Histological, Nutritional and Yield Responses of Three Tomato Cultivars to *Fusarium oxysporum*-Associated Wilt in Girei, Adamawa State, Nigeria

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Abstract
Vascular wilt caused by Fusarium oxysporum (f. sp. lycopersici) is among the most damaging diseases of tomato, particularly in warm, acidic, sandy tropical soils. Tomato producers in Adamawa State, Northeastern Nigeria, face a critical knowledge deficit concerning the incidence, severity, and nutritional impacts of Fusarium wilt, as well as the comparative tolerance of local cultivars. During the 2026 rainy season, this study surveyed disease occurrence across 12 farms (120 plants) in six communities within Girei Local Government Area (LGA), Adamawa State. The causal fungus was isolated on potato dextrose agar and identified morphologically. Screenhouse (Completely Randomised Design) and field (split-plot randomised complete block) trials evaluated three cultivars (Roma, Dandino, Syria) under inoculated and control conditions. Fruit nutritional composition was determined via AOAC methods, while root and stem histopathology were examined using paraffin histology. Mean disease incidence and severity were 61.2% and 36.7%, respectively, showing no significant variation across communities ($p > 0.05$). Inoculation with F. oxysporum significantly reduced plant growth, flowering, and yield ($p < 0.001$) across both environments. Roma was the most susceptible cultivar, suffering final fruit-weight reductions of 82.5% (field) and 97.1% (screenhouse), alongside severe vitamin C (-61.7%) and vitamin A (-49.9%) losses. Conversely, Syria demonstrated the highest tolerance, exhibiting only a 21.5% screenhouse fruit-weight reduction. Infection also degraded fruit moisture, ash, and protein, increased crude fibre and carbohydrates, and caused severe vascular disruption in roots and stems. These findings support adopting tolerant cultivars like Syria within integrated management strategies.

Keywords: *Tomato cultivar; Fusarium oxysporum; Fusarium wilt; Resistance; Screening*

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most widely cultivated and consumed vegetable crops in the world and an important cash crop in tropical and subtropical regions. Nigeria is one of the world's top tomato producers cultivating almost about 0.5 to 4 hectares of land contributing about 85% of the total tomato production and the leading producer in Sub-Saharan Africa, where over 1.8 million metric tonnes, accounting for approximately 68.4% of

the total tomato production in West Africa (Ibrahim *et al*., 2025). Despite favourable conditions for its cultivation in Nigeria, production is constrained by biotic factors, notably soil-borne fungal pathogens (Ekwomadu and Mwanza, 2023).

Vascular wilt caused by *Fusarium oxysporum* (f. sp. *lycopersici*) is among the most damaging diseases of tomato, particularly in warm, acidic, sandy tropical soils. The pathogen persists for long periods in soil and plant debris as chlamydospores, enters through roots, colonises the xylem and disrupts water transport, ultimately causing yellowing, wilting and plant death (Maurya *et al*., 2019; Rhouma *et al*., 2024). Reported yield losses in susceptible cultivars range from 25% to 55% and may reach 90% under conditions highly favourable to infection (Ziedan, 2022). Control has traditionally relied on soil fumigation and systemic fungicides, but these are costly, can select for resistant pathogen populations and carry environmental and health risks (Reddy, 2010). Host resistance and integrated management are therefore widely regarded as the most sustainable options (Chitwood-Brown *et al*., 2021; Mwaka *et al*., 2026).

Tomato cultivars differ in their reactions to Fusarium wilt, and recent work shows that tolerant genotypes can restrict fungal colonisation within the xylem and maintain growth better than susceptible ones (Šimkovicová *et al*., 2024; Tzionis *et al*., 2025). Infection may also alter the composition of the harvested fruit, for example by reducing dry weight and lycopene while raising sugar content (Adisa *et al*., 2018), and cultivars differ in baseline proximate composition even when healthy (Sanusi *et al*., 2020). Understanding the disease at the levels of field occurrence, whole-plant response, fruit quality and tissue structure is therefore needed to guide cultivar choice and management.

Tomato producers in Adamawa State, northeastern Nigeria, face a critical knowledge deficit concerning the incidence, severity, and nutritional impacts of Fusarium wilt, as well as the comparative tolerance of local cultivars. In the absence of empirical baseline data and an understanding of the underlying vascular tissue pathology, both farmers and extension personnel adopt non-evidence-based management strategies and cultivar selections. Consequently, the region experiences preventable yield deficits, compromised fruit quality, and a persistent dependence on chemical interventions.

While research on tomato Fusarium wilt in Nigeria has extensively explored management interventions (e.g., nanoparticles and chemical inducers) and accession screening for yield and resistance (Ajiwe & Popoola, 2024; Falade & Oyetunji, 2024; Sultan et al., 2024), critical knowledge gaps persist. Specifically, the reviewed literature lacks a multidisciplinary investigation in north-eastern Nigeria that combines on-farm incidence and severity surveys, pathogen isolation, comparative field and screenhouse evaluations of local cultivars, fruit proximate and vitamin profiling post-infection and root and stem histopathological analyses. Little is known about how histological damage relates to whole-plant performance and fruit nutritional quality within the same cultivars, and empirical data from Girei LGA and Adamawa State are notably absent.

Smallholder farmers in Girei LGA rely heavily on tomatoes during both the dry and rainy seasons to supply urban markets in the Yola–Girei area. This study records a baseline measurements of Fusarium wilt incidence and severity across six local communities. It also evaluates three locally available tomato varieties to determine which ones suffer the smallest losses in yield and nutrition when infected, equipping agricultural extension services with practical, local data to advice growers. The study aimed to test how susceptible different tomato cultivars are to vascular wilt and to observe the cellular tissue damage caused by the disease.

Materials and Methods

Study area

The study was conducted in Girei LGA, Adamawa State, Nigeria (Latitude 9° 20' 56.19" N; Longitude 12° 30' 11.42" E; 198.9 m above sea level). The screenhouse and field experiments waere carried out at the Botanical Garden, Department of Plant Science, Modibbo Adama University, Yola, and laboratory work in the departmental laboratory.

Disease survey

A survey was carried out to determine the incidence and severity of vascular wilt disease of tomato grown on farmers' fields within Girei Local Government Area. Six communities were surveyed: *Battare, Wuro Mallum, Wuro Babba, Damare, Geriyo and Labondo*. In each community, 2 farms were inspected for vascular wilt infection, and in each farm, 10 tomato plants were assessed, making a total of 120 tomato plants sampled across the study area. Random sampling techniques were used in the field survey to select infected tomato plants, with the aid of a field guide for tomato disease identification (Aumentado *et al*., 2025). Disease incidence and severity were determined using the following formulae:

Severity (%) = (Infected area of the sample plant / Total area of the sample plant) × 100

Incidence (%) = (Number of infected plants / Total number of plants sampled) × 100. The percentage disease index (PDI) was graded using the following 0–5 disease rating scale (Chiang *et al*., 2017):

0 = no disease symptom;
1 = 1–25% of leaf area showing several dark purplish-brown patches;
2 = 26–50% of leaf area covered;
3 = 51–75% of leaf area covered by streaks;
4 = 76–100% of leaf area covered by streaks;
5 = complete drying of the leaves, or breaking of the leaves from the center.

The Disease Severity Index (DSI) was calculated using the following formula:

DSI (%) = (Total sum of numerical ratings / (Number of observations × Maximum disease rating on the scale)

Isolation and identification of the pathogen

Sterilization of materials

Petri dishes were sterilized in a hot air oven at 160°C for two hours. The inoculation needle and other metallic instruments were sterilized by dipping them in alcohol and heating over a flame. The work table was sterilized using 70% alcohol for 30 minutes.

Preparation of Potato Dextrose Agar (PDA)

The laboratory bench was sterilized with 70% ethanol. Potato Dextrose Agar medium (19.5 g) was weighed out using an electronic weighing balance and dissolved in 300 ml of distilled water. The medium was autoclaved at 121°C for 15 minutes, after which it was allowed to cool to 45°C, and an antibiotic (Chloramphenicol) was added to suppress bacterial growth. The medium was then poured into sterile Petri dishes and left to solidify (Hare, 2013).

Isolation and identification of the fungal pathogen

Five infected tomato stems from each farm were surface-sterilized by dipping in 1% sodium hypochlorite (NaOCl) solution for one minute, then rinsed in five changes of sterile distilled water and placed on sterile paper towels to dry. Small pieces (about 1–2 mm) were cut from the infected area and placed on solidified Potato Dextrose Agar medium, with three replicates per sample. Inoculated plates were incubated at 28±2°C for five days and observed for microbial growth. After five days, the colonies developed were sub-cultured on fresh Potato

Dextrose Agar medium to obtain pure cultures, which were stored in McCartney bottles for further use.

Fungal isolates were identified based on macroscopic morphology and microscopic characteristics using lactophenol cotton blue (LPCB) wet mounts. Briefly, a small portion of each pure culture was teased into a drop of LPCB stain on a clean glass slide, covered with a coverslip without trapping air bubbles, and examined under a compound microscope at 40× magnification."

(Nasser *et al*., 2021). Colony characteristics such as appearance, change in medium color, growth rate, and shape of conidia and conidiophores were observed and matched against standard descriptions in a fungal identification manual (Nasser *et al*., 2021).

Evaluation of the Responses of Tomato Cultivars to Vascular Wilt

Screenhouse evaluation of responses of tomato cultivars to vascular wilt

The screenhouse experiment was laid out in a Completely Randomized Design (CRD) using plastic pots, each with a capacity of 6–7 liters and containing 6.5 kg of sterilized soil. The experiment tested the three selected tomato cultivars, each either inoculated with the pathogen or maintained as a non-inoculated control, giving six treatment combinations, each replicated five times. An apparently healthy stalk of the growing tomato (one stand per pot) was planted in each pot. Inoculated pots were inoculated with 2 ml of spore suspension of *Fusarium oxysporum* using a 2 ml syringe and needle, while control pots received 2 ml of sterile distilled water without conidial suspension. Pots were observed for 30 days for disease symptoms, which were compared with the symptoms originally observed in the field survey (Kumari *et al*., 2026).

Field evaluation of responses of tomato cultivars to vascular wilt

A field experiment was laid out in a Randomized Complete Block Design (RCBD) in a split-plot arrangement, replicated three times. Inoculation status constituted the main-plot factor, with two levels - pathogen-inoculated and non-inoculated (control) - assigned to the main plots to minimize cross-contamination of *Fusarium* inoculum between inoculated and control areas. The three tomato cultivars constituted the sub-plot factor, randomly assigned to sub-plots within each main plot. Standard agronomic practices (land preparation, transplanting, spacing, weeding and irrigation as required) were applied uniformly across all plots. Inoculated main plots were inoculated at the seedling/transplanting stage following the same conidial suspension procedure described for the screenhouse experiment. This field experiment supplied the field-level cultivar-response data, and the infected and non-infected fruit used for the proximate composition analysis, in addition to the pot-based screenhouse trial. Plant height, leaf number, branch number, flower number, fruit set and fruit weight were recorded at 4, 6, 8 and 10 weeks after transplanting and inoculation in both experiments.

Determination of the Proximate Composition of Infected and Non-Infected Tomato

Ripe fruit was sampled separately from inoculated (infected) and non-inoculated (control) plants from the screenhouse and field experiments. Samples were oven-dried, milled into fine powder, and analysed for moisture, ash, crude protein, crude fat, crude fibre, carbohydrate, vitamin A and vitamin C content, following standard analytical procedures (Latimer *et al*., 2023).

Moisture content: Two grams of the sample was weighed into a pre-weighed crucible and dried in a hot-air oven at 105°C to constant weight. Moisture content was calculated from the loss in weight of the sample.

Ash content: Two grams of the sample was weighed into a pre-weighed crucible and incinerated in a muffle furnace at 550°C until a light grey ash of constant weight was obtained. Ash content was calculated from the weight of the residue.

Crude protein: Crude protein was determined by the micro-Kjeldahl method, involving digestion of the sample with concentrated sulphuric acid and a catalyst mixture, followed by distillation of the liberated ammonia into boric acid and titration with standardized hydrochloric acid. The nitrogen content obtained was multiplied by the conversion factor of 6.25 to obtain the crude protein content**.**

Crude fat: Crude fat was determined by continuous solvent extraction of a dried sample with petroleum ether in a Soxhlet extraction apparatus for six hours. The solvent was evaporated off, and the extracted fat was dried and weighed.

Crude fibre: Crude fibre was determined by sequential digestion of the defatted sample with dilute sulphuric acid followed by dilute sodium hydroxide, under reflux. The residue was filtered, dried, weighed, and then ashed, with crude fibre calculated as the loss in weight on ashing.

Carbohydrate content: Carbohydrate content was determined by difference, that is, by subtracting the sum of the percentages of moisture, ash, crude protein, crude fat and crude fibre from 100.

Vitamin A content: Vitamin A content was determined spectrophotometrically after saponification of the sample and extraction of the unsaponifiable fraction, with absorbance read at the appropriate wavelength against a beta-carotene standard curve.

Vitamin C content: Vitamin C (ascorbic acid) content was determined by the 2,6-dichlorophenolindophenol (DCPIP) titrimetric method. A known weight of sample was extracted in oxalic acid solution and titrated against the standardized DCPIP dye solution until a faint pink colour persisted, with the ascorbic acid content calculated from the titre value against a standard ascorbic acid solution.

Histopathological Response of Tomato Cultivars to *Fusarium* Wilt Pathogen

Preparation of tomato for histopathological studies: Normal, healthy and rotted tomato stems and roots were collected from the experimental pots. The stems were washed gently and cut into 1 cm long pieces. Three stem pieces from each treatment were processed for histopathological studies (Yousaf *et al*., 2021) as follows:

Fixation of tissue segments: Fixation is the preservation of cell and tissue constituents to prevent their degradation due to autolysis and putrefaction. The pieces were immersed in a fixative of formalin-aceto-alcohol, prepared by mixing 90 ml of 50% ethanol, 5 ml of glacial acetic acid and 5 ml of 37% formaldehyde. The stems were kept in the fixative for 24 hours.

Dehydration of tissue segments: This step removes the fixative and water from the tissue and replaces them with a dehydrating fluid. The fixed tissue segments were dehydrated stepwise in a series of ethanol solutions of increasing concentration (70%, 80%, 90% and 100%), for one hour in each of the 70%, 80% and 90% concentrations, and two hours in the 100% concentration.

Clearing of tissue segments: Clearing replaces the dehydrating fluid with a fluid that is fully miscible with both the dehydrating fluid (ethanol) and the embedding medium (paraffin wax). Dehydrated tissue was cleared with three changes of xylene, one hour in each change.

Infiltration of tissue segments: Infiltration is the filling of tissue cavities and cells with a supporting medium (paraffin wax). After clearing, the tissue segments were transferred to a container of molten paraffin and kept for one hour. They were then transferred to a second container of melted wax and kept in an incubator at about 65°C for three hours, after which the molten paraffin was poured off and the tissue segments allowed to cool.

Embedding of tissue segments: Embedding surrounds the tissue with a medium such as agar, gelatin or wax, which on solidifying provides sufficient external support during sectioning. Plastic moulds were used, with inner surfaces first coated with a thin layer of glycerin to prevent the wax sticking to the moulds; melted paraffin was then poured into the moulds. Stem pieces were placed gently on the solidifying surface using heated forceps, and more melted wax added until the tissue segments were completely immersed. After hardening, the block was cut into smaller pieces according to the position of the tissue segments.

***Sectioning of tissue segment*s**: Sectioning is the cutting of biological specimens into very thin segments for microscopic examination. The small wax blocks containing the tissue segments were trimmed to remove excess wax, fixed in a microtome, and 10 µm thick transverse and longitudinal sections were cut.

Staining of tissue sections: Staining applies a stain to a sample to colour cells, tissues or metabolic processes to facilitate examination under the microscope. The cut tissue sections were transferred into a watch glass containing 10 ml of water and one drop of Carbolfuchsin stain, and left in the stain for 10 minutes, before being rinsed in running water for 30–40 seconds to remove excess stain.

Mounting of tissue sections: After staining, the tissue sections were placed on slides coated with gum arabic syrup (prepared from 50g gum arabic and 50 g table sugar dissolved in 100 ml of distilled water), and cover slips placed gently over them. Prepared slides were left at room temperature for 24 hours, then placed in a tray in an incubator at 60°C overnight for proper drying of the mounting medium. Slides were then examined under the microscope (low and high power) to observe the tissue sections, with photographs taken as necessary, before being stored in slide boxes.

Microscopic examination: Sections were observed under a compound light microscope at low and high magnification. The cellular changes noted were: Tyloses (balloon-like outgrowths that form from living parenchyma cells of the plant's xylem into the lumen of an adjacent xylem vessel or tracheid; when a plant detects injury, drought stress or infection, often by pathogens such as Fusarium or Verticillium, the parenchyma cells adjacent to the vessel push their cell walls through pits into the vessel's hollow space, appearing under the microscope as rounded plugs blocking the vessel and impeding the movement of water and pathogens through the xylem); cell wall thickening (deposition of callose, a β-1,3-glucan polymer deposited at the plasma membrane–cell wall interface, especially around plasmodesmata and infection sites, which reduces pathogen spread from cell to cell); and necrosis or cell death (Yousaf *et al*., 2021).

Statistical analysis

Data were analysed using IBM SPSS Statistics v27. Disease survey data (Table 1) were analysed by one-way analysis of variance (ANOVA) with community as the factor. Screenhouse and fruit composition data were analysed as a 3 × 2 factorial experiment (cultivar × inoculation) in a completely randomised design with three replicates, and field data as a split-plot randomised complete block design (inoculation as main plot, cultivar as sub-plot) as described by Gomez and Gomez (1984).

Results

Incidence and Severity of Fungal Disease on Tomato in Girei LGA during the 2026 Rainy Season.

Table 1 showed that fungal disease incidence varied among the surveyed locations. Battare recorded the highest disease incidence of 73.33 ± 11.55%, followed by Wuro Mallum with 68.00 ± 10.00%, while Geriyo, Damare, Wuro Babba and Labondo recorded 59.33 ± 15.54%, 56.67 ± 26.63%, 56.67 ± 27.01% and 53.33 ± 12.06%, respectively. Disease severity followed a similar pattern, with Battare and Wuro Mallum recording the highest severity values of 40.93 ± 6.33% and 40.93 ± 3.35%, respectively, whereas Labodoh recorded the lowest severity of 30.93 ± 5.60%. Geriyo, Damare and Wuro Babba recorded 37.47 ± 7.29%, 34.40 ± 14.14% and 35.47 ± 14.80%, respectively. However, the disease incidence was not significantly different among locations ($p = 0.75$) likewise disease severity ($p = 0.77$). The corresponding LSD values of 32.95% for incidence and 17.11% for severity indicate that the observed differences among locations were not large enough to establish statistical separation. Thus, although Battare appeared to have greater disease pressure numerically, the fungal disease was generally widespread across the study area rather than being restricted to a particular location.

Table 4.1: Incidence and Severity of Fungal Disease on Tomato in Girei LGA during the 2026 Rainy Season.

LOCATIONS	Disease Incidence %	Disease Severity %
Battare	73.33±11.55	40.93±6.33
Damare	56.67±26.63	34.40±14.14
Geriyo	59.33±15.54	37.47±7.29
Labodoh	53.33±12.06	30.93±5.60
Wuro Babba	56.67±27.01	35.47±14.80
Wuro Mallum	68.00±10.00	40.93±3.35
P-value	0.75	0.77
LSD	32.95	17.11

Means are not significantly different ($P < 0.05$)

Identification of the Fungus Pathogen

The isolated fungus from the tomato plants was identified *as Fusarium oxysporum*. The fungus was identified based on the patterns of mycelial growth, the colour of the fungal colonies, and the septation of the hyphae. *Fusarium oxysporum* exhibited dense, cottony growth with a pinkish-white surface and rapid growth. Microscopically, it produced septate hyphae and multicellular conidia with three to five septa, features typical of the species responsible for tomato wilt, as shown in Plate 1**.** Identification was morphological; molecular confirmation was not performed.



Front Plate Reverse Plate Micrograph

Plate I: ***Fusarium oxysporum f. sp. lycopersici***

Performance of Control and Inoculated Tomato Cultivars and Percentage Reduction (means) 10 Weeks after Transplanting and Inoculation *Fusarium oxysporum* under Field and Screenhouse Conditions

In both environments, inoculation significantly reduced plant height, leaf number, flower number, fruit set and fruit weight (main effect of inoculation for each trait), and the cultivar × inoculation interaction was significant for each of these traits (Table 2). Differences between inoculated and control plants widened with time and were greatest at week 10, when fruit was produced. Roma was the most affected cultivar. At week 10, Roma plant height fell by 40.6% in the field and 56.2% in the screenhouse, whereas Syria declined by 6.0% and 9.5%. Final fruit weight in Roma declined by 82.5% in the field (876.63 - 153.13 g) and 97.1% in the screenhouse (516.07 - 14.80 g). In Syria, the corresponding losses were 52.8% in the field (1016.17 - 479.92 g) and only 21.5% in the screenhouse (658.70 - 517.23 g). Dandino was intermediate in the screenhouse (59.1% fruit-weight loss) and similar to Syria in the field (48.8%). Fruit-set reductions followed the same ranking: Roma 72.4% (field) and 90.9% (screenhouse), Dandino 39.4% and 44.4%, Syria 19.1% and 15.8%.

Branch number was reduced significantly by inoculation, but the three-way cultivar × inoculation × time interaction was not significant, so branching declined similarly over time. Branching was largely unaffected in Dandino in the field (6.67 vs. 6.67) and in Syria in both environments (≤ 8.7% reduction), but fell by 41.3–53.4% in Roma.

Table 2. Performance of Control and Inoculated Tomato Cultivars and Percentage Reduction (means) 10 Weeks after Transplanting and Inoculating *Fusarium oxysporum* under Field and Screenhouse Conditions

Trait	Cultivars	Field control	Field infected	Field % reduction	Screenhouse Control	Screenhouse infected	Screenhouse % reduction
Height	Roma	57.50	34.17	40.6	62.33	27.30	56.2
(cm)	Dandio	62.47	52.40	16.1	69.37	51.27	26.1
	Syria	70.43	66.17	6.0	80.73	73.10	9.5
Leaves	Roma	36.33	22.67	37.6	42.67	18.67	56.2
(no.)	Dandio	43.67	41.00	6.1	47.00	35.00	25.5
	Syria	50.00	49.33	1.3	55.33	52.00	6.0
Branches	Roma	5.67	3.33	41.3	5.00	2.33	53.4
(no.)	Dandio	6.67	6.67	0.0	6.00	4.33	27.8
	Syria	7.67	7.00	8.7	6.67	6.33	5.1
Flowers	Roma	26.33	13.00	50.6	22.33	9.33	58.2
(no.)	Dandio	30.33	24.33	19.8	27.00	21.00	22.2

	Syria	31.67	29.00	8.4	28.00	28.00	0.0
Fruit set	Roma	19.33	5.33	72.4	14.67	1.33	90.9
(no.)	Dandio	22.00	13.33	39.4	18.00	10.00	44.4
	Syria	22.67	18.33	19.1	19.00	16.00	15.8
Fruit	Roma	876.63	153.13	82.5	516.07	14.80	97.1
weight (g)	Dandio	1003.23	513.73	48.8	635.97	260.03	59.1
	Syria	1016.17	479.92	52.8	658.70	517.23	21.5

% reduction = percentage reduction relative to the control. Inoculation main effect and cultivar × inoculation interaction significant ($p \leq 0.001$) for height, leaves, flowers, fruit set and fruit weight in both environments; the interaction for branches was not significant.

Proximate and vitamin composition of fruit from non-infected (N) and infected (I) Tomato Cultivars

Table 3 demonstrates considerable differences in the proximate and vitamin composition of infected and non-infected tomato fruits. In Dandino, moisture content decreased from 92.98 ± 0.21% in the non-infected fruits to 89.40 ± 0.76% in infected fruits. Roma showed a similar reduction from 92.66 ± 0.12% to 85.14 ± 0.12%, while Syria declined from 93.51 ± 0.14% to 92.96 ± 0.05%. The reduction in moisture in infected fruits, particularly in Roma, may reflect tissue breakdown, membrane damage and loss of cellular water as the pathogen colonizes the fruit tissues. The statistical result confirmed a significant treatment effect on moisture content. Ash content also decreased following infection. Dandino decreased from 0.63 ± 0.01% in the non-infected condition to 0.48 ± 0.01% in the infected condition, Roma decreased from 0.62 ± 0.01% to 0.37 ± 0.02%, and Syria decreased from 0.67 ± 0.01% to 0.64 ± 0.02%. The reduction was most pronounced in Roma, suggesting greater alteration of mineral-associated components in that cultivar. Ash represents the mineral fraction of the fruit, and reductions may result from changes in soluble mineral constituents and metabolic disruption following infection. The overall difference was statistically significant. Crude protein content was consistently reduced by infection. Dandino decreased from 1.08 ± 0.03% in non-infected fruits to 0.78 ± 0.02% in infected fruits, Roma from 1.04 ± 0.03% to 0.59 ± 0.05%, and Syria from 1.14 ± 0.04% to 1.01 ± 0.02%. The greater reduction observed in Roma suggests that the effect of infection on protein metabolism differed among cultivars. The reduction in protein may be associated with fungal utilization of host nutrients, degradation of cellular proteins and changes in nitrogen metabolism during pathogen colonization. The treatment effect was significant.

Crude fat also declined numerically in all three cultivars after infection. Dandino decreased from 0.23 ± 0.01% to 0.19 ± 0.02%, Roma from 0.21 ± 0.01% to 0.17 ± 0.01%, while Syria declined from 0.23 ± 0.00% to 0.21 ± 0.01%. However, unlike most other nutritional variables, the difference in crude fat was not statistically significant. This indicates that infection did not produce a sufficiently consistent alteration in total crude fat to demonstrate a significant treatment effect. Crude fibre showed the opposite trend, increasing after infection in all cultivars. Dandino increased from 1.18 ± 0.02% in non-infected fruits to 1.60 ± 0.01% in infected fruits, Roma from 1.14 ± 0.02% to 2.08 ± 0.07%, and Syria from 1.07 ± 0.03% to 1.23 ± 0.03%. The particularly large increase recorded in Roma indicates greater modification of fruit tissue structure following infection. Such increases may result from changes in the relative composition of structural cell-wall materials as susceptible tissues deteriorate. The effect was statistically significant. Carbohydrate content increased markedly in Dandino and Roma following infection. Dandino increased from 3.90 ± 0.26% to 7.55 ± 0.09%, while Roma increased from 4.33 ± 0.08% to 11.65 ± 0.05%. Syria showed a smaller increase from 3.73 ± 0.10% to 3.95 ± 0.03%. The statistical analysis showed significant treatment effect. The increase may reflect changes in the relative concentration of soluble carbohydrates as other components are metabolized or degraded during infection, as well as pathogen-induced

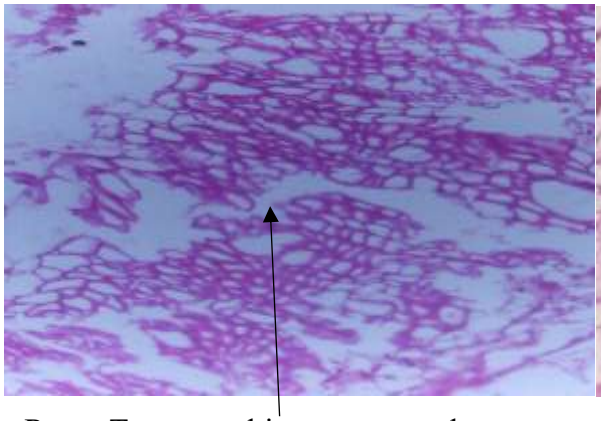
alterations in host carbohydrate metabolism. Vitamin C was markedly reduced by infection. Dandino declined from 17.76 ± 0.43 mg/100 g to 11.25 ± 0.53 mg/100 g, Roma from 17.32 ± 0.36 mg/100 g to 6.64 ± 0.28 mg/100 g, and Syria from 22.50 ± 0.35 mg/100 g to 19.78 ± 0.64 mg/100 g. Roma therefore exhibited the greatest reduction in vitamin C following infection. This decline may be associated with oxidative stress caused by pathogen invasion, since ascorbic acid participates directly in antioxidant defense and may be consumed during the plant's response to oxidative stress. The effect was significant. Vitamin A showed a similar response. Dandino declined from 451.87 ± 9.94 µg/100 g in non-infected fruits to 342.30 ± 1.64 µg/100 g in infected fruits. Roma decreased from 435.30 ± 5.24 µg/100 g to 218.20 ± 1.93 µg/100 g, while Syria decreased from 510.33 ± 1.06 µg/100 g to 485.53 ± 5.55 µg/100 g. The particularly strong reduction in Roma indicates substantial alteration of vitamin-related compounds during infection. The overall effect was significant. These results demonstrate that *F. oxysporum* infection can substantially alter the nutritional quality of tomato fruits, with the magnitude of the effect varying according to cultivar and nutrient component.

Histopathology

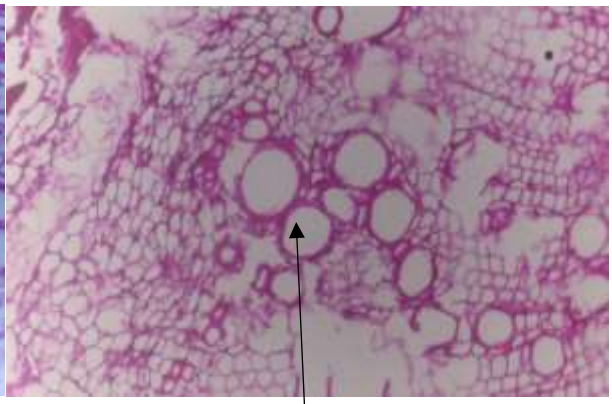
Healthy roots and stems of all three cultivars showed organised cells with defined walls, distinguishable vascular tissue and continuous, regularly oriented longitudinal elements. Infected tissues showed cell separation, distortion, enlarged intercellular spaces, areas of dense staining and loss of continuity in the vascular region. Infected Syria roots showed compression and distortion around a densely stained central region, and infected stems showed larger spaces between cells. Infected Roma roots showed uneven, distorted cells around prominent vessel-like structures, and infected stems showed expanded or separated cells, densely stained central tissue and fragmentation. Infected Dandino roots showed marked tissue separation and a disturbed, darkly stained region, while infected stems retained some longitudinal organization but had gaps and irregular boundaries. The observations were qualitative and were not scored.

Table 3: Mean proximate and Vitamin Composition of three Tomato Cultivars under *Fusarium oxysporum* Inoculated and Non-Inoculated (control) Treatments.

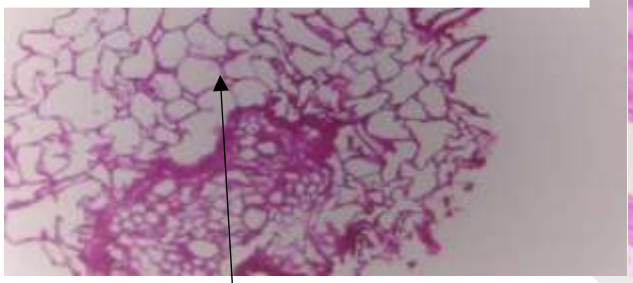
Cultivars		Moisture (%)	Ash (%)	Crude Protein (%)	Crude Fat (%)	Crude Fiber (%)	Carbohydrate (%)	Vitamin C (mg/100g)	Vitamin A (µg/100g)
Dandino	Infected	89.40±0.76	0.48±0.01	0.78±0.02	0.19±0.02	1.60±0.01	7.55±0.09	11.25±0.53	342.30±1.64
	Non-infected	92.98±0.21	0.63±0.01	1.08±0.03	0.23±0.01	1.18±0.02	3.90±0.26	17.76±0.43	451.87±9.94
Roma	Infected	85.14±0.12	0.37±0.02	0.59±0.05	0.17±0.01	2.08±0.07	11.65±0.05	6.64±0.28	218.20±1.93
	Non-infected	92.66±0.12	0.62±0.01	1.04±0.03	0.21±0.01	1.14±0.02	4.33±0.08	17.32±0.36	435.30±5.24
Syria	Infected	92.96±0.05	0.64±0.02	1.01±0.02	0.21±0.01	1.23±0.03	3.95±0.03	19.78±0.64	485.53±5.55
	Non-infected	93.51±0.14	0.67±0.01	1.14±0.04	0.23±0.00	1.07±0.03	3.73±0.10	22.50±0.35	510.33±1.06
P-value		0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00
LSD		0.23	0.01	0.05	0.02	0.06	0.22	0.80	9.32



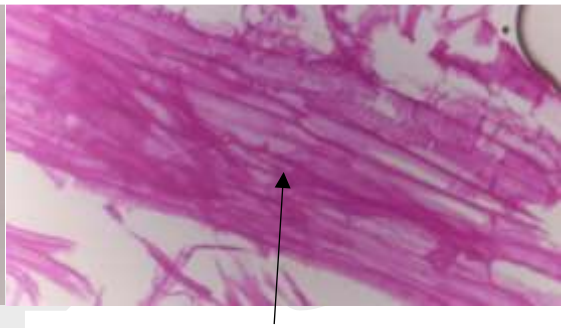
Roma Tomato cultivar root sample showing infected tissues damaged by *Fusarium oxyporum*



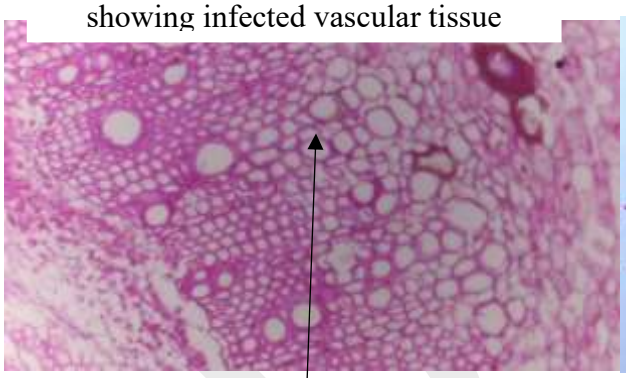
Roma Tomato cultivar root sample showing uninfected tissue, not damaged



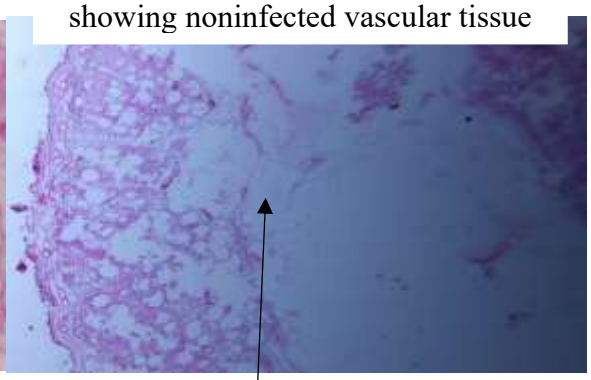
Dadinio tomato cultivar stem sample showing infected vascular tissue



Dadinio tomato cultivar stem sample showing noninfected vascular tissue



Syria Tomato cultivar stem sample showing uninfected (control sample)



Syria Tomato cultivar stem sample showing infected tissue damaged by *Fusarium oxyporum*

Discussion

Disease occurrence and pathogen identity

Wilt was present in every surveyed community at moderate-to-high incidence (mean 61.2%), and the absence of significant differences among communities indicates widespread inoculum rather than a localised outbreak. Numerically higher values in Battare and Wuro Mallum may reflect differences in moisture, sanitation, cultivar mix or cropping history, factors known to modulate disease expression within a production region, but these cannot be separated with the present sampling (two farms per community). The wide standard deviations also limit statistical power. Nigerian studies similarly show that Fusarium wilt expression depends strongly on host genotype and environment (Ajiwe and Popoola, 2024; Sultan *et al*., 2024). The isolate's cottony pink-white colonies, septate hyphae and multiseptate conidia are the standard

diagnostic features of *F. oxysporum* from tomato (Rhouma *et al*., 2024). However, morphology cannot confirm the species or race, so molecular identification (e.g., *TEF-1α* sequencing and *SIX*-gene or race-specific PCR) is needed before the isolate is named *F. oxysporum* f. sp. *lycopersici*.

Cultivar responses

The reductions in height, leaf number, flowering, fruit set and fruit weight are consistent with xylem colonisation, which restricts water and mineral transport, lowers photosynthetic capacity and reduces assimilate available for reproduction (Mwaka *et al*., 2026; Rhouma *et al*., 2024). The ranking Syria > Dandino > Roma was consistent across traits and environments, and the significant cultivar × inoculation interaction shows that the cultivars did not respond equally. Cultivar-dependent responses are well documented in Nigeria (Falade and Oyetunji, 2024; Sultan *et al*., 2024) and elsewhere, where partially resistant genotypes maintain growth and biomass under inoculation through stronger immune responses (Khan *et al*., 2026; Tzionis *et al*., 2025). Effects were generally larger in the screenhouse where uniform conditions and placement of inoculum favour infection, than in the field, where soil heterogeneity can dilute inoculum effects. An important condition is that in the field Syria and Dandino lost a similar proportion of fruit weight (about 49–53%), so Syria's advantage in yield retention was clear only in the screenhouse, and its field fruit-weight data were highly variable (SD = 272.88 g). Branching was less sensitive than other traits; Dandino's branching was unchanged, suggesting that lateral shoot initiation can continue while vascular stress reduces flowering and fruit set. Because the responses were measured on three cultivars from one season and one isolate, "tolerance" is the more defensible term than "resistance", and the results should not be treated as proof of genetic resistance.

Effects on fruit nutritional quality

Lower moisture, ash, protein, vitamin C and vitamin A in fruit from infected plants indicate that wilt reduces nutritional as well as marketable value. Reduced vitamin C is plausible because ascorbate is consumed in detoxifying reactive oxygen species during pathogen attack, and similar changes in antioxidants have been reported in Fusarium-challenged tomato (López-Pérez *et al*., 2024) and in diseased fruit (Javed *et al*., 2024). Lower protein agrees with reports of Attia *et al*. (2022) who reported reduced soluble protein in infected tomato and with altered nitrogen metabolism. The increases in crude fibre and carbohydrate differ from the reduced carbohydrate reported in vegetative tissues by Attia *et al*. (2022). Carbohydrate was computed by difference, so it rises mechanically when moisture and protein fall, and fibre and carbohydrate on a fresh-weight basis can increase as water is lost. Expressing results on a dry-matter basis and measuring soluble sugars and lycopene directly would clarify whether true compositional shifts occurred (Adisa *et al*., 2018). The cultivar-dependent magnitude, with Roma most affected and Syria least, mirrors the growth data and suggests that tolerant cultivars protect fruit quality as well as yield, although baseline differences between cultivars also contribute (Sanusi et al., 2020).

Histopathology

Infected tissues showed separation, distortion and densely stained regions in the vascular area, consistent with previous histological descriptions of vascular occlusion, accumulation of gels and phenolics, tylose formation and tissue breakdown in Fusarium-infected tomato (Yousaf *et al*., 2021; Rhouma *et al*., 2024), and with studies showing genotype-dependent vascular damage (Sikandar *et al*., 2024; Šimkovicová *et al*., 2024). Several limits apply. The study did not specifically identify or quantify fungal hyphae, tyloses, or vascular plugs. Additionally, tissue voids can be caused by sample processing, and carbolfuchsin lacks the specificity to

differentiate fungal structures. The differences among cultivars therefore remain qualitative, therefore quantitative vessel-occlusion scoring and fungal-specific staining is needed strengthen this component.

Conclusion

Fusarium wilt associated with *F. oxysporum* is widespread in tomato fields in Girei LGA. Inoculation reduced plant growth, flowering, fruit set and fruit weight, and lowered fruit moisture, protein, ash, vitamin C and vitamin A, with significant cultivar differences. Roma was most susceptible, Syria showed the highest tolerance in most traits, and Dandino was intermediate. Infection was accompanied by structural damage to root and stem tissues. Farmers in the area should prioritise cultivars such as Syria within integrated management that includes sanitation, healthy planting material and laboratory-confirmed diagnosis. Further work should confirm the pathogen molecularly, screen more cultivars across seasons and sites, quantify tissue damage and test integrated control options.

Conflicts of Interest

The authors declare no conflicts of interest about the publication of this paper.

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