al., 2012a, 2012b; de Brauw et al., 2018; Jaarsveld et al., 2005 Jones, K., & de Brauw, 2005). Backed by the solid evidence, OFSP varieties have been widely promoted among smallholder farmers in many countries in Africa, including Malawi, Mozambique and Madagascar in southern Africa, but not so much in Zimbabwe. Accordingly, through a collaboration between the Department of Research and Specialist Services (DR&SS), HarvestPlus and CIP, six OFSP varieties were introduced in the country from CIP's sweetpotato breeding hub for southern Africa, in Mozambique, for evaluation under Zimbabwean agricultural environments before wider dissemination to farmers.

1.4 Study Objectives

The main objectives of the evaluation were as follows:

1. To evaluate the agronomic performance of the six OFSP varieties under on-station and smallholder farmers' conditions in Zimbabwe.
2. To identify the most important agronomic and sensory traits that farmers in Zimbabwe use in evaluating and selecting sweetpotato varieties to grow.
3. To allow farmers to evaluate the performance of the six OFSP varieties against their preferred agronomic and sensory trait.
4. To make recommendations on the best-performing, farmer-preferred OFSP varieties that should be promoted for adoption at scale.

2 MATERIALS AND METHODS

2.1 Experimental varieties introduced and used in trials

A total of six OFSP varieties introduced from CIP Mozambique and 2 local checks, namely Chingova and Germany II, were evaluated on-station and on-farm. The six OFSP varieties were selected from a pool of nineteen varieties that were officially released in Mozambique between 2011 and 2016. Varieties that performed well in Mozambican agricultural environments that resemble agro-ecological conditions in Zimbabwe were selected. In addition, dry matter and beta-carotene content and processing quality were also considered in the final selection of varieties to introduce. Table 1 presents key agronomic and root attributes of the introduced varieties.

Table 1: Selected agronomic and root attributes of the OFSP varieties introduced from Mozambique

Variety	Year of release in Mozambique	Dry matter (%)	Beta carotene mg/100g (dry weight)	Maturity period (months)	Other key features
Alisha	2016	29.40	24.94	4.5 to 6	Suitable for diverse utilization, including forage and fried products
Sumaia	2011	19.80	20.90	4.5 to 6	Suitable for diverse utilization, processing into puree and baked products
Namanga	2011	26.40	22.43	4.5 to 6	Suitable for diverse utilization, processing into puree and baked products
Delvia	2011	29.80	31.30	4.5 to 6	Suitable for diverse utilization, including fried products
Irene	2011	26.00	33.32	4.5 to 6	Suitable for diverse utilization, processing into puree and baked products
Victoria	2016	25.60	54.41	4.5 to 6	Suitable for diverse utilization

Sources: Andrade et al. (2016); Andrade et al. (2017); Musembi et al. (2019)

2.2 Experimental sites

The study was conducted in Zimbabwe during the 2019/20 cropping season in sites that represent agro-ecological zones I, II, III and IV. The trials were set up at seven DR&SS research stations, namely Kadoma, Horticulture (Marondera), Harare, Henderson, Gwebi, Makoholi and Panmure research stations; as well as in twelve districts, namely Bindura, Gokwe North, Gokwe South, Guruve, Kwekwe, Makoni, Mazowe Mount Darwin, Mutasa, Mutare, Shurugwi and Zvimba. The agro ecological classification of the experimental sites is given in Table 2.

Table 2: Site characterization of the seven research station sites used in the study

Research station	Coordinates	Altitude (masl)	Agro-ecological Region	Temperature Range (°C)	Soil Conditions
Harare	17°51'S 31°03'E	1506	IIa	17- 31	Clay
Panmure	17^{0} 10'0" S 31^{0} 40'0" E	881	IIb	15- 32	Sandy clay loam
Henderson	17^{0}10'0" S 31^{0} 0'0" E	1 300	IIb	18.2	Sandy loam
Kadoma	18^{0}20'24" S 9^{0}54'0'0" Ë	1183	III	20.4	Sandy clay loam
Makoholi	20^{0} 30'0" S 31^{0} 0'0" Ë	1 204	IV	6-28	Sand
Gwebi	17^{0}40'60" S 30^{0}52'0" Ë	1450	II	15-30	Sandy clay loam
Marondera	18^{0}18'85" S, 31^{0}54'87" Ë	1200	IIa	19-24	Sand

2.3 Experimental design and approach

2.3.1 On farm trials

The mother-baby trial approach as described by Snapp (1999) was used for the on-farm trials, with each of the 12 districts hosting two replicated mother trials and 8 non-replicated baby trials. In each district, one mother trial was established under irrigation and another complete trial under rain-fed conditions, while all baby trials were rain-fed. Therefore, a total of 12 irrigated mother trials, 12 rain-fed mother trials and 96 rain-fed baby trials hosted by farmers were established in 12 districts. The trial design used in each of the mother trials was a randomised complete block design (RCBD).

2.3.2 On station trials

Two mother trials were established at 7 research stations, one under irrigation and another under rain fed conditions. The trial design used in each of the trials was a randomised complete block design (RCBD).

2.3.3 Field layout and trial management

All irrigated trials were supplied with water three times per week from February to April, beyond which no irrigation was administered. In the dryland treatment, the plants were irrigated in the first week to allow establishment and irrigation was completely withdrawn thereafter. In all trials, sweetpotato vines were planted on ridges that were 90 cm apart from one top to the next. Each plot was made up of five ridges measuring 5m long. Vine cuttings of 25-30 cm were planted at the crest of a 30cm high ridge with a spacing of 30 cm between the plants along the length of the ridge/row, totalling 17 plants per ridge and 85 plants per plot. The research station trials were all researcher-managed while on-farm trials were managed by farmers with the technical support of trained extension workers. Weeding was done manually as and when necessary. Trials were managed for 4.5 months.

2.4 Agronomic data collection

The agronomic data was collected from ten consecutive plants from each row of the three middle ridges, totalling 30 plants per plot. For both on-station and on-farm trials data were collected on the following agronomic parameters:

- Total storage root yield: All the roots from the 30 plants in the middle rows were harvested, and weighed using a balance then expressed on a per hectare basis
- Commercial root yield: This was done by selecting all the saleable storage roots from 30 harvested plants, free from any form of damage and of standard size defined by minimum diameter of 4 cm, weighed using a balance

All agronomic data was subject to analysis of variance (ANOVA) on treatment means using Genstat 18th Edition statistical package.

Percent improvement of yield due to irrigation was calculated according to:

$$\frac{\boldsymbol{Yield}(\boldsymbol{irrigation}) - \boldsymbol{Yield}\ (\boldsymbol{rain} - \boldsymbol{fed})}{\boldsymbol{Yield}(\boldsymbol{rain} - \boldsymbol{fed})}$$

2.5 Approach and tools for collecting farmer-stated agronomic and sensory preference data

The participatory evaluations for both on-station and on-farm trials was undertaken during the harvesting of the 23 on-farm mother and 45 baby trials that managed to produce harvestable roots. As the trials were planted late, some trials failed to establish while others were lost to livestock damage before harvest. Although the target was to have at least 30 farmers for the evaluation at each site, the actual number of farmers per site was variable, and in some cases less than the target due to Covid19 restrictions. A total of 1,763 (59% female) farmers across all sites took part in the evaluation.

The tool used for collecting sensory evaluations data was a short questionnaire that was administered by trained enumerators. The questionnaire included questions covering four components: 1) farmer socioeconomic characteristics and crops considered most important; 2) agronomic and sensory traits considered most important in selecting sweetpotato varieties; 3) ranking of the eight varieties and 4) farmers' general perceptions on the OFSP varieties.

The first component included questions on i) the sociodemographic profile of respondents and their households ii) total land owned, iii) main crops grown and iv) sweetpotato production history.

The second component of the questionnaire was a table with a list of traits identified in previous studies in Zimbabwe (Mudombi, 2007) and elsewhere (Adekambi et al., 2020; Masumba et al., 2004; Mwiti et al., 2020; Shikuku et al., 2017; Naico & Lusk, 2010) as important in farmers' evaluation and selection of sweetpotato varieties. These included a combination of agronomic and sensory traits such as root yield, drought tolerance, early maturity, weevil resistance, disease resistance, taste, dry matter content, and marketability among others. Following the approach proposed by Coe (2002) and applied in other participatory evaluation studies (e.g. Worku et al., 2020) for each trait, farmers were asked to score the importance of each trait on a scale of 1 (not important at all) to 5 (very important).

The third component presented two tables, one with the 8 varieties on the columns and agronomic traits on the rows and farmers were asked to score each variety against each agronomic trait and overall agronomic performance on a six-point Likert scale of 1 (very poor) to 6 (excellent). The second table was of similar format except that it asked farmers to score each variety on sensory traits and overall sensory performance, using the same scale. The final component of the tool was meant to understand farmers' general perceptions on the OFSP varieties including whether they be willing to buy OFSP planting material with or without information on its nutritional value and how they feel about certain OFSP attributes. These questions were framed as a combination of positive and negative statements to avoid agreement bias and farmers were asked to provide their perception on a five-point Likert scale of 1 (strongly disagree) to 5 (strongly agree).

During the field day, farmers participated in the harvesting of the trials and agronomic data collection. Each farmer then received a printed questionnaire written in their local language. A trained enumerator then explained each question to the farmers one question at a time and asked them to respond to each question by writing their response on the printed questionnaire. The enumerators assisted illiterate farmers by writing the responses on the questionnaire on their behalf. Less than 20 farmers needed assistance in filling in the questionnaire.

The sections of the questionnaire with socio-economic characteristics, list of traits and scoring varieties for agronomic traits were administered while the farmers were in the field. Thereafter, sample roots of each variety were collected and boiled simultaneously in 8 different pots with each pot containing a specific variety. Farmers were then asked to taste the roots, one at a time and score each variety for its sensory traits soon after tasting. The farmers were asked to rinse their mouths with water before tasting the next variety.

Thereafter, the questionnaires were collected and the data captured on open data kit (ODK) platform.

2.6 Analysis of socio-economic and farmer-stated agronomic and sensory preference data

The data collected was analysed using SPSS (Statistical Package for Social Sciences, Version 24.0. Armonk, NY: IBM Corp), STATA (Statistics/Data Analysis Version 16.0, College Station, Texas: StataCorp) and Microsoft Excel. The analysis used was mainly descriptive. Mean scores were calculated to identify the level of importance of different traits and to get the rating of each of the varieties on individual traits and overall. The data was analysed for significant gender differences in the importance attached to different traits in selecting sweetpotato varieties using the non-parametric Wilcoxon rank sum test (Mann Whitney U test) considering that the ordinal scores violate the normality assumption, making the usual t-test for significance inappropriate.

To come up with a ranking of the varieties based on the participants' scores, the mean scores combining the varietal score on agronomic and sensory traits for each variety was calculated. Means were also used to analyze participants' socio-economic characteristics. Frequencies, presented either in tabular or bar graph form, were used to analyse data on major crops grown by site and overall, perceptions on OSFP and the proportion of participants who rated the varieties below average, average and above average for particular traits based on categorization of the Likert scale.

3 RESULTS AND DISCUSSION

3.1 Agronomic results

3.1.1 Total storage root yield on-station

Under research station conditions, the total storage root yield of the eight sweetpotato varieties ranged from 0.2 tha^{-1} for variety Namanga under rainfed conditions at Marondera to 34.8 tha^{-1} for Alisha under irrigation at Harare (Table 3). Performance at Marondera was poorest overall. However, the yield data was collected after extensive damage to research plots by livestock; while data at Henderson is reflective of two rain-fed sites due to failure of irrigation. At Gwebi research station (AER IIa), there was no significant difference in storage root yield observed in all varieties under irrigation and rain-fed conditions ($p<0.05$). A similar trend was observed at Harare research station (AER IIa) except that at this station, Alisha had a significantly higher storage root yield under irrigation than under rain-fed conditions. At Kadoma research station (AER III), all varieties had a significantly higher storage root yield under irrigation than in rain-fed conditions. All varieties at Makoholi (AER IV) and Panmure research stations (AER IIb) had a significantly higher root yield under irrigation than under rain-fed conditions.

On average, Irene, Namanga and Victoria were significantly outperformed by the two local varieties Germany II and Chingova in all stations both under irrigation and dry land conditions (Table 3). Alisha, Delvia and Sumaia were comparable to or significantly outperformed Chingova and Germany II under irrigation and dryland conditions at some stations (Table 3). Among the OFSP varieties, pooled data for all the research stations indicated Alisha, Delvia and Sumaia as highest, second and third, respectively, under dryland and irrigated conditions (Table 3). Their yields were lower than those of the two local varieties ($P< 0.01$).

Overall, the trend of yield rankings for sweetpotato varieties observed was similar under rain-fed conditions as under irrigation. However, the value of irrigation was highest for Irene whose yield more than doubled under irrigation (Figure 1). This suggests that with a full agricultural season of growth, associated with timely planting, this variety has high potential for improved performance. Our results also suggest that under natural region II, the effect of irrigation was masked by maintenance of similar moisture levels under rainfed conditions due to rainfall received, shown by the lack of significant difference in yields attained under the two conditions at Harare and Gwebi. In contrast, the value of irrigation was emphasized at the AER III and IV sites, in line with agro-ecological classification of agricultural zones in Zimbabwe.

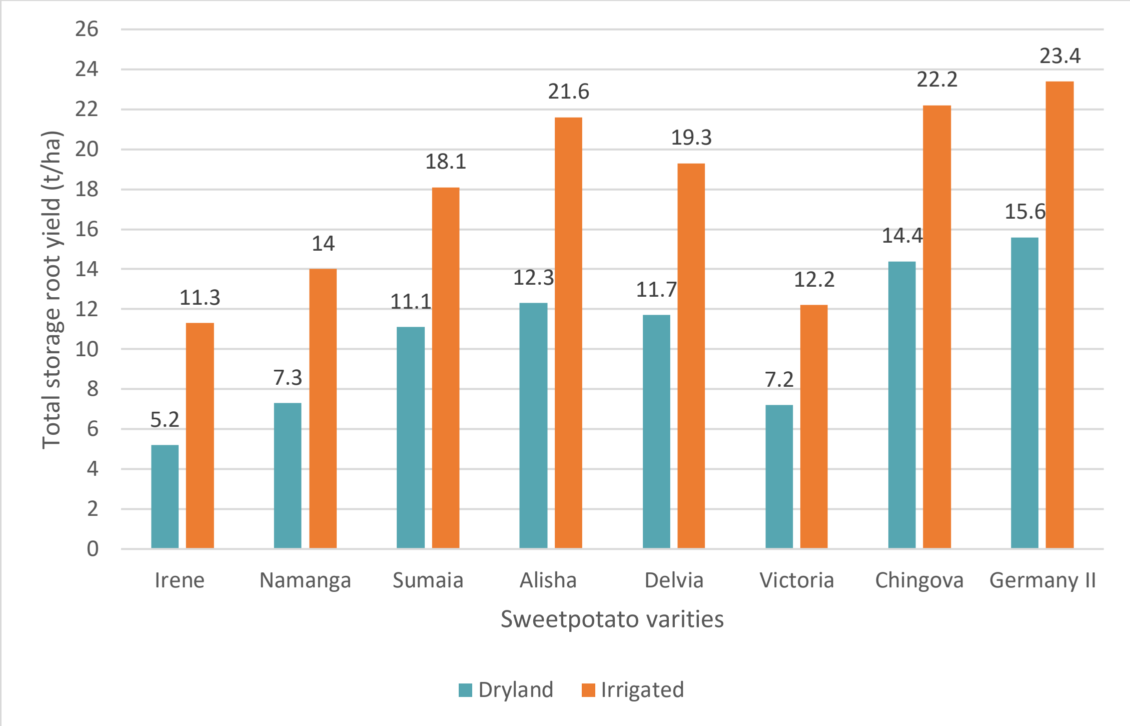

Figure 1: Total storage root yield of eight sweetpotato varieties under dryland and irrigated conditions at seven research stations in Zimbabwe

Table 3: Total storage root yield (t/ha) of eight sweetpotato varieties under irrigation and dryland conditions at seven research stations in Zimbabwe in the 2019/2020 cropping season

Site	Gwebi		Harare		Henderson		Kadoma		Makoholi		Marondera		Panmure		Overall		Improvement due to irrigation (%)
Variety	Rain-fed	Irrigated	Rain-fed	Irrigated	Rain-fed	Rain-fed	Rain-fed	Irrigated	Rain-fed	Irrigated	Rain-fed	Irrigated	Rain-fed	Irrigated	Rain-fed	Irrigated	
Irene	13.1	15.9	6.7	14.4	2.3	0.7	6.4	20.2	2.5	13.2	1.4	4.2	3.8	10.8	5.17	11.34	119.34
Namanga	12.9	17.3	9.2	12.1	3.4	4.1	12.7	28.2	4.1	15.9	0.2	1.1	8.9	19.6	7.34	14.04	91.25
Sumaia	24.6	19.5	19.1	24.2	9.1	6.9	13.7	28.2	5.7	27.6	2.3	5.1	3.2	14.9	11.10	18.06	62.68
Alisha	25	31.7	19.3	34.8	6.9	5.7	17.1	30.4	5.9	19.8	2.1	7.3	10	21.2	12.33	21.56	74.86
Delvia	21.9	27.3	14.4	20.9	5.4	5.6	17	26.5	5.8	18.2	0.9	4	16.4	32.7	11.69	19.31	65.28
Victoria	13.9	15.1	11.1	15.6	8.1	6.8	8.2	14.2	4.6	15.7	1.4	7.1	3.1	11.4	7.20	12.27	70.44
Chingova	26.9	29.2	20.6	18.2	9.7	11.2	17.3	32.9	8.5	24	3.2	9.7	14.8	30.4	14.43	22.23	54.06
German II	26.4	25.3	23.2	32.3	15.6	11.5	13.5	28.2	9.4	24.5	5.8	12.3	15	29.6	15.56	23.39	50.32
Mean	**20.6**	**19.3**	**15.5**	**21.6**	**7.6**	**6.6**	**14.3**	**26.1**	**5.8**	**19.9**	**2.1**	**6.4**	**9.4**	**21.3**	10.60	17.78	73.53
LSd	**4.1**		**8.4**		**4.2**		**4.3**		**2.2**		**2.6**		**5.5**				

3.1.2 Total storage root yield on-farm

On farm performance for total storage root yield was pooled together at analysis and variety Alisha was the best performing of all, at an average yield of 14.7 tha^{-1} under irrigation (Figure 2). The second and third best performing OFSP varieties were Sumaia and Delvia, respectively, such that the three-best performing OFSP varieties on-station were also the three best performing on-farm. Under rain-fed conditions, local variety Germany II generated the best total storage root yield at 7.9 tha^{-1}, followed by the second local variety Chingova at 6.6 tha^{-1}, while Irene was the lowest at 3.9 tha^{-1}. Of the OFSP varieties, Alisha was also the best performing under rain-fed conditions at 5.8 tha^{-1}. There were significant differences between irrigated and rain-fed-trials for all varieties ($P< 0.01$). Irene generated the least total storage root yield under both irrigated and rain-fed conditions.

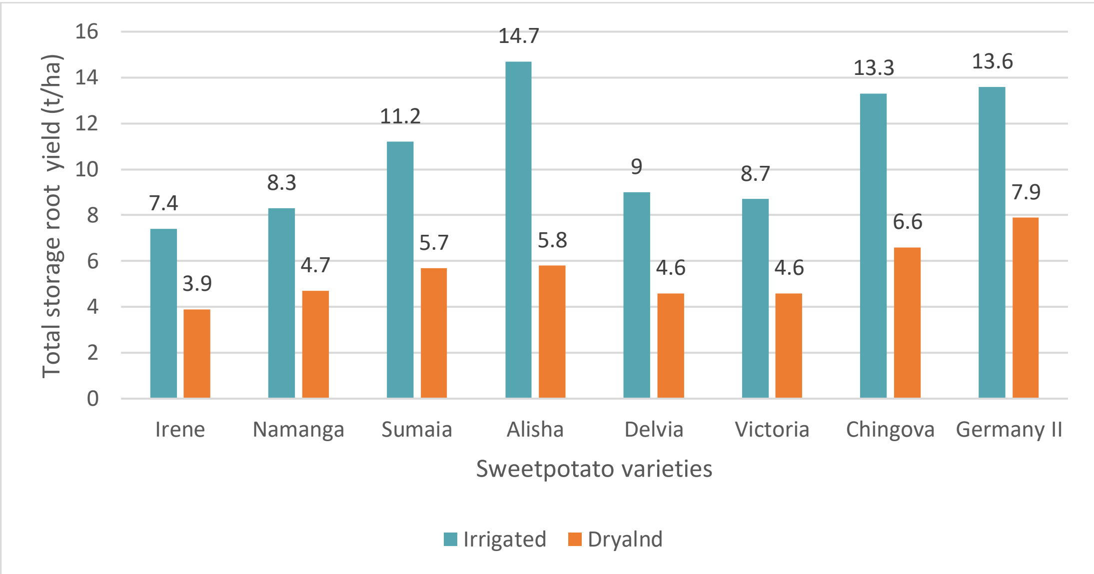

Figure 2: Total storage root yield of eight sweetpotato varieties under dryland and irrigated conditions across 12 on farm sites

3.1.3 Commercial root yield

3.1.3.1 On station commercial root yield

Mean commercial grain yield varied from 4.4tha-1 for Irene under rain-fed conditions to 21.84 tha-1 for the local Germany II (Table 4). The largest losses due to unmarketable roots was suffered by Victoria, both under rain-fed or irrigation conditions. At Gwebi and Harare, there was no significant difference in commercial root yield under rain-fed and irrigated conditions for all varieties except for Alisha. At Panmure, Makoholi and Kadoma research stations, commercial root yield was significantly higher under irrigated than rain-fed conditions except for Delvia at Kadoma and Irene at Panmure. Under both rain-fed and irrigated conditions, the OFSP variety Alisha consistently had similar or higher commercial root yield than the two local checks in all research stations except under irrigated conditions at Marondera and Makoholi (Table 4). In addition, the commercial root yield in the varieties Alisha and Sumaia were not significantly different in all research stations under both rain-fed and irrigation treatments except under irrigation at Makoholi and Gwebi.

Pooled data in all the seven research stations showed that the average commercial root yield of all varieties was higher under irrigation compared to rain-fed conditions (Figure 3). Among OFSP varieties however, Alisha, Delvia and Sumaia had best commercial root yield averaging 19.9t/ha and 17.8t/ha, and 17.0 t/ha, respectively. The commercial root yield for Sumaia and Delvia was significantly lower than that of Germany II but not different from that of Chingova. Alisha was not significantly different from both Chingova and Germany II. Irene and Victoria consistently had the lowest commercial root yield both under rain-fed and irrigated conditions. These two lowest performing varieties may not be adaptable to most agro-ecologies in Zimbabwe

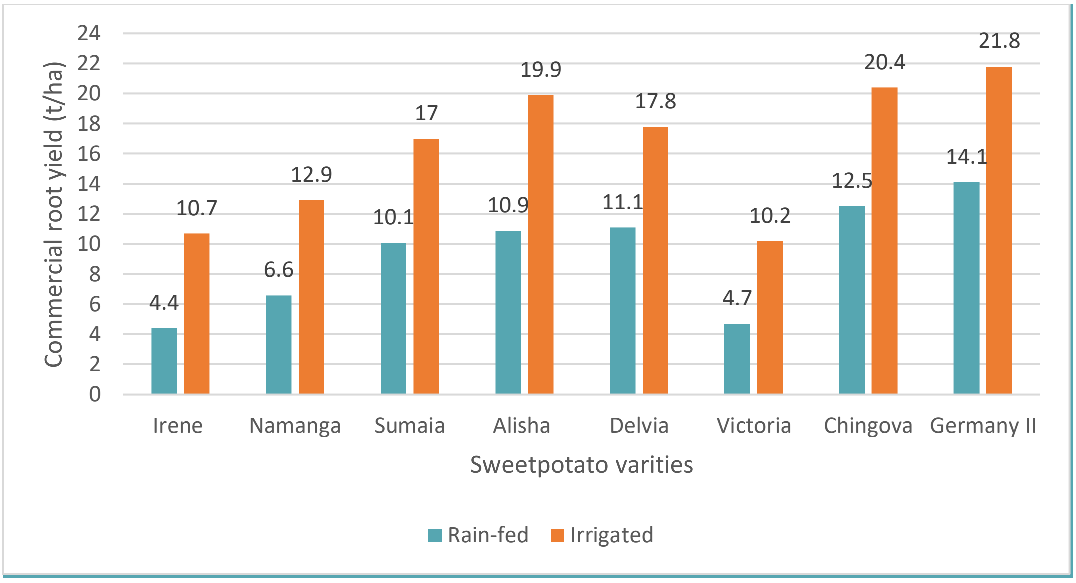

Figure 3: Average commercial storage root yield of eight sweetpotato varieties under rain-fed and irrigated conditions at seven research stations in Zimbabwe

Table 4: Commercial root yield of eight sweetpotato varieties grown at seven research stations under dryland and irrigated conditions in the 2019/2020 growing seasons

Site	Gwebi		Harare		Henderson		Kadoma		Makoholi		Marondera		Panmure		Overall		Percent improvement due to irrigation
Variety	Rain-fed	Irrigated	Rain-fed	Irrigated	Rain-fed	Irrigated	Rain-fed	Irrigated	Rain-fed	Irrigated	Rain-fed	Irrigated	Rain-fed	Irrigated	Rain-fed	Irrigated	
Irene	12.7	15.2	5.2	12.6	0.8	0.6	5.6	19.9	2.2	12.5	1.1	3.7	3.4	10.4	4.43	10.70	1.42
Namanga	12.3	15.8	7.5	11.4	2.4	1.6	12.4	27.3	3.2	14.6	0.2	0.8	8.4	18.5	6.63	12.86	0.94
Sumaia	22.9	18.5	17.5	23.8	6.8	3.9	12.9	27.2	5.2	26.8	1.9	4.7	3.2	13.8	10.06	16.96	0.69
Alisha	23.9	29.3	15.9	31.9	4.8	3.2	15.7	28.8	4.9	18.6	1.5	6.8	9.6	20.5	10.90	19.87	0.82
Delvia	21.2	26.1	13.8	18	3.7	2.8	16.7	25.7	5.4	16.8	0.6	3.4	16.2	32.1	11.09	17.84	0.61
Victoria	13.3	12.1	7.7	11.3	4.7	3.5	0	12.8	3.7	15.3	0.6	6.9	2.6	9.3	4.66	10.17	1.18
Chingova	25.4	27.3	14	16.3	7	6.9	16.6	31	7.9	22.5	2.5	9.4	14.4	29.4	12.54	20.40	0.63
German II	24.9	23.6	20.6	30.6	12.7	7.1	12.8	26.8	9	23.6	4.6	12.1	14.4	29.1	14.14	21.84	0.54
Mean	**19.6**	**21**	**12.8**	**19.5**	**5.4**	**3.7**	**11.6**	**24.9**	**5.2**	**18.8**	**1.6**	**6.0**	**9.0**	**20.4**	9.31	16.33	0.85
LSd	**4.1**		**7.4**		**3.8**		**4.2**		**2.2**		**2.5**		**5.5**				

3.1.3.2 On-farm commercial root yield

Alisha outperformed the other seven varieties on-farm for commercial root yield by recording an average of 12.2 tha-1 under irrigation (Figure 4). Similar to the total storage root yield scores, the second and third highest values were generated by the local varieties Chingova and Germany II. The trend that was observed in commercial root yield from pooled research station data was also observed on the pooled on-farm data. Varieties Sumaia (7.9t/ha), Alisha (12.2 t/ha) were the most productive among the OFSP varieties in terms of commercial root yield Variety Alisha particularly outperformed both Chingova (9.5t/ha) and Germany II (9.3t/ha) under irrigated conditions (Fig 4). The results of this study show that while sweetpotato is drought tolerant, its yield increases with constant moisture availability**.**

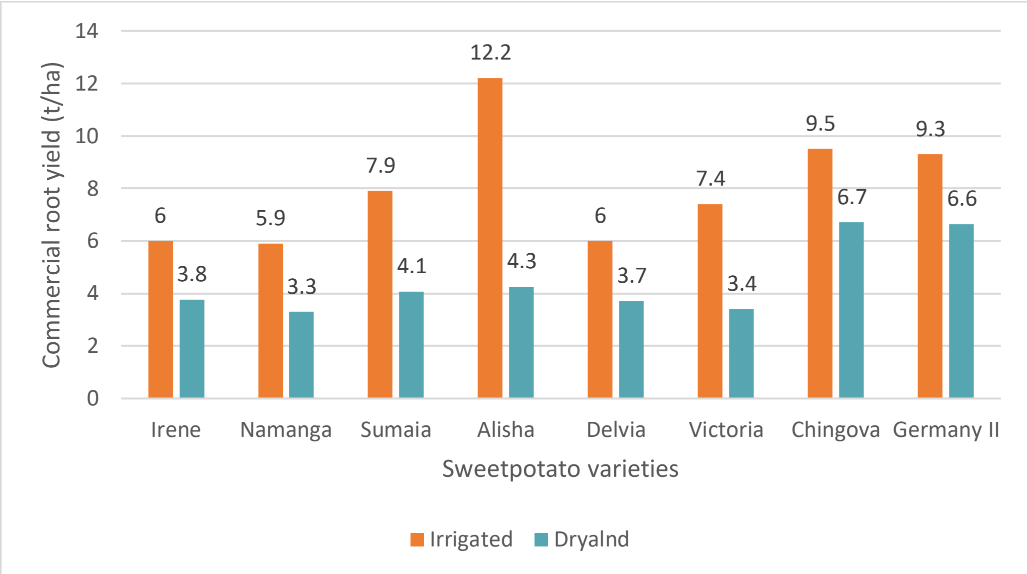

Figure 4: Commercial storage root yield of eight sweetpotato varieties under dryland and irrigated conditions across the 12 on farm sites

3.2 Socio-economic results

3.2.1 Socio-economic characteristics of participants

Appendix 1 presents the socioeconomic characteristics of the participants in the evaluation. In total, 1763 farmers participated in the sweetpotato variety evaluation. More than half (59%) were female. Participants were mostly middle-aged, with mean age of 48 years. The mean size of their households was 5.7 members, with less than 2 children under the age of 5 years. All participants were farmers with mean landholding size was 2.7 hectares.

3.2.2 Importance of sweetpotato

In order to get an understanding of the relative importance of sweetpotato across the evaluation sites, which is important for identifying potential pilot sites for promoting OFSP, participating farmers were asked to provide a ranking of their top 3 most important crops. According to results presented in Table 5, sweetpotato was ranked the 3rd most important crop in most districts after maize and groundnuts. Overall, 75% of the participating farmers grew sweetpotato during the 2019/20 season, with the two local varieties Chingova and German II being the most widely grown. From the results, it can be concluded that sweetpotato is a key food security crop that is widely grown in the country. Most farmers were oblivious to the existence of OFSP varieties, with 70% of the participating farmers hearing about OFSP for the first time. The major sources of sweetpotato planting material were other farmers (50%) and own garden (36%).

Table 5: Percentage of participants who grew sweetpotato in 2019/20 season by district, and top three crops in terms of importance to farmers per district

District	% who grew sweetpotato in the 2019/20 season	Main sweetpotato variety grown	Most important crop	2nd most important crop	3rd most important crop
Bindura	66.40	Chingova	Maize	Groundnuts	Sweetpotatoes
Gokwe North	50.40	Germany II	Groundnuts	Maize	Sorghum
Gokwe South	80.40	Chingova	Maize	Groundnuts	Cotton
Guruve	85.80	Chingova	Maize	Groundnuts	Sweetpotatoes
Kwekwe	87.10	Germany II	Groundnuts	Maize	Sweetpotatoes
Makoni	76.70	Germany II	Maize	Groundnuts	Sweetpotatoes
Mazoe	77.10	Chingova	Maize	Groundnuts	Sweetpotatoes
Mt Darwin	93.90	Chingova	Maize	Groundnuts	Sugar beans
Mutare	84.00	Germany II	Groundnuts	Maize	Sweetpotatoes
Mutasa	87.90	Germany II	Maize	Sweetpotatoes	Sugar beans
Shurugwi	71.30	Chingova	Maize	Groundnuts	Horticultural crops
Zvimba	72.20	Germany II	Maize	Groundnuts	Sweetpotatoes
All	75.30	Chingova			

3.2.3 Farmer-stated trait preferences for sweetpotato varieties

Participating farmers ranked root yield, early maturity, drought tolerance and weevil resistance, taste and dry matter content as the most important traits that they consider when selecting sweetpotato varieties to grow. This is consistent with previous studies (e.g. Adhekambi et al., 2020; Masumba et al., 2004; Mudombi 2007). On the taste parameters, studies across Africa generally found high dry matter content of sweetpotato as very important for farmers and consumers, and also positively associated with taste (Naico & Lusk, 2010). These highly ranked attributes are among the major traits that have been targeted by sweetpotato breeding programs in Africa, including the CIP's sweetpotato breeding hub for Southern Africa in Mozambique.

There were no significant differences in importance of almost all traits between men and women except early maturity which was ranked significantly ($p<0.01$) more importance by men than women (Table 6).

Table 6: Mean scores of importance of various sweetpotato varietal traits by gender

	Mean scores: 1 (not important at all) to 5 (very important)				
Trait	Male	Female	All	Rank of trait	Wilcoxon rank sum test p value
Root yield	4.70	4.66	4.68	1	0.300
Early maturity	4.72	4.64	4.67	2	0.006***
Drought resistance	4.54	4.54	4.54	3	0.803
Weevil resistance	4.46	4.46	4.46	4	0.847
Root Taste	4.37	4.40	4.39	5	0.288
Root size	4.38	4.38	4.38	6	0.789
Vine yield	4.20	4.18	4.37	7	0.745
Number of commercial roots	4.35	4.38	4.18	8	0.275
Dry matter	3.92	3.91	3.91	9	0.589
Flesh colour	3.85	3.88	3.87	10	0.228
Root shape	3.63	3.63	3.66	11	0.792
Root skin colour	3.62	3.68	3.63	12	0.191

3.2.4 Score for the varieties against agronomic, and sensory traits and overall ranking

The results of the mean scores of each variety against agronomic, sensory and combined traits and overall are presented in Tables 7, 8 and – 9, respectively. The three most preferred varieties both in terms of agronomic and sensory traits were Alisha (OFSP), Chingova (white fleshed) and German II (White fleshed). Among the orange-fleshed varieties, Sumaia was the second most preferred variety after Alisha for its agronomic traits though it was less preferred on sensory traits including taste and dry matter content. As shown earlier in Table 1, Sumaia has the least dry matter content among the six OFSP varieties under evaluation which could explain why farmers didn't like its taste. Given its high yield potential, the variety could still be produced for processing into puree and baked products. The two farmer-preferred OFSP varieties in terms of taste, Alisha and Delvia had relatively higher dry matter content than the other four (Table 1), confirming the preference by farmers for varieties with high dry matter content. Victoria was rated the least of all the varieties under evaluation on both agronomic and sensory traits.

Table 7: Mean varietal scores for the most important agronomic traits

Traits	Germany II	Chingova	Alisha	Sumaia	Delvia	Namanga	Irene	Victoria
Root yield	5.33	5.27	4.88	4.44	4.14	3.84	3.57	3.26
Early maturity	5.50	5.40	5.16	4.71	4.41	4.16	3.87	3.27
Drought resistance	5.35	5.23	4.98	4.59	4.34	4.08	3.86	3.38
Weevil resistance	5.18	5.1	4.91	4.56	4.28	4.26	4.15	3.86
Root size	5.32	5.17	4.85	4.48	4.27	3.97	3.66	3.19
Vine yield	5.27	5.12	4.78	4.51	4.31	4.09	3.88	3.65
No. of commercial roots	5.21	5.15	4.65	4.38	4.05	3.84	3.53	3.19
Overall agronomic score	5.25	5.23	4.91	4.33	4.12	3.95	3.74	3.22
Ranking on mean agronomic score	1st	2nd	3rd	4th	5th	6th	7th	8th

Table 8: Mean varietal scores for the most important sensory traits

Traits	Chingova	Germany II	Alisha	Delvia	Namanga	Sumaia	Irene	Victoria
Taste	5.36	5.19	4.98	4.67	4.40	4.13	3.91	3.68
Flesh colour	5.25	5.13	5.15	4.89	4.73	4.75	4.52	4.23
Root shape	5.06	5.20	4.76	4.27	3.98	4.52	3.80	3.32
Root skin colour	5.16	5.19	5.02	4.39	4.29	4.66	4.21	3.72
Dry matter	5.21	5.09	4.85	4.65	4.34	4.24	4.02	3.76
Overalll Sensory trait score	5.32	5.12	4.88	4.59	4.21	4.03	3.80	3.48
Ranking on mean sensory score	1st	2nd	3rd	4th	5th	6th	7th	8th

Table 9: Mean varietal scores for the most important agromic and sensory traits (combined)

Traits	Chingova	Germany II	Alisha	Delvia	Sumaia	Namanga	Irene	Victoria
Agronomic traits score	5.23	5.25	4.91	4.12	4.33	3.95	3.74	3.22
Sensory traits score	5.32	5.12	4.88	4.59	4.03	4.21	3.80	3.48
Overall mean score	5.31	5.21	4.90	4.40	4.21	4.13	3.85	3.40
Ranking on overall mean score	1st	2nd	3rd	4th	5th	6th	7th	8th

Appendix 2 shows the overall mean scores and top 4 ranking of the sweetpotato varieties based on stated farmer preferences per district. The district-level results also confirm that Alisha, Chingova and Germen II were the top three most preferred varieties across all districts. Among the OFSP varieties, Alisha was the most preferred across all districts, with Sumaia and Delvia featuring in the top 3 ranking of some districts. Victoria and Irene were consistently least preferred across the districts.

3.2.5 Rating of sweetpotato varieties against farmers' most preferred agronomic and sensory traits

The analysis of farmers' evaluation of sweetpotato varieties presented in section 3.2.4 is based on mean scores. However, the small range of these scores makes it difficult to easily discern differences in farmer preferences for different varieties. To complement the mean score analysis, an an analysis was also done to determine the percentage of farmers who rated the varieties below average, average and above average for root yield, early maturity, drought resistance, weevil resistance and taste.

3.2.5.1 Root yield

Figure 5 shows the farmers' rating of the varieties on root yield performance. Consistent with results from the mean score analysis, these results show GermanII, Chingova and Alisha as the rated varieties, with Alisha being the most preferred OFSP variety followed by Sumaia.

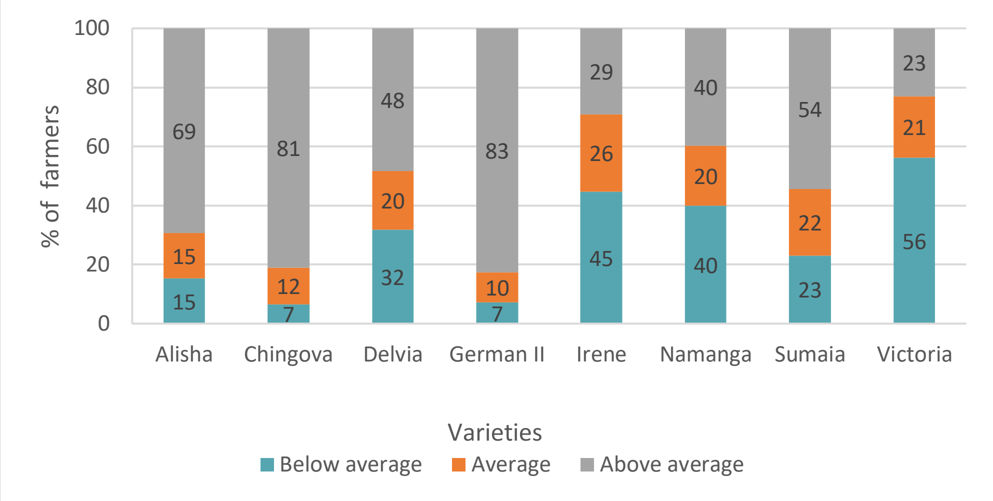

Figure 5: Farmers' rating of sweetpotato varieties on root yield performance

3.2.5.2 Early maturity

Farmer ratings on early maturity, mirrors that for root yield performance, with German II and Chingova most favorably evaluated and quite close to each other followed by Alisha and Sumaia in that order (Figure 6). It is worth noting that although quantitative data showed Delvia to be as high yielding as Alisha and Sumaia, farmers did not quite like the variety, and this was probably due to its tendency to produce very large cracked roots under high rainfall conditions.

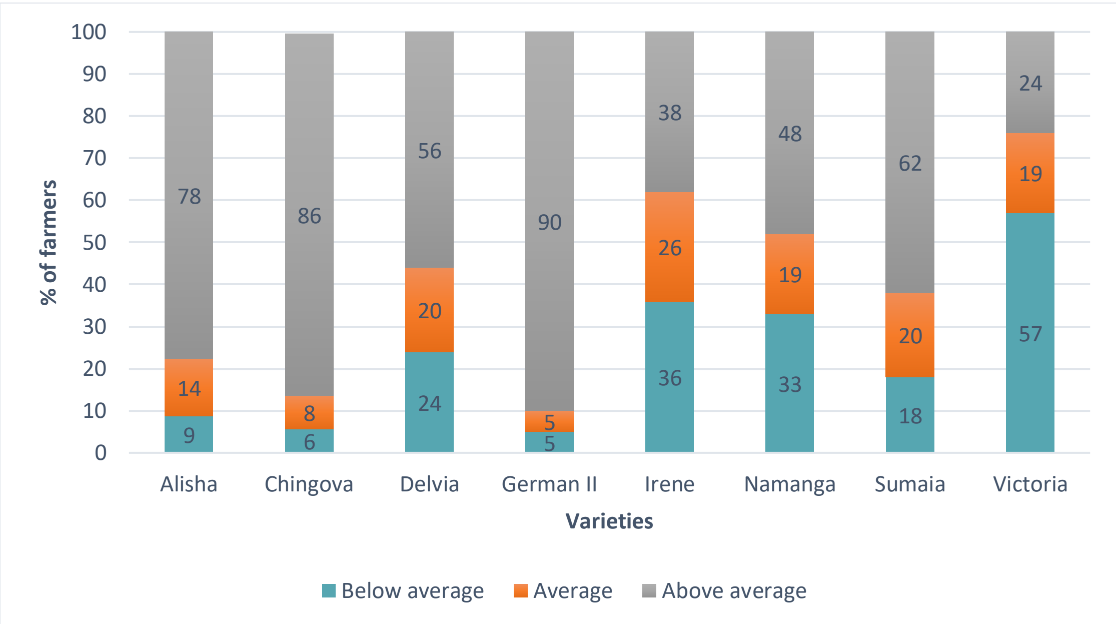

Figure 6: Farmers' rating of sweetpotato varieties on early maturity

3.2.5.3 Drought tolerance and weevil resistance

The same ratings were observed for drought tolerance (Figure 7) and weevil resistance (Figure 8). However, one interesting observation is that, while the gap in farmers' root yield preference between the two local varieties and the most preferred OFSP variety (Alisha) is relatively large, this gap tends to get narrow for the other key traits of early maturity, drought tolerance and weevil resistance. This result confirms that the orange-fleshed variety Alisha compares quite favorably to these two local varieties in terms of early maturity, drought tolerance and weevil resistance.

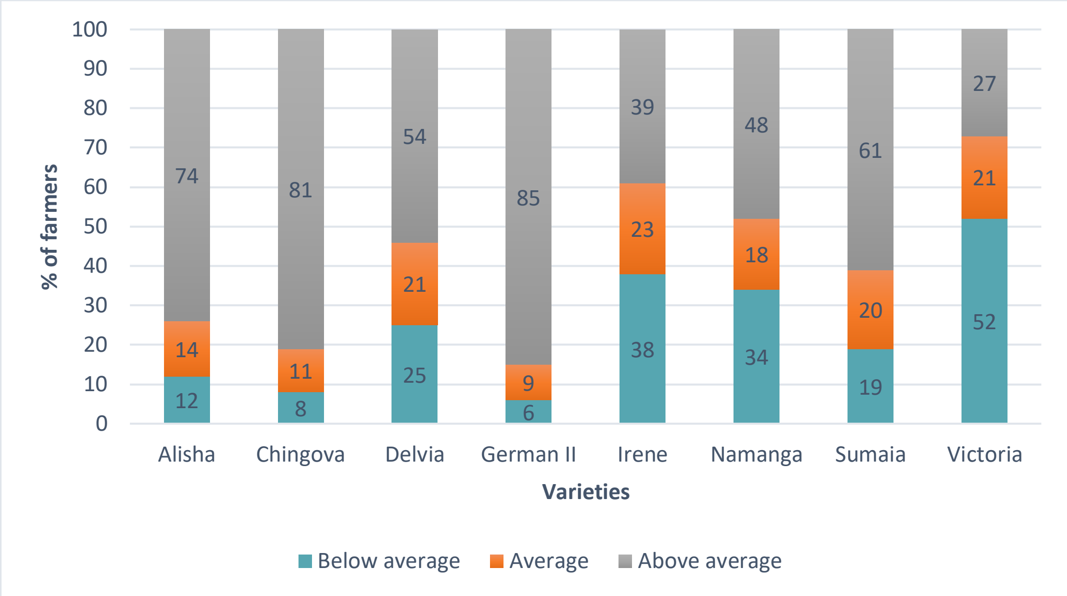

Figure 7: Farmers' rating of sweetpotato varieties on drought tolerance

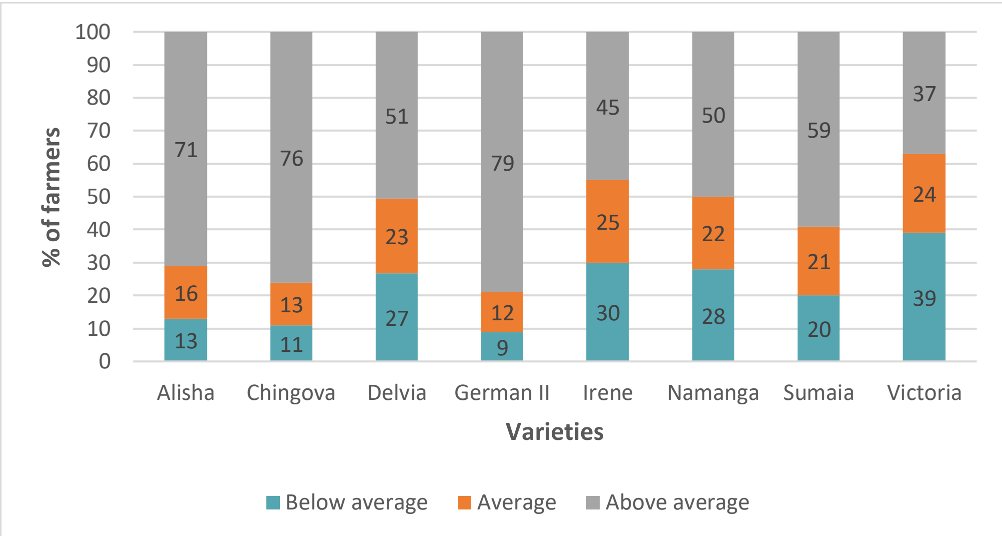

Figure 8: Farmers' rating of sweetpotato varieties on weevil resistance

3.2.5.4 Taste

The most important sensory trait that farmers identified is taste. Farmers in Zimbabwe and indeed in most parts of Africa consume sweetpotato mainly as boiled roots. Therefore, the sensory evaluation was based on farmers' rating of boiled roots. Figure 9 shows farmers' rating on taste of boiled roots for each of the varieties under evaluation. While German II was slightly more preferred to Chingova in terms of agronomic traits, with respect to taste the latter was more preferred by farmers. Similarly, among the OFSP varieties, Sumaia which was rated second to Alisha on all key agronomic traits falls behind Delvia in so far as taste is concerned. This switch could be linked to the fact that Alisha and Delvia have the highest dry matter content among the OFSP varieties under evaluation and Sumaia has the least (Table 1). These results, which are also confirmed in the mean score analysis

(Tables 7 and 8), have significant implications on the overall rating of the varieties. However, it is worth noting that sweetpotato varieties can be consumed in other difference forms, and therefore, some varieties that may not be appreciated in one form could actually be well suited for other uses.

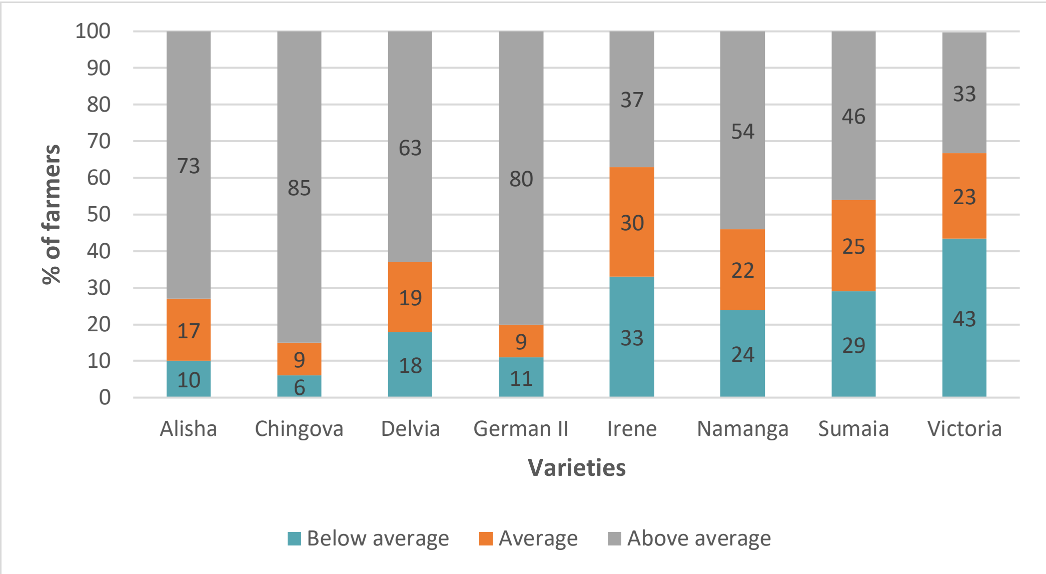

Figure 9: Farmers' rating of sweetpotato varieties on taste of boiled roots

After evaluating farmers' preferences of the varieties on individual traits we sought to assess the overall rating of the varieties by combining their rating for both agronomic and sensory traits. The results from both mean score (Table 9) and frequency (Figure 10) analyses are quite consistent and show that the local varieties were favored, and among the OFSP varieties under evaluation Alisha was most preferred followed by Delvia and Sumaia in that order. Victoria was least preferred.

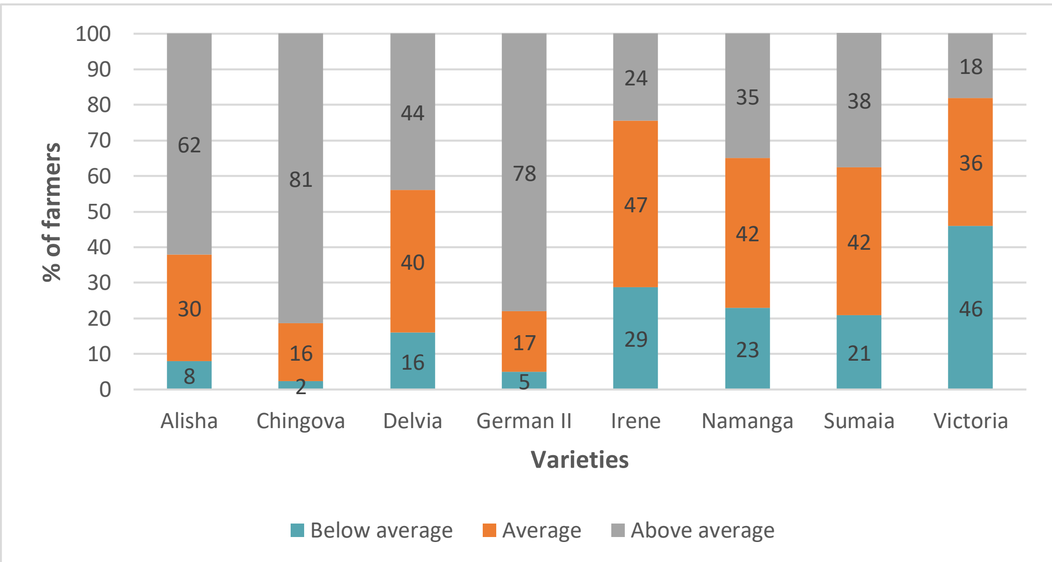

Figure 10: Farmers' overall rating of sweetpotato varieties

3.3 Correlation between yield performance and farmers' evaluation

The results presented in Figure 11 show that there was consistency between measured root yield performance and farmer stated agronomic evaluation with Chingova, German II and Alisha being the top 3 although there weren't significant differences among the three in terms of their yield performance.

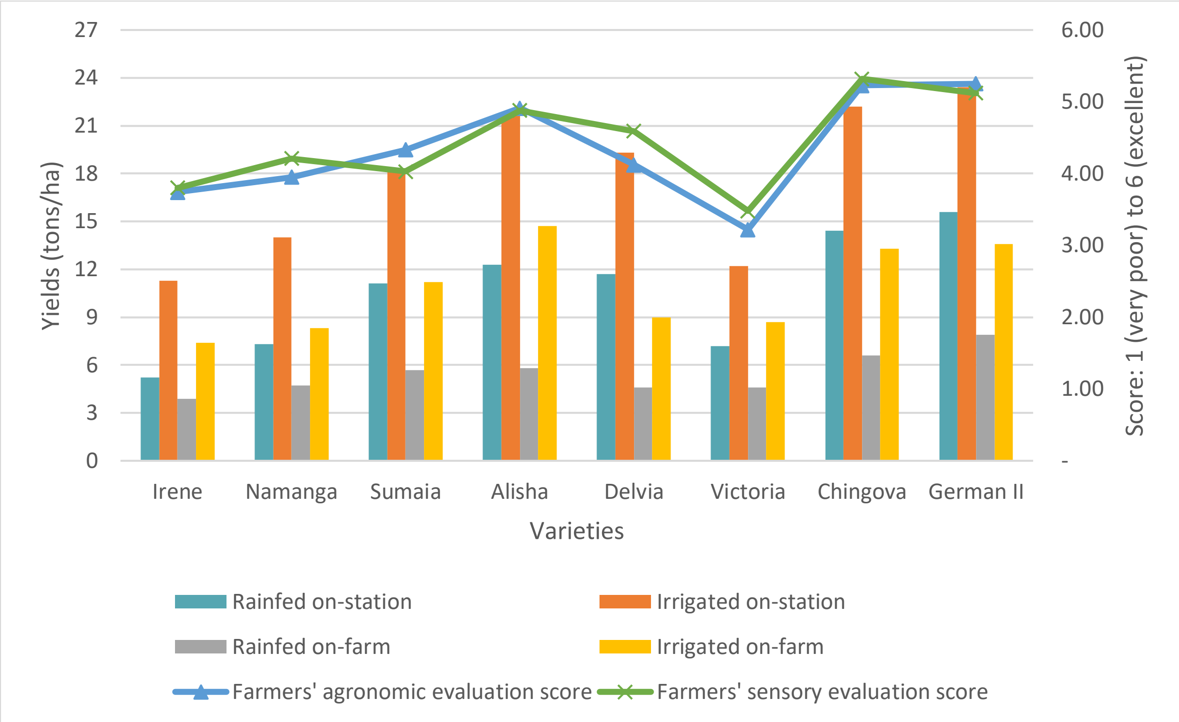

Figure 11: Correlation between root yield performance and farmer evaluations

3.4 Farmer perceptions on OFSP varieties

The results of the analysis of farmer perceptions on OFSP (Figure 12) showed that farmers liked the taste and agronomic performance of the OFSP varieties and 80% of the respondents were willing to grow them on their farms especially if informed about their nutritional benefits. The fact that most farmers disagreed with the negative constructs corroborates the assertion that farmers are optimistic about the potential for production and consumption of OFSP varieties by farmers. It should be borne in mind, however, that the differences in agronomic and sensory traits among the OFSP varieties will have a bearing on their production and consumption prospects among farmers, making it important to promote those varieties with the most preferred traits.

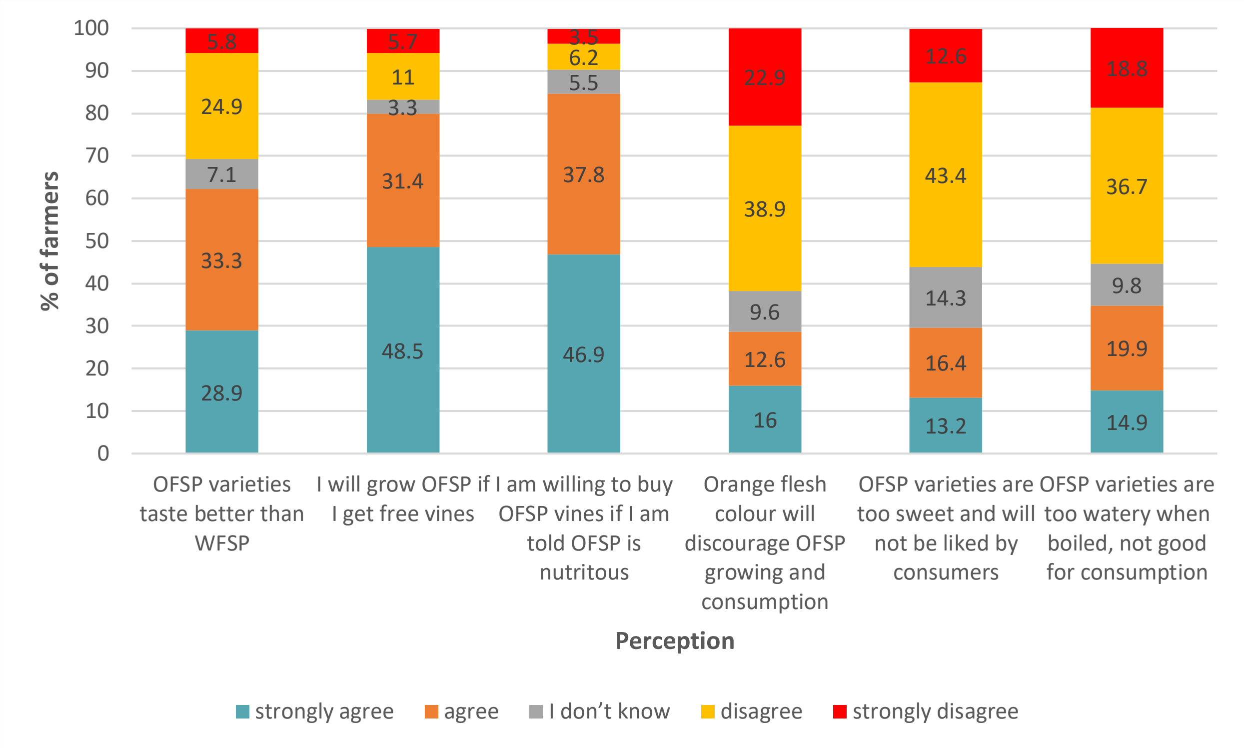

Figure 12: Perceptions of farmers on OFSP taste and willingness to buy vines

3.5 General constraints to sweetpotato production

The main constraints to sweetpotato production identified by farmers were weevil and other pests, shortage of vines and water shortage (Figure 13). Accordingly, even as new farmer-preferred sweetpotato varieties are introduced, strategies to address these constraints are needed. These should include establishing a decentralized vine multiplication system to ensure farmers access disease free sweetpotato planting material and agronomic practices for managing water and weevils.

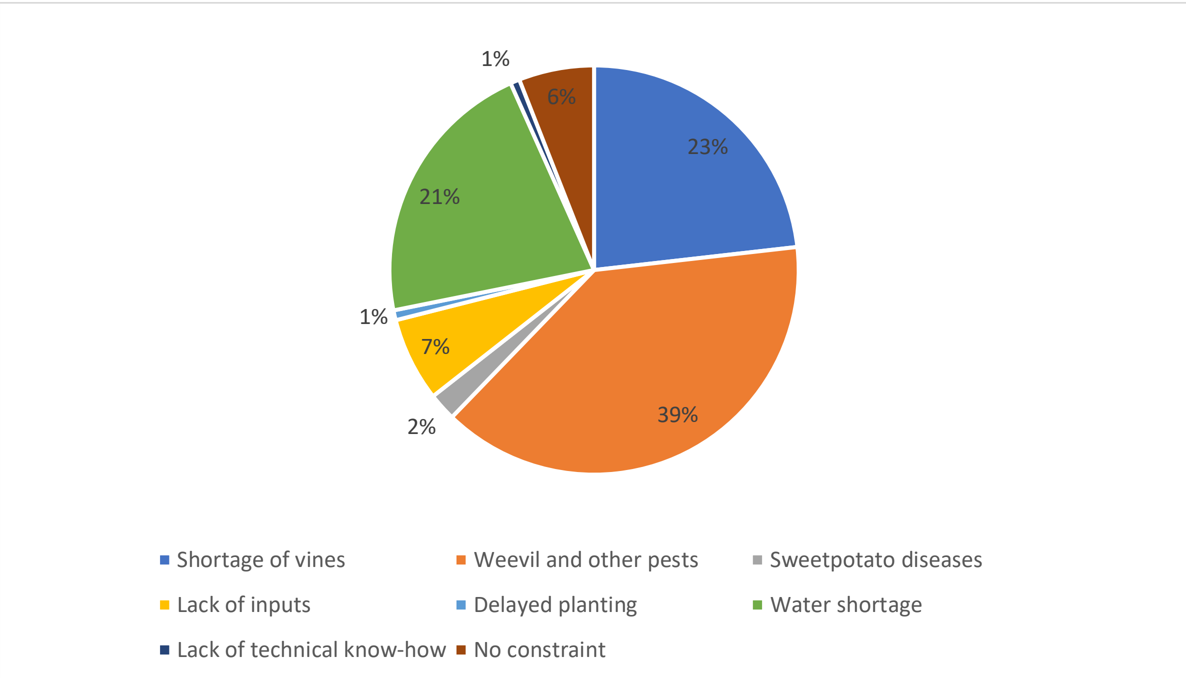

Figure 13: Constraints to sweetpotato production

4 CONCLUSIONS AND IMPLICATIONS

This study sought to evaluate the agronomic performance and sensory preference of six introduced OFSP varieties against the two widely grown local sweetpotato varieties in Zimbabwe. Based on the study findings, out of the six OFSP varieties evaluated, Alisha was the overall best performing and most preferred by farmers. Its performance was comparable to that of the two dominant local varieties, German II and Chingova. Alisha is therefore the most suitable variety for rapid upscaling and promotion in the country. The high yielding variety Sumaia, though less preferred in terms of taste, can still be grown commercially for the processing industry.

It is however important to note that the findings presented in this report are based on data from just one season, which is rarely enough to make solid conclusions especially on the performance of new varieties. Moreover, the OFSP vines planted in the trials had been directly imported from Mozambique and had to be harvested a few days earlier and transported by road to the country and, as a result most vines had lost vigor by the time of planting. This affected their establishment and performance as compared to the local checks which were planted from freshly harvested vines. The arrival of the vines was also delayed due to logistical challenges resulting in late planting, during a season in which rainfall was below average and unevenly distributed. Accordingly, we recommend that the evaluation be repeated for a second season to validate the results.

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Appendix 1: Socio-economic characteristics of participants in the evaluation

	Bindura	Gokwe North	Gokwe South	Guruve	Harare	Kadoma	Kwekwe	Makoni	Masvingo	Mazoe	Mt Darwin	Mutare	Mutasa	Shamva	Shurugwi	Zvimba	All
Number of participants in the evaluation (% female)	110 (59)	125 (50)	56 (61)	155 (54)	47 (42)	31 (39)	139 (65)	86 (60)	14 (43)	249 (60)	33 (55)	100 (59)	140 (64)	34 (56)	268 (68)	176 (56)	1,763 (59)
Household size (number)	6.25	6.54	6.50	5.86	4.23	5.23	5.66	5.30	5.71	5.53	6.33	6.13	5.16	4.85	5.47	5.38	5.65
Age (years)	45.45	48.98	49.12	48.07	39.02	41.43	50.51	46.43	38.23	45.55	49.27	52.03	49.30	39.58	48.31	47.95	47.54
Number of children aged under 5 years	1.55	1.84	2.25	1.59	2.06	1.52	1.50	1.61	1.33	1.48	1.91	1.53	1.44	1.61	1.56	1.56	1.60
Number of female members aged 15-49 years	2.09	2.12	2.82	1.96	2.10	2.13	2.09	1.64	2.69	1.93	2.28	2.10	2.29	2.18	1.99	1.99	2.06
Area of farm owned (hectares)	2.32	4.60	5.27	2.66	6.00	2.69	2.33	2.14	7.89	1.97	3.22	2.09	1.34	2.32	2.90	2.57	2.71

Appendix 2: Farmers' overall mean scores and ranking of varieties by district

	Mean scores for varieties								Top 4 varieties			
District	Alisha	Chingova	Delvia	Germany II	Irene	Namanga	Sumaia	Victoria	1st	2nd	3rd	4th
Bindura	4.39	5.38	4.26	5.19	3.73	3.95	4.17	3.14	Chingova	Germany II	Alisha	Delvia
Gokwe North	5.09	4.86	3.20	5.05	2.82	3.70	4.50	3.99	Alisha	Germany II	Chingova	Sumaia
Gokwe South	3.99	5.04	2.67	4.77	3.55	3.46	4.47	2.82	Chingova	Germany II	Sumaia	Alisha
Guruve	5.22	5.19	4.88	5.41	4.46	4.61	4.96	3.60	Germany II	Alisha	Chingova	Sumaia
Harare	5.05	5.12	4.58	4.87	3.99	4.20	4.57	3.56	Chingova	Alisha	Germany II	Sumaia
Kadoma	5.44	5.25	5.07	5.45	4.79	5.12	5.07	3.65	Alisha	Germany II	Chingova	Namanga
Kwekwe	5.03	4.89	3.99	5.33	3.51	4.44	4.51	3.80	Germany II	Alisha	Chingova	Sumaia
Makoni	5.15	5.16	4.65	5.30	4.15	4.83	4.69	3.54	Germany II	Alisha	Chingova	Namanga
Masvingo	3.46	5.08	4.05	5.44	3.43	4.17	4.48	2.74	Germany II	Chingova	Sumaia	Namanga
Mazoe	4.25	5.21	4.06	5.26	3.71	3.60	4.08	3.30	Germany II	Chingova	Alisha	Sumaia
Mt Darwin	5.10	4.96	4.57	5.22	3.78	4.46	4.42	3.41	Germany II	Alisha	Chingova	Delvia
Mutare	5.19	5.11	4.11	5.29	3.90	4.43	4.61	4.18	Germany II	Alisha	Chingova	Namanga
Mutasa	5.06	5.46	4.58	5.33	4.45	5.06	4.46	3.84	Chingova	Germany II	Alisha	Namanga
Shamva	4.51	5.30	4.63	5.30	3.62	4.32	4.25	3.34	Chingova	Germany II	Delvia	Alisha
Shurugwi	5.53	5.53	5.10	5.33	4.57	4.12	4.79	4.14	Alisha	Chingova	Germany II	Delvia
Zvimba	4.77	5.18	4.36	5.13	3.81	4.09	4.27	3.40	Chingova	Germany II	Alisha	Delvia

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