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Evaluation of selected improved genotypes of tomatoes (Lycopersicon esculenta) during the wet season in Samoa

Luaiufi Dave Joseph Aiono[1]*, Md. Abdul Kader[1], Viliame Savou[1], and Falaniko Amosa[1]

ABSTRACT

Tomato (Lycopersicon esculenta) remains one of the world's most important vegetables, including Samoa, due to its economic and nutritional significance. The limited production and availability of tomatoes in Samoa during the wet season have significant implications for the country. Previous research focused on improving tomato production via the use of various techniques, such as hydroponics and integrated pest management, but there is a lack of studies on the development of a suitable variety that can withstand rainy weather conditions in Samoa. Eight tomato genotypes collected from the World Vegetable Centre (AVRDC, Taiwan) were assessed at the University of the South Pacific Samoa Campus during the wet season under open field conditions to find a suitable genotype. The experiment used a Randomized Complete Block Design with three replications. Results showed a significant variation in the number of days to 50% flowering, disease infestation, number of fresh and marketable fruits/plant, weight of individual fruit, yield, organoleptic characteristics, and Growing Degree Days (GDD) among the nine genotypes. During the study, three diseases were observed, with the highest number recorded for leaf mould, followed by bacterial wilt and fruit rot. Genotypes AL946 and AVTO9801 had significantly higher fresh yields compared to genotypes AVTO1424 and AVTO9304, but their fresh yield was statistically identical to the rest of the five genotypes. The total fresh and marketable yield varied from 3.2 to 9.3 t ha-1 and 2.2 to 8.5 t ha-1, respectively. Genotypes AVTO9801 and AL946 yielded 30.1 and 35.3 and 36.9 and 47.6% higher fresh and marketable yield, respectively, compared to the reference local variety ALTONNUU. Our study found that genotype AVTO9801 outperformed the other genotypes in terms of yield, fruit production, tolerance to pests and diseases, organoleptic characteristics, and GDD. In comparison, genotype AL946 although promising in the initial stages of harvest, succumbed to diseases in the latter stages of the research. Selected genotypes should be further assessed for additional parameters namely nutrient content, nutritional requirements, seasonal variability, disease and pest management, crop modelling prior to recommendation as a suitable genotype/variety for Samoa.

KEYWORDS: *Tomato genotype, yield, Samoa, wet season*

INTRODUCTION

Fresh vegetables have been recognized as a very important constituent of the human diet for their nutritional values throughout the world (Prasad, 2015; Falkowski et al. 2022; Yousuf et al. 2020). However, securing an adequate supply of fresh fruit and vegetables is a common challenge amongst the island countries of the Pacific. Recently, awareness programs shifted consumption lifestyle to a more nutritious and healthier alternative, as well as the demand from the hospitality and food service significantly increased the market demand and value for vegetables (Kammholz et al. 2021; Pacific Farmers, 2019). However, hindering factors stall the availability of locally produced vegetables all year round, resulting in the importation of these produce to cater for the shortfall in supply. In 2022, total vegetable, fruit, and nut preparations imported to Samoa amounted to 33% of all EU Agri-food imported products (European Commission, 2022).

In the Pacific, production of vegetables such as tomatoes, capsicum, Chinese cabbage, head cabbage, lettuces, and cucumbers are strongly hampered by high rainfall, high temperatures, and humidity, resulting in supply shortages and higher prices (PIFON and SPC, 2015). The climatic stresses have been identified to have undermining effects on the productivity and quality of tomatoes in the tropics (Amoroso et al. 2023; Rezk et al., 2021). The availability and access to quality planting materials is one obstacle identified through many forums by Samoan farmers, affecting all-year-round production, particularly in the wet season. Tomato (Lycopersicon esculenta) production and cultivation in the tropics, such as Samoa, are constrained by such problems. In addressing these factors, interventions have been introduced with varying degrees of success, such as the production of open-pollinated seed varieties, the use of different designs of protective shelters for cultivations (tunnel houses) and the installation and application of irrigation systems (protected cultivation and open field). To solve this problem, introduction of potential exotic varieties and research into the application of various propagation techniques has also been explored in different part of the world (Haq et al. 2024; Zandalinas et al. 2023) and some extent to Samoa.

Samoan tomato cultivars that have undergone rigorous evaluation and screening tests include Alafua Early, Alafua Large, Alafua Winner and Alton/Nu'u (Aiono, 2022; Epila-otara et al. 1994). An effort to evaluate 22 genotypes for bacterial wilt resistance was discontinued due to Cyclone Val in 1991 (Liyanage et al., 1991). Apart from farmer field selections on locally open-pollinated varieties ('Roma') and imported hybrid varieties ('Raising sun#2'), there have been no

[1]Discipline of Agriculture and Food Technology, School of Agriculture, Geography, Environment, Ocean, and Natural Sciences, The University of the South Pacific – Samoa Campus
Corresponding author Email: mdabdul.kader@usp.ac.fj

recommendations for additional tomato varieties for Samoa for close to three decades. Even though 'Raising sun#2' is a very popular variety fetching higher returns in the domestic market, it is a hybrid and costly with an average of WS $13 per tray of seedling from local nurseries (Ministry of Agriculture and Fisheries, 2022). However, numerous high-yielding, disease-resistant, and temperature-tolerant open-pollinated genotypes of tomatoes have been developed throughout the world, with none being tested in Samoa for their adaptability.

Hence, the main objective of this work is to evaluate some of the improved tomato genotypes from the World Vegetable Centre (WorldVeg, previous AVRDC), in Samoan climatic conditions, and to reintroduce the tomato genotypes (Alafua Large and Alton/ Nu'u) which are still available at the Sigatoka Research Station in Fiji. The underlying focus is to increase the capacity of Samoan farmers to produce high-quality vegetables a1 Adapted from Morrison et al., 1986. and to sustain production including the critical off-season period. Screening and evaluation processes will also identify and determine suitable genotypes for the off-season that will overcome the constraints indicated above. This should result in the recommendation of appropriate genotypes that farmers could utilize to boost the production and availability of tomatoes domestically, hence minimizing the need to import.

Furthermore, with climate change endangering food security and nutrition, the use of simulation models which require the measurement of Thermal Time or Growing Degree Days (GDD), will enable predictions of the production of tomatoes within Samoa at any ecological location and at any given time interval will be used for model development at a later stage. This will permit for better management of tomatoes in the farmers' field, contributing to effective use of resources to achieve optimum returns.

METHODOLOGY

Site and soil

The research study was conducted at the University of the South Pacific Samoa Campus, Alafua, Apia, Samoa, a country in the South Pacific Ocean located between latitudes 13° S - 15° S and longitudes 171° W–173° W. The climate of Samoa is tropical with abundant rainfall. The average annual temperature range is from 26 °C to 31 °C, with a standard hot and wet season (November – April) and a cool and dry season (May – October). Average rainfall ranges from 3,000 mm in the lowlands to 6000 mm in the highlands, with about 70% of the precipitation occurring during the hot and wet season (Samoa Meteorology Division, 2018; FAO, 2016). Soils of Samoa are of volcanic origin with a very small amount of coastal sand areas, the soil classification of the site however is of a Typic Humitropept, fine, and oxidic isohypertemic soil (Morrison et al., 1986). The physical and chemical properties of the soil are presented in Table 1.

Table 1. General characteristics of the soil[1]

Soil Physical Properties	**Values**
Clay (%)	38
Silt (%)	31
Sand (%)	31
Textural class	Clay loam
Soil Chemical Properties	
pH	6.40
Organic C (g kg^{-1})	2.99
N (g kg^{-1})	2.59
Olsen P (mg kg^{-1})	12.5
Exchangeable Ca (cmol(+) kg^{-1})	4.22
Exchangeable Mg (cmol(+) kg^{-1})	1.94
Exchangeable K (cmol(+) kg-1)	0.10
Extractable Fe (mg kg^{-1})	57.10
Extractable Mn (mg kg-1)	58.50
Extractable Cu (mg kg-1)	2.58
Soil Morphological properties	
Location Name	Alafua Campus
Elevation	89 m
Soil series	Papauta
Soil pattern	Lowlands and foothills
Soil type	Latosolic soil
Drainage	Moderate
Color	Reddish brown
USDA classification	Typic Humitropept, fine, oxidic isophyperthemic

[1] Adapted from Morrison et al., 1986.

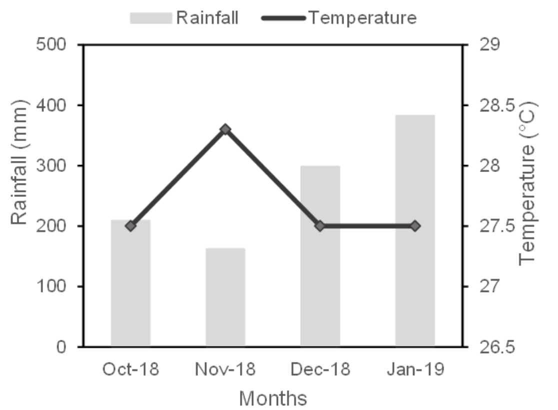

Figure 1. Monthly rainfall (mm) and mean daily temperature (°C) during the field experiment in Alafua from October 2018 to January 2019.

Experimental Design

The study compared the performance of nine tomato genotypes with eight (AVT09304, AVT00102, AVTO9801, AVTO9802, AVTO1424, AL 946, FLCS14, Raising sun #2) obtained from the World Vegetable Centre (WorldVeg), whilst one variety (ALTONNUU) sourced from a local seed supplier which was used as a control. These were evaluated using the standard protocols indicated in the international co-operators guide (Dinssa et al., 2015) in conjunction with the determination of GDD taken to reach each development stage for all the nine genotypes. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications having 24 plants in each accession separated with a guard row from other accession. Tomato was planted maintaining a plant spacing of 60 cm x 60 cm.

Cultivation of tomato

The selected land was tractor-tilled before transplanting the tomato seedlings. The elevated beds were prepared manually by removing all the rocks and debris to encourage optimum root formation for the tomato seedlings during the various stages of growth. Tomato seedlings were raised in seed raising mix (Yates brand) and hardened before transplanting to the experimental plots. Chicken manure was the only means of fertilizer used throughout the research as per normal local farmers' practice and was applied before transplanting of seedlings @ 150 grams of dry chicken manure per planting holes. Twenty-one-day-old tomato seedlings were transplanted to the field around 15 cm in plant height. The stakes for the seedlings were established 2 days after transplanting for all the seedlings, ensuring no damage to the root system and providing maximum support for the plants during the lifetime of growth. Similarly, trellis support was provided using the polymer green twines obtained from the Agriculture store. Water application was applied ad-lib, ensuring adequate soil moisture was retained. During the crucial early stages of field growth, the plants which did not survive post-transplant were replaced immediately. Molluscicide pellets were applied during the early stages of growth and at ad-lib around the border of the research block to ensure the prevention of snails and slugs from encroaching onto the research site. Other management aspects, such as staking and/ or pruning, were applied at the necessary time.

Physical and physiological data collection

Data on plant height, growth habit, number of days to 50% flowering and fruiting, severity of any pests or diseases, fruit weight, and marketable and non-marketable fruit yield were recorded following the universal guidelines set by AVRDC (AVRDC, 1990). Plant height was recorded on a weekly basis by taking the measurement from the base of the main stem to the highest growing tip. Pests and diseases incidence were calculated by the following equations:

$$\text{Disease or pest incidence (\%)} = \frac{\text{No. of infected plants}}{\text{Total no. of plants}} \times 100$$

For severity, a scale is used from 1 – 3, hence 'none = 0', 'slight' = 1', moderate =2 and 'severe = 3'.

Thermal time or Growing Degree Days (GDD) was calculated for each tomato accession by following Miller et al., 2001. To calculate GDD, the maximum and minimum temperature were recorded by an automated weather station (Spectrum Watchdog 2900ET). The following equations were used for calculating GDD.

$$GDD = T_{mean} - T_{base}$$

Where:
T_{base} = 10 °C for tomato
T_{mean} = average of daily minimum and maximum temperature

Sensory evaluation

Sensory evaluation of tomatoes from each accession was done by a panel of 10 members. The overarching properties assessed were appearance, odor, and taste, which were subdivided to shape, size, colour, and blemishes for appearance, smell and feel for odor, and finally texture, flavour, juiciness and firmness for taste.

Statistical Analysis

Collected data were analyzed through the Statistical Tool for Agricultural Research (STAR) software with the R package. One-way analysis of variance (ANOVA) was performed with Duncan's Multiple Range posthoc Test (DMRT) for all the plant growth parameters, yield and yield contributing characters, disease incidence, organoleptic characters, and GDD. The level of probability was fixed at 5%. Pearson correlation was performed between the tomato growth parameters and yield contributing characters.

RESULTS

Growth Parameters

Plant Height

The plant heights of all nine tomato genotypes gradually increased with significant differences ($P<0.05$) between the sampling points (Fig. 2). At each sampling date, no significant differences ($P>0.05$) in plant height were observed among the tomato genotypes. There was no significant interaction effect of tomato genotypes and sampling points to plant height noted.

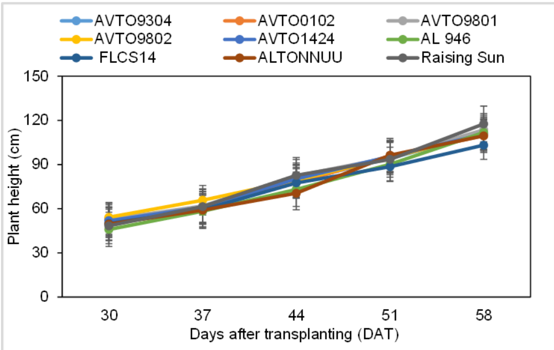

Figure 2. Average plant heights of nine tomato genotypes recorded at different DAT.

Leaf Canopy

The leaf canopy spread of the nine-tomato genotype increased over time (Fig. 3) and reached its peak at 51 DAT. Thereafter, canopy spread of all the tomato genotypes decreased and canopy spread at 58 DAT was statistically identical to 44 DAT. There was a significant difference ($P>0.01$) in the canopy spread among the nine tomato genotypes, as well as at the five sampling points, but their interaction was insignificant. The highest canopy spread was recorded for AVTO 1424 (38.58 cm) followed by AVTO 9801 (38.43 cm), AVT00102 (36.21 cm), ALTONNUU (35.67 cm), AVTO9802 (35.65 cm), AVT09304 (35.41 cm) Raising sun#2 (30.87 cm), Al 946 (30.51 cm), and FLCS14 (28.93 cm). The former five genotypes were statistically identical while AVTO 1424 and AVTO 9801 genotypes were significantly superior to latter three genotypes (Raising sun#2, Al 946, and FLCS14). The canopy spread of AVTO 1424 was 33% higher than that of genotype FLCS14.

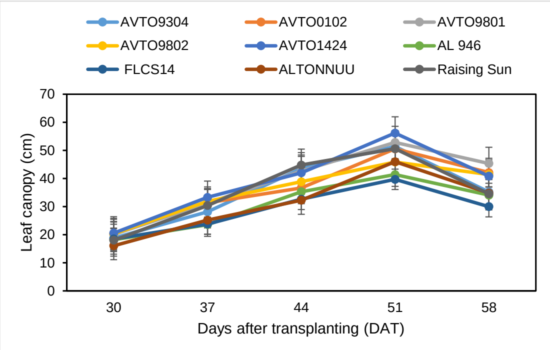

Figure 3. Average canopy spreads of nine tomato genotypes recorded at different DAT.

Flowering Cluster & Fruiting

Flower cluster formation in all genotypes started at 30 DAT and increased significantly over time (P>0.01) (Table 2). However, fruit setting in most of the tomato genotypes started two weeks later after flowering at 44 DAT. Tomato genotypes that stand out in terms of early flower cluster formation were AVTO9801, AVTO9802, AVTO0102 and AVTO1424. However, early fruit setting was observed mainly in AVTO9802, AVTO0102, and FLCS14. Most of the genotypes started to develop fruits at 44 DAT, with AVTO9802 taking the lead, but there was no significant difference between the genotypes with reference to flowering at any sampling date (Table 2). However, combined analysis showed a significant difference (P>0.01) in flowering among the genotypes and sampling points with no significant interaction effect.

The fruit formation showed a significant difference amongst the nine genotypes (P>0.05) and sampling points (P>0.01), but with no significant interaction (Table 2). On an average of sampling points, tomato genotype AVTO9801 was noted to have the most count of fruit formation (4.67) followed by AVTO9802 (2.86), ALTONNUU (2.48) FLCS14 (2.34), Raising sun#2 (1.99), AVTO0102 (1.96), AVTO1424 (1.65), AL946 (1.64), and AVTO9304 (0.59). AVTO9801 was significantly higher than AVTO9304, while it was statistically identical to other tomato genotypes. Fruit setting in AVTO9801 was 84.7 % more compared to AVTO9304.

The number of days required for 50 % flowering was significantly different (P<0.05) among the nine tomato genotypes (Table 2). Genotype AL 946 required the longest duration (46 days) which was significantly higher (53%) than the genotypes AVTO 0102, AVTO 9801, AVTO 9802, FLCS 14 and ALTONNUU. These five genotypes required only 30 days to flower. For the remaining genotypes, AVTO 9304, AVTO 1424 and Raising sun #2, the number of days required for 50 % flowering was statically identical to both the genotypes that requires the longest and shortest duration for 50 % flowerings. However, the number of days required for 50 % fruiting in nine tomato genotypes did not vary significantly and ranged between 51 and 60 days (Table 2).

Pest and Diseases

No pests recorded during the tomato trial, but symptoms of different tomato diseases, namely Early Blight, Bacterial Wilt, Fusarium Wilt, Leaf Mould, Southern Blight and Fruit Rot, were observed throughout the tomato growing period. However, only three disease symptoms were observed and recorded in the trials, namely leaf mould, bacterial wilt, and fruit rot (Fig. 4). The highest number of disease incidence was recorded for leaf mould, followed by bacterial wilt and fruit rot. The nine tomato genotypes were all infected by leaf mould with a disease incidence ranging from 1.17 (AVTO0102) to 2.46 (AL946) (Fig. 4). The analysis of variance showed that there was a significant difference in leaf mould disease incidence (P<0.05) between genotypes AL946 and AVTO0102, AVTO9802, AVTO1424, ALTONNUU and Raising Sun. In the remaining three genotypes, namely AVTO9304, AVTO9801 and FLCS14, leaf mould infections were statistically identical to both the groups having the highest (AL946) and lowest (AVTO0102, AVTO9802, AVTO1424, ALTONNUU and Raising Sun #2) leaf mould infection.

There was also a significant difference (P<0.05) observed in bacterial wilt infection among the nine tomato genotypes. AL946 was again noted to be the most affected genotype, significantly higher infection than the rest of the eight genotypes. Surprisingly, no bacterial wilt infection was observed in genotype AVTO9801.

The analysis of variance for fruit rot infection also noted a significant difference (P<0.05) between the nine genotypes. Genotype AVTO102 was the most affected and significantly differed from the remaining eight genotypes. No significant difference in fruit rot infection was observed between genotypes FLCS14 and AVTO9801, however, the difference was significant between the genotypes AVTO9801 and AVTO1424.

No significant difference in fruit rot infection was observed between genotypes FLCS14 and AVTO1424. No fruit rot infection was observed in AVTO9802, AVTO9304, AVTO9802, AL946, ALTONNUU and Raising Sun #2.

Table 2. Average flowering cluster and fruit count recorded at different DAT and number of days for 50% flowering and fruiting for the nine tomato genotypes

Treatment	Flower clusters/plant					Fruits/plant			No of days for 50%	
	30 DAT	37 DAT	44 DAT	51 DAT	58 DAT	44 DAT	51 DAT	58 DAT	Flowering	Fruiting
AVTO9304	0.87	0.87	1.97	4.23	4.52	0.00	0.14	1.63	35ab	59
AVTO0102	1.34	1.34	2.60	4.88	6.12	0.53	2.24	3.12	30b	50
AVTO9801	1.67	1.29	2.05	5.78	7.50	0.00	3.36	10.64	30b	52
AVTO9802	1.46	1.46	3.58	4.42	6.26	1.24	1.59	5.76	30b	51
AVTO1424	1.26	1.11	2.80	5.90	7.29	0.10	0.91	3.93	35ab	54
AL 946	0.65	0.65	1.22	1.98	2.81	0.00	0.72	4.20	46a	60
FLCS14	0.75	0.75	1.96	3.88	5.76	0.34	1.50	5.18	30b	52
ALTONNUU	0.89	0.78	2.46	4.56	5.81	0.00	2.60	3.38	30b	51
Raising Sun	0.63	0.63	1.59	4.46	6.18	0.17	2.38	4.91	42ab	52
P value	*0.307*	*0.578*	*0.210*	*0.068*	*0.150*	*0.344*	*0.359*	*0.081*	*0.015*	*0.335*

Treatments indicated with different letters are statistically different. Within columns, means with similar lowercase letters are not significantly different at ($p < 0.05$).

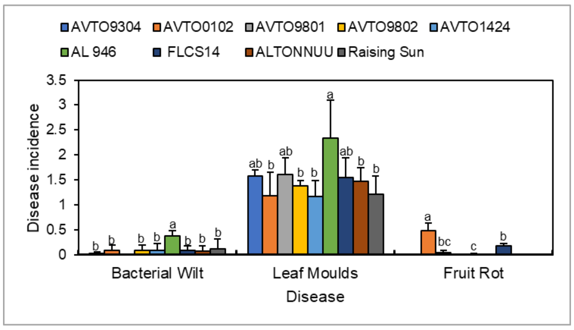

Figure 4 Average incidence of bacterial wilt, leaf mould and fruit rot diseases recorded in nine tomato genotypes.

Harvest

Maturity patterns

The number of fruits harvested from the nine (9) tomato genotypes is presented below (Fig. 5). The initial harvest recorded three genotypes, FLCS14, AVTO9801, and AL946, with a distinct high number of fruits harvested from FLCS14. However, progressing to the final harvest, the number of fruits gradually decreased except for AVTO9801. The number of fruits harvested from genotype AVTO9801 increased again after the third harvest, ultimately becoming the highest genotype with the highest number of average fruits during the final harvest. In contrast, progressing to the harvesting date, the number of fruits harvested from genotypes Raising sun#2, AVTO9304, AVTO1424, and ALTONNUU gradually increased. Raising sun#2 displayed a steady pattern, recording a low number of fruits in the initial harvest but with the second highest number in the final harvest. The other genotypes (AVTO102 and AVTO9802) noted a more constant trend in number of fruits harvested from the first harvest to the final harvest of the experiment. This indicates that the three (3) genotypes, FLCS14, AVTO9801, and AL946, have early maturity compared to the other genotypes. It was noted that apart from AVTO9801, they started to bear fewer fruits with progression to the final harvest. Raising sun#2, in comparison, had a slow maturity but was noted to produce more towards the final harvest.

The average weight of fruits harvested per genotype (Fig. 6) resembled the data for number of fruits harvested. FLCS14 and AL946 recorded the highest average weights in the initial harvest, gradually decreased with progression to the final harvest. AVTO9801 also recorded a high average weight in the initial harvest, which decreased gradually, before increasing again in the final harvest with the second-highest recorded average weight amongst the genotypes. In contrast, Raising sun #2 recorded a low average weight in the initial harvest, which gradually increased, and recorded the highest average weight in the final harvest. This trend supports the results previously mentioned on the maturity indication of the noted tomato genotypes (Fig. 5).

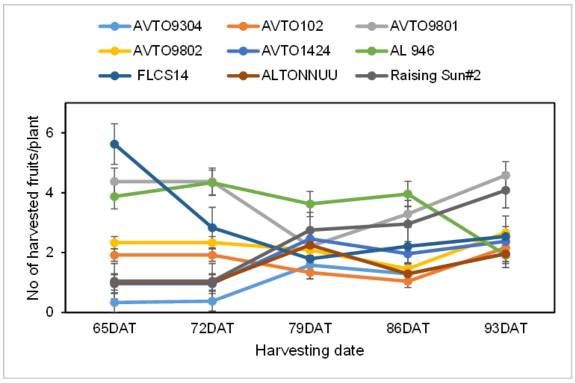

Figure 5 Average number of fruits harvested per harvest from the nine tomato genotypes.

Yield Contributing Characteristics

The recorded yield contributing characters were significantly different ($P<0.05$) among the nine tomato genotypes (Table 3). The relationship between the average number of fresh yield and average marketable yield between the genotypes is evident. The total number of fresh fruits per plant varied from 5.8 to 18.3 per plant, while it varied from 4 to 15.9 per plant in case of marketable fruits

(Table 3). AL946 had the highest average number of fruits per plant, followed by the genotypes AVTO9801 and FLCS14. However, all three genotypes were statistically identical. The other five genotypes were also statically identical with the genotypes AVTO9304 which had the least number of fruits per plant. The tomato genotype AL946 had 215 % more fruits per plant than AVTO9304. The marketable number of fruits per plant also followed a similar trend, with AVTO9801 having the highest number of marketable fruits per plant and the lowest in AVTO9304.

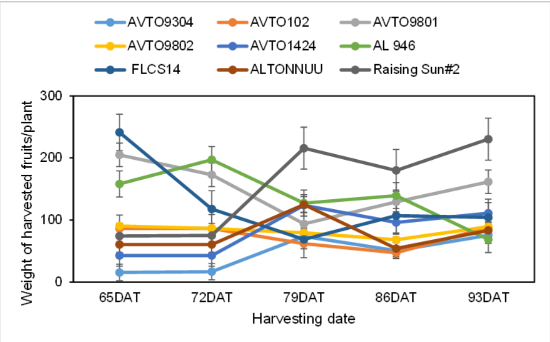

Figure 6 Average weight of fruits harvested per harvest from nine tomato genotypes.

It was noted that Raising sun#2 produced the heaviest fruits in both the fresh yield and marketable yield, followed by ALTONNUU. The other genotypes produced the lightest fruits, but all were statistically identical in fruit weights, both in the case of fresh and marketable fruits. The weight of tomatoes produced in Raising sun#2 was 79% heavier than the tomatoes produced in the AL946 genotype.

The total average weight of tomatoes produced per plant by each genotype showed trends closely related to the number of fruits recorded for fresh yield compared to the marketable yield. Hence, as previously reported for the average number of fruits for fresh and marketable yield, AL946 recorded the highest average weight of fruits per plant. The genotype AVTO9801 produces the second highest number of fruits, followed by FLCS14, Raising sun#2, AVTO1424 and the lowest AVTO9304. AL946 produced three times (196 %) higher fresh yield than AVTO9304. In case of fresh yield per plant, the genotypes AVTO9801, AL946 and FLCS14 were statistically superior to AVTO9304. The other five genotypes statistically matched with either the former and/or latter group. The marketable yield per plant of the same AVTO9801, AL946 and FLCS14 belongs to the superior group while the genotype AVTO1424 was included with AVTO9304 in the inferior group. The other four genotypes were statistically matched with either superior and/or inferior group.

Yield

There was a significant variation in both total average fresh yield ($P< 0.05$) and marketable yield ($P< 0.01$) among the nine tomato genotypes (Fig. 7). The total average of fresh and marketable yield varied from 3.2 to 9.3 t ha^{-1} and 2.2 to 8.5 t ha^{-1}, respectively. Genotypes AL946 and AVTO9801 had significantly higher fresh yields compared to genotypes AVTO1424 and AVTO9304, but the fresh yields were statistically identical to the rest of the five genotypes including Raising sun #2. On the other hand, genotype FLCS14 produced a significantly higher fresh yield than AVTO9304, but a statistically similar fresh yield to the other seven genotypes. Genotype AL946 produced 196 % higher fresh yield and 286 % higher marketable yield than AVTO9304.

However, the analysis of variance for the total average marketable yield noted that genotype AL946 produced the highest marketable yield followed by AVTO9801, FLCS14, ALTONNUU, and Raising sun#2. The latter four genotypes were statistically identical to the former, but statistically superior to genotypes AVTO9304, AVTO102, AVTO9802, and AVTO1424. Moreover, genotypes AVTO9801 and FLCS14 produced significantly higher marketable yields compared to genotypes AVTO9304 and AVTO1424.

Table 3 Fresh and marketable fruit yields (number and weight) of nine tomato genotypes.

Treatment	Fresh yield			Marketable yield		
	No of fruits /plant	Wt. of fruit (g/fruit)	Fruit wt. (g/plant)	No of fruits /plant	Wt. of fruit (g/fruit)	Fruit wt. (g/plant)
AVTO9304	5.8d	42.2c	245.3c	4.0c	40.3c	171.7c
AVTO0102	10.8bcd	42.2c	443.5abc	8.2bc	40.1c	356.9bc
AVTO9801	16.9ab	42.5c	689.9a	15.1a	40.8c	585.2ab
AVTO9802	10.6bcd	41.8c	435.6abc	8.7bc	40.0c	347.0bc
AVTO1424	8.3cd	46.9c	374.3bc	4.6c	44.8c	221.2c
AL 946	18.3a	40.3c	726.3a	15.9a	39.4c	638.1a
FLCS14	14.4abc	42.8c	618.0ab	13.2ab	42.4c	560.0ab
ALTONNUU	9.6cd	56.7b	530.5abc	7.6bc	55.1b	432.4abc
Raising Sun#2	7.8cd	72.7a	544.8abc	5.8c	71.1a	417.2abc
P value	0.007	0.03	0.031	0.002	0.008	0.008

Treatments indicated with different letters are statistically different. Within columns, means with similar lowercase letters are not significantly different at ($p < 0.05$).

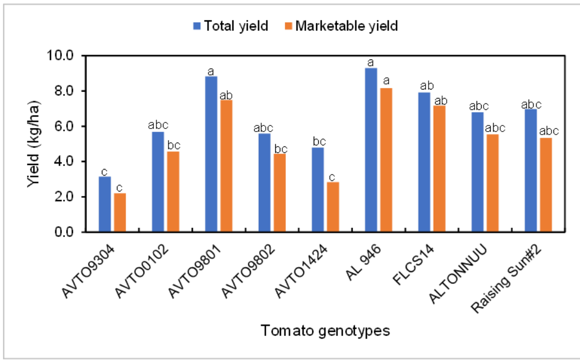

Figure 7 Total average fresh yield and marketable yield for the tomato genotypes

Organoleptic Characteristics

The assessed organoleptic properties varied between the nine (9) genotypes (Table 4). The genotype Raising sun #2 ranked significantly higher (P<0.01) in shape as compared to genotypes AVTO0102, FLCS14 and AL946. The shapes of genotypes AL946, AVTO0102 and FLCS14 were not significantly different, however AL946 ranked significantly lower than the remaining genotypes. The size was also significantly (P<0.01) different between the nine (9) genotypes. The size recorded for genotype AVTO9802 was significantly higher compared to AL946 and AVTO1424. The size of genotype AVTO1424 was significantly less than all the remaining genotypes.

For colour, it was also determined to be significantly (P<0.01) different amongst the nine (9) genotypes, with AVTO9802 ranked to be significantly higher than ALTONNUU, FLCS14 and AVTO0102. There was no significant difference in comparison of ALTONNUU, FLCS14 and AVTO0102, however, genotype ALTONNUU and AVTO0102 were both significantly lower than the remaining 6 genotypes under assessment for colour preference.

When ranking blemishes, it was determined that genotype AVTO9801 had no significant difference to AVTO9802 and Raising sun #2, however it was significantly higher than the remaining 6 genotypes under study.

In the order subcategory of smell, there was no significant difference (P>0.05) between the nine genotypes although there was a significant difference (P<0.01) with reference to subcategory feel, in which genotype AVTO9801 was ranked significantly higher than AL946, ALTONNUU and FLCS14. In contrast, the genotype FLCS14 was not significantly different to AL946 and ALTONUU but was significantly lower than the remaining six genotypes of tomatoes.

Looking at the final category of taste, there was a significant difference between the genotypes in subcategory texture (P<0.01) and flavour (P<0.05), whilst for subcategory juiciness and firmness there was no significant difference (P>0.05) between the genotypes. In the subcategory of texture, it was found that genotype AL946 was significantly lower than AVTO9801, AVTO9802 and AVTO1424, however it was not significantly different to the remaining five genotypes. When analyzing the subcategory of flavour, it was determined that genotype AL946 was significantly lower than AVTO9801, AVTO1424 and Raising sun #2. In comparing genotype AL946 to genotype AVTO9304, AVTO0102, AVTO9802 and FLCS14, no significant differences were observed.

In overall assessment of the organoleptic properties, there was a significant (P<0.01) difference between the genotypes. Genotypes AVTO9801, AVTO9802, AVTO1424 and Raising sun #2 were the best scorer and significantly better than genotype AL946 and FLCS14. However, the former four genotypes scored statistically identical to AVTO9304, AVTO0102 and ALTONNUU.

Growing Degree Days (GDD)

There was no significant difference during the vegetative stages for all nine genotypes, approximately calculating 596 GDD for each (Table 5). For the flowering stage, AVTO0102, AVTO9802, and FLCS14 required the lowest GDD (142), with no significant difference in comparison to AVTO9801, AVTO1424, ALTONNUU, and Raising sun#2 (P<0.01). However, they all required significantly less GDD compared to the genotype AL946 (414). This genotype was statistically identical to AVTO9304 (369).

With reference to fruiting, there was no significant difference (P≥0.05) amongst all nine genotypes, in ascending order when comparing the table of means, the least GDD for fruiting was recorded and calculated from genotypes AVTO9801, AVTO9802, Raising sun#2, AL 946, AVTO1424, ALTONNUU, AVTO0102, AVTO9304 and finally genotype FLCS14.

Table 4: Organoleptic Characteristics for the nine tomato genotypes

Treatment	Appearance (look)				Order		Taste				Overall
	Shape	Size	Colour	Blemishes	Smell	Feel	Texture	Flavour	Juiciness	Firmness	
AVTO9304	4.63ab	4.50ab	4.38abc	3.75cd	4.63	4.50ab	4.25ab	4.25ab	4.50	4.25	4.36ab
AVTO0102	4.25bc	4.75ab	3.88c	3.75cd	4.25	4.25ab	4.38ab	4.38ab	4.13	4.25	4.23ab
AVTO9801	4.75ab	4.63ab	4.38abc	5.00a	4.63	5.00a	4.50a	4.63a	4.38	4.50	4.64a
AVTO9802	4.63ab	4.50ab	5.00a	4.75ab	4.38	4.50ab	4.63a	4.50ab	4.63	4.50	4.60a
AVTO1424	4.88ab	5.13a	4.63ab	3.75cd	4.38	4.25ab	4.50a	4.63a	5.00	4.38	4.55a
AL 946	3.63c	3.38b	4.63ab	3.88bcd	4.25	4.13bc	3.63b	3.63b	4.50	4.63	4.03b
FLCS14	4.13bc	4.25ab	3.88c	3.50d	3.75	3.38c	3.88ab	4.25ab	4.75	4.50	4.03b
ALTONNUU	4.50ab	4.63ab	4.13bc	3.50d	3.75	4.13bc	4.38ab	4.63a	4.50	4.63	4.28ab
Raising Sun #2	5.25a	4.75ab	4.50abc	4.63abc	3.75	4.75ab	4.38ab	4.63a	4.63	4.88	4.61a
P value	0.000	0.000	0.000	0.000	0.051	0.000	0.003	0.014	0.180	0.580	0.000

Score 1 = very poor, 2 = poor, 3 = fair, 4 = good, 5 = very good, 6 = excellent

The total GDD of tomatoes until the physiological maturity of the plants varied from 1098 to 1458 showing a significant difference ($P<0.05$) among the genotypes (Table 5). Genotypes AVTO9304 and AL946 required significantly ($P<0.05$) higher GDDs than AVTO9802. However, compared to the remaining seven genotypes, it was not significantly different from each other and was found statistically identical with both the genotypes that required the highest and the lowest GDDs.

Table 5 Growing Degree Days of different vegetative stages of the nine tomato genotypes

Treatment	Vegetative	Flowering	Fruiting	Total
AVTO9304	596	369ab	493	1458a
AVTO0102	596	142c	480	1218ab
AVTO9801	596	188c	359	1143ab
AVTO9802	596	142c	361	1098b
AVTO1424	596	188c	434	1218ab
AL 946	596	414a	404	1413a
FLCS14	596	142c	556	1293ab
ALTONNUU	596	188c	435	1218ab
Raising Sun #2	596	233bc	389	1218ab
P value	n.s.	0.0001	0.4051	0.0203

n.s. non-significant

Correlation between physical and yield contributing parameters of Tomato

Pearson correlation showed that the plant height of tomato is correlated with canopy spread and flowering ($P<0.01$) but none of the yield and yield contributing characters (Table 6). Similarly, canopy spread correlates with flowering and fruit setting ($P<0.01$) but none of the yield parameters. Flowering also does not correlate with any yield and yield contributing parameters but only with fruit setting ($P<0.01$). However, fruit setting is correlated with fruit/plant, marketable fruit/plant, fresh yield, and marketable yield ($P<0.05$) but not with fruit weight. Tomato fruit weight does not correlate with tomato yield.

DISCUSSION

There are many factors which determine the screening of tomato genotypes, in this research the main factors which were looked at included the physical growth parameters, the yield contributing factors, yield, the incidence of diseases, the organoleptic properties and the Growing Degree Days. The main interest of farmers is the maximum returns per unit area, meaning less inputs with the output or results outweighing the cost of the resources being implemented.

Plant physical parameters

All nine (9) tomato genotypes were subjected to the same growing conditions, so the plant height results obtained between the genotypes are reliable. Towards plant maturity, plants are expected to increase in size, and this is evident in the plant height and leaf canopy which recorded a gradual increase in the spread of leaf canopy from the initial point to the final recording point (Fig. 2). However, the canopy decreases as plants prepare for flower formation as noted at 58 DAT for all the nine genotypes. Previous studies carried out on tomato responses to the effects of plant density, water stress, and fertilizer application on tomatoes. According to the correlation study of the growth of the plant as it approaches maturity, plant height and canopy spread are positively correlated as the plant produces its food and prepares for fruit production. The growth, yield and quality of tomatoes are highly influenced by factors such as the genetic constitution of variety, the microclimate of the area and management aspects (Rosca et al. 2023; Tezcan et al. 2023; Mukherjee et al. 2023). The parameters of plant height and canopy spread are important aspects of the vegetative stage of the plant as height would assist the plant in the capturing of optimum sunlight, whilst the leaves (AVRDC, 1990) for its photosynthetic functions to produce carbohydrates and other compounds relevant to support production and growth of flowers, fruits, and seeds.

Table 6 Pearson correlation between physical and yield contributing parameters of Tomato

Parameters	Flowering	Fruiting	Canopy	Fr/plant	Mrk Fr/plant	Fresh fruit (kg/ha)	Mrk fruit (kg/ha)	Fruit wt/tomato	Mrk Fr wt/tomato
Plant height	0.526**	0.285	0.619**	0.053	-0.003	0.080	-0.001	-0.052	-0.060
Flowering		0.596**	0.645**	-0.044	-0.123	-0.075	-0.186	-0.117	-0.134
Fruiting			0.381*	0.501**	0.481*	0.485*	0.410*	-0.083	-0.133
Canopy				-0.070	-0.159	-0.130	-0.226	-0.149	-0.120
Fr/plant					0.979**	0.898**	0.896**	-0.359	-0.342
Mrt Fr/plant						0.881**	0.916**	-0.336	-0.348
Total fr (kg/ha)							0.971**	0.067	0.074
Mrk fr (kg/ha)								0.016	0.026
Fr wt/tom									0.965**

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Yield contributing characteristics of tomato

The flowering aspects in crops are important in evaluation experiments, as this relates to the expected potential yield, the crop maturity time, and duration. There was a significant difference in the flower cluster formation between the different genotypes (Table 2). Flower formation in tomato in the tropics is a challenge, especially in the wet season. Rainfall has a direct impact on flower production which often hampers the successful fruit setting of crops such as tomatoes (Xu et al. 2023; Chami et al. 2023). Therefore, open field conditions during the wet season in which the genotypes were grown showed that some genotypes, namely AVTO 0102, AVTO 9801, AVTO 9802, FLCS 14, and ALTONNUU were able to produce flowers within 30 DAT successfully but failed to progress towards the fruit setting stage. There was no significant difference in the number of days required for 50 % fruit setting among the nine tomato genotypes though some of the genotypes produced flower much earlier. Moreover, four genotypes, AVTO9801, AVTO9802, AVTO102, and AVTO1424, developed more flowers than others.

Heavy rain causes abortion of fruit development and in some cases, the dropping off or washing away of pollen (Jain et al. 2023; Tazeem et al. 2023). This caused delay in fruit formation until 44 DAT except Raising sun #2 while the flowering started in all the genotypes at 30 DAT. The highest number of fruits set per plant in AVTO9801 at 58 DAT is an early indication of the fruit setting ability of genotype during the off-season conditions they were grown in, while AVTO9304 had the least number of fruits per plant. The successful formation of fruits is also attributed to pollen viability of a particular genotype to various field conditions (Pravallika and Parveen, 2023).

There are successive different processes involved with growth during fruit ageing, and there is an expectation for responses to fluctuating towards environmental variations, including rainfall and temperature (Bhandari et al. 2021; N'dakpaze 2022). The genotypes AL946, AVTO9801 and FLCS14 produced significantly higher number of fruits per plant compared to the remaining six genotypes. This reflects the different plant forms, physiology and growth circumstances between the genotypes (Banoo et al. 2024). The fruiting characteristics of a tomato plant can significantly be altered by the genotype (Breniere et al. 2024) which explains the differences in the number of fruits produced per plant between the genotypes.

The genetic improvement of various tomato genotypes through hybridization can enable the development of tomato with increased fruit quantity and quality (Pereira et al. 2024). Raising Sun #2 genotype produced the biggest and heaviest fruit for both the fresh yield and marketable yield, next was ALTONNUU (Fig. 6). The other 7 genotypes were produced significantly lesser fruits, although no significant difference was reported between them. There is a direct effect of plant growing conditions and adverse environmental factors as excessive rainfall and temperature fluctuation on fruit number, fruit size, and tomato fruit quality (Sotelo-Cardona et al. 2021; Penchovsky and Kaloudas, 2023). The weight of fresh fruit was significantly influenced by genotype differences where the higher weight of fresh fruit was directly correlated to larger fruit sizes (Tables 3 and 4). The tomato genotypes that with low number of fruits produced larger fruit sizes, as Raising Sun #2, whilst those that produced slightly smaller sized fruits produced a greater number of fruits per plant, to compensate for their smaller size (Nguyen et al. 2024).

Pest and Diseases

The tomato trial reported no pests, however, the USP Alafua Farm Manager (Oliver, 2018) revealed that they had been applying several chemical pesticides during that year in the location, and the surrounding vicinity where the trial was established. This could account for the absence of pests throughout the duration of the experiment. There were three diseases observed to affect the tomato genotypes in the trials, namely leaf mould, bacterial wilt, and fruit rot. The level of tolerance or resistance to the 3 diseases amongst the genotypes is reflected through the significant difference in disease incidences observed on the tomato plants (Fig. 4).

Leaf mould (Passalora fulva) is a common and severe leaf disease of tomatoes in the tropical countries including Samoa, and it occurs throughout the year wherever tomatoes are grown. The mould causes a fruit yield reduction of more than 50%. The first symptoms appear on the older leaves several weeks after plants have started to flower. Light, yellow-green blotches appear on the upper leaf surface, while a grey-green fluffy mould is visibly appearing on the lower leaf surface. As the disease develops, the leaves turn yellow, then brown, and finally, they dry up (Ally et al. 2023). Although leaf mould infection in tomatoes is common in Samoa, the humid and wet conditions further aggravated the infection and spread of the disease during the research trial. Since it was untreated, the severity of the infection was moderately high. Even though the genotype AL946 recorded the highest leaf mould disease incidence, the effect was significantly identical to genotypes AVTO9304, AVTO9801, and FLCS14 (Fig. 4). Moreover, apart from AL946, leaf mould disease incidence recorded for other genotypes was significantly identical. Fortunately, although leaf mould can be severe if left untreated, it is highly manageable with early detection and application of the correct fungicide at recommended dosages (Panthee et al. 2004).

Tomato bacterial wilt is caused by a bacterium (Ralstonia solanaceum) and is one of the most destructive plant diseases in the tropical and subtropical areas of the world. The bacteria multiply in the plants and block water flow in the vessels which causes the plants to wilt and die (Soesanto et al. 2023; Lee et al. 2021). There are no effective chemical controls for bacterial wilt, the use of resistant genotypes and crop management which promotes sanitation, hygiene, and crop rotation is recommended (Ma et al. 2023; Wamani et al. 2023). This disease is difficult to control and can incur a yield loss of up to 80-100 % (Wamani et al 2023), making the disease a serious threat to tomato cultivation in Samoa. The disease incidence level of bacterial wilt disease was low throughout all nine genotypes, even the weather was favourable for this disease development (Fig. 4). This indicates that most of the studied genotypes had some degree of resistance to bacterial wilt. The genotype AL946 recorded a significantly higher disease incidence compared to all the other eight genotypes, while AVTO9801 was found without any infection of bacterial wilt, indicating that it is fully resistant to bacterial wilt.

Anthracnose fruit rot is a soil-borne disease that affects ripe tomato fruits. Infections go unnoticed on immature fruit but as fruit ripens, depressed circular water-soaked spots appear on red fruit (Singh et al. 2023). Anthracnose of tomatoes is caused by Colletotrichum species which eventuates to post-harvest decay hence having an impact on the marketability of fruits (Peralta-Ruiz et al 2023; de Oliveira et al 2023). Prevention of fruit rot is highly recommended, which can be achieved by proper land preparation, provision of good aeration and drainage in the soil, crop rotation, and healthy planting materials (Ma et al. 2023; Hebbar et al. 2023). Fruit rot incidence level was also recorded as very low, with the genotype AVTO102 being significantly higher than the others. There were no symptoms of fruit rot infection in genotypes AVTO9802, AVTO9304, AVTO9802, AL946, ALTONNUU and Raising Sun, indicating that all these genotypes are mostly resistant to fruit rot.

Yield

The productivity index of any tomato plant is dependent on the potential of the genotype used and the timely availability of resources (Lemma et al. 2024). Hence, the variation in growth and yield of genotypes is directly linked to the physiological process which in turn is controlled by the interactions between the genetic makeup of that genotype and the environment (Ullah et al. 2023; Delgado-Vargas et al. 2023; Vijayakumar 2023). In addition, cultivars could fulfill their genetic potential for yield and quality only under optimal conditions (Yaşar, 2023). A significant yield variation among the nine tomato genotypes was noted, for the fresh yield, as well as marketable yield. This is due to the difference in their genetic makeup, as they all were exposed to the same growing conditions. The tomato genotype AL946 produced the highest yield, significantly higher than genotypes AVTO1424 and AVTO9304 (Table 3). There was no significant difference between AL946 and the remaining 6 genotypes, including the reference, describing the response these genotypes have according to their genetic makeup and the growing conditions they are exposed to. The marketable yield of genotype AL946 was also significantly higher than genotypes AVTO1424V, AVTO9304, and AVTO102 (Table 3). There was no significant difference noted between AL946 and the remaining 5 genotypes assessed. However, the genotypes AVTO9801, AL946, and FLCS14 yielded 30.1, 35.3, 36.9 %, and 47.6, 16.5 and 29.5 % higher fresh and marketable yield respectively compared to the reference ALTONNUU. This suggests that these genotypes, particularly AVTO9801 and AL946, are promising for Samoa. The comparatively low yield of all the genotypes may be attributed to the unfavourable rainy weather conditions when the experiment was conducted. In addition, no chemical fertilizers were applied here. Tomato was cultivated here like the farmers' practice in Samoa, only based on inherent soil fertility with some application of manure. This is already reported that the yield and production of tomatoes are very limited in Samoa during the off-season (wet season) (MAF, 2015).

Growing Degree Days

Even though there is a significant difference in the calculated total GDD for the nine genotypes (P<0.05), there is not much variation when comparing all the genotypes (Table 5). This achieved variation was mainly due to the GDD variation in the flowering stage. The genotypes AL946 and AVTO9304 require more GDD to reach 50 % flowering compared to AVTO9802, and there is no significant difference in comparison to the remaining six genotypes. Moreover, there is no significant difference in GDD between AVTO0102, AVTO9801, AVTO1424, FLCS14, ALTONNUU, and Raising #2 when compared to the remaining three genotypes (AL946, AVTO9304 & AVTO9802). The range was the lowest for genotype AVTO9802 at 1098 GDD while the highest at 1458 GDD for genotype AVTO9304. The abovementioned GDD is in the close range (1208.9 – 1307.9 GDD) of GDD previously reported for tomato trials from transplanting to maturity for processing (Chami, et al. 202; Anrea et al., 2009). On the other hand, research conducted in 2019 reported GDD of tomatoes ranged from 769 to 1563 from planting to maturity, depending on the time of the year (Rubanga and Shimada, 2019). This range of GDD is comparable to the GDD reported for the nine tomato genotypes. However, in 2007 tomato trials reported the requirement of 1500 – 2000 GDD units (Papparizos and Matzarakis, 2017), which was a little more than the GDD recorded here for the nine tomato genotypes Usually, tomato requires 1600 to 1850 GDD from planting to maturity depending on the tomato variety (Samani, 2014).

CONCLUSION

Tomato is an important crop for Samoa due to its economic and nutritional value. The research trials showed that AVTO9801 is the suitable genotype, in terms of disease incidence, yield capacity, and GDD. The genotype AVTO9801 reported no disease while other genotypes showed bacterial wilt, leaf moulds, and fruit rot disease infections. At 93 DAT, AVTO9801 recorded the highest average number of fruits harvested per harvest. However, in terms of the average weight of fruits per harvest, AVTO9801 recorded the second-highest average weight, after the genotype Raising Sun #2. This suggests that flowering and fruiting stages can withstand rainy conditions. The AVTO9801 genotype recorded the second-highest fresh and marketable yield and produced small-sized fruit but obtained the best score in the organoleptic test. Even though ALTONNUU displayed potential during the stages of growth and was not affected much by the diseases, it produced an inferior harvest in the number of fruits compared to AVTO9801. A similar assessment should be carried out for the 9 genotypes in the dry season. Moreover, with farmers' increasing access to tunnel house technology in Samoa, it would be worthwhile to repeat the assessment in the dry and wet seasons but having in tunnel house conditions. The crop management aspects would be another good factor to consider when investigating the nutritional requirements, feeding intake of the genotypes, and conventional and/ or organic amendments to the soil.

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