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THE DEVELOPMENT OF AARI GINGER-23: FIRST GINGER VARIETY OF PAKISTAN SUITABLE FOR TUNNELS CULTIVATION

Original Article

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ABSTRACT

Background: Ginger production in Pakistan remains limited due to poor adaptability of available genotypes, low yield stability, and susceptibility to biotic and abiotic stresses, resulting in heavy reliance on imports. The development of locally adapted, high-yielding ginger varieties with acceptable quality and resistance traits is therefore essential to strengthen domestic production, improve farmer profitability, and support the medicinal and spice value chain.

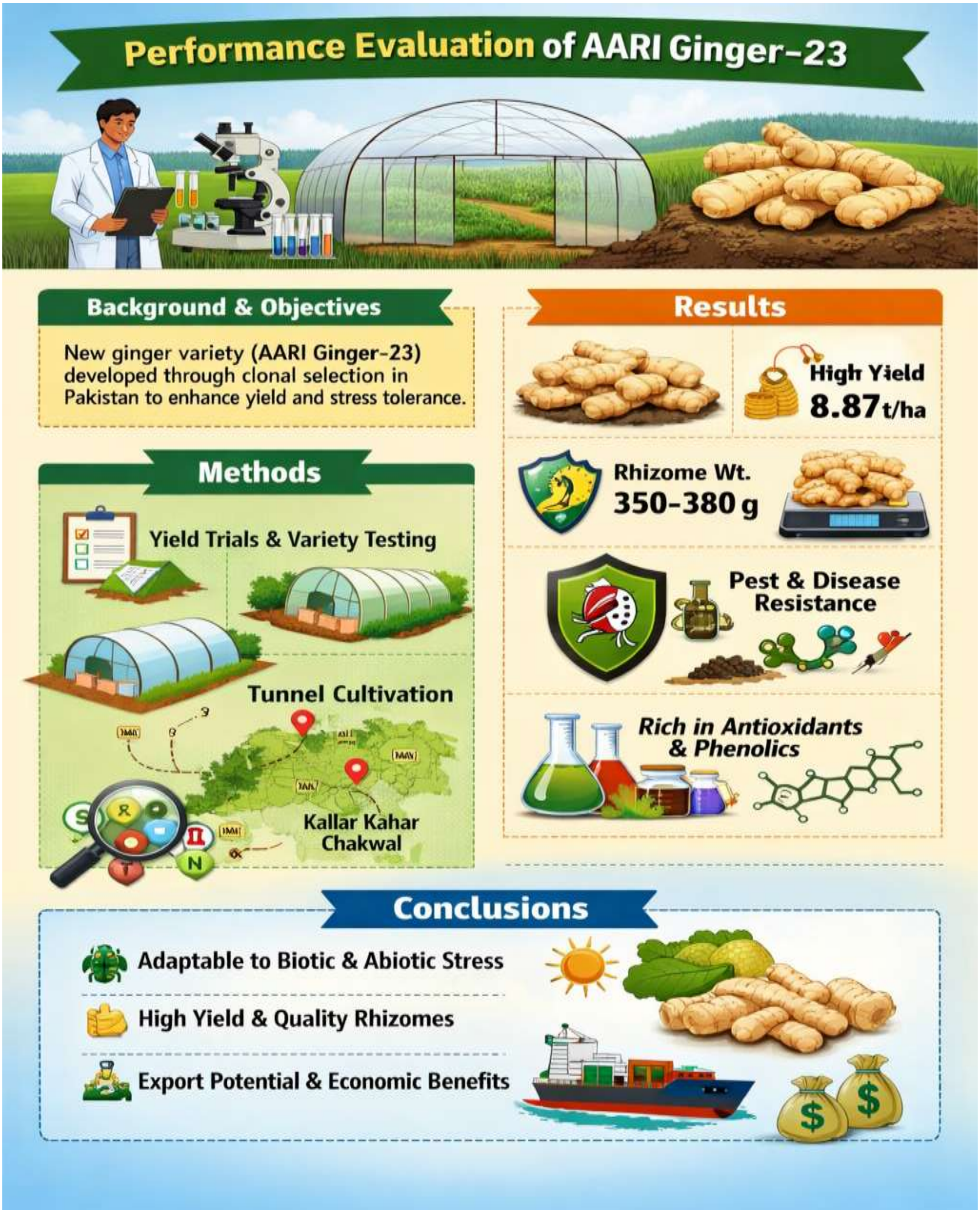
Objective: To evaluate the agronomic performance, adaptability, and quality attributes of a newly developed ginger variety, AARI Ginger-23 (VGC-19005), under experimental stations and farmer field conditions in Punjab, Pakistan.

Methods: AARI Ginger-23 was developed through clonal selection from exotic germplasm and evaluated in replicated varietal yield trials from 2020 to 2023. Trials were conducted under tunnel cultivation at the Vegetable Research Institute, Faisalabad, and across multiple locations including Kallar Kahar and Chakwal. Agronomic traits such as yield and average rhizome weight were recorded. Nutritional and biochemical analyses included dry matter, crude protein, crude fat, fiber, ash, carbohydrates, and antioxidant activity (DPPH). Pathological and entomological observations were also documented.

Results: AARI Ginger-23 consistently exhibited superior performance, producing yields up to 8.87 t/ha at Faisalabad and multi-location averages reaching 16.4 t/ha, with average rhizome weights ranging from 350–380 g. The variety showed smooth, straight rhizomes with yellowish-white skin and light-yellow flesh. Nutritional profiling revealed crude protein of approximately 9.8–10.0%, crude fat up to 5.97%, crude fiber around 4.5%, and antioxidant activity nearing 75% (DPPH). No serious insect pest or disease incidence was recorded during evaluation.

Conclusion: AARI Ginger-23 demonstrated high yield potential, adaptability, and favorable nutritional and quality traits under Punjab conditions, indicating its suitability for commercial cultivation and its potential role in reducing ginger imports while supporting medicinal and export markets.

Keywords: Adaptation, Antioxidants, Ginger, Rhizome Yield, Spices, Varietal Trials, Zingiber officinale.


Performance Evaluation of AARI Ginger-23
Background & Objectives
New ginger variety (AARI Ginger-23) developed through clonal selection in Pakistan to enhance yield and stress tolerance.
Methods
Yield Trials & Variety Testing
Tunnel Cultivation
Kallar Kahar
Chakwal
Results
High Yield
8.87 t/ha
Rhizome Wt.
350-380 g
Pest & Disease Resistance
Rich in Antioxidants & Phenolics
Conclusions
Adaptable to Biotic & Abiotic Stress
High Yield & Quality Rhizomes
Export Potential & Economic Benefits

INTRODUCTION

Ginger (*Zingiber officinale* Rosc.) is a perennial herbaceous plant of the family Zingiberaceae, a botanical group that also includes economically and medicinally important species such as turmeric and cardamom. Although cultivated worldwide as an annual crop, ginger has no known wild progenitor, and its precise origin remains uncertain; however, historical and ethnobotanical evidence strongly suggests South-East Asia or the Indian subcontinent as its center of domestication (1). Commonly known as "Adrak" in Pakistan and India, ginger has long occupied a dual role as both a culinary spice and a medicinal plant, making it relevant not only to agriculture but also to nutrition, public health, and pharmacological research. The edible portion of ginger is its rhizome, an underground stem whose growth and biochemical composition are closely influenced by soil and environmental conditions. Fresh ginger rhizomes typically contain high moisture levels (75–90%) with modest dry matter content, alongside appreciable amounts of crude protein, fiber, and ether extracts (2,3). These compositional traits underpin its widespread use in diverse forms—fresh, dried, pickled, candied, preserved, and powdered—and explain its value in the food industry for flavoring beverages, confectioneries, and processed foods (4). The characteristic pungent aroma and taste of ginger are largely attributed to gingerol, the principal bioactive compound, which has attracted significant biomedical interest due to its anti-inflammatory, antioxidant, and anticancer properties. A growing body of experimental and clinical evidence indicates that ginger and its active constituents can inhibit proliferation and induce apoptosis in cancer cells across a wide spectrum of malignancies, including gastrointestinal, breast, prostate, hepatic, and gynecological cancers (5). Beyond oncology, ginger has been used for centuries in traditional medical systems to manage conditions such as nausea, dyspepsia, arthritis, hypertension, migraines, and gastrointestinal motility disorders, reflecting its broad therapeutic relevance (6). Contemporary studies further support these traditional claims, reporting reductions in exercise-induced muscle pain and highlighting the synergistic antioxidant effects of gingerols, beta-carotene, caffeic acid, and salicylates present in the rhizome (7,8). This convergence of traditional use and modern biomedical validation underscores ginger's importance as a functional food with medicinal potential.

Despite its global significance, ginger production remains unevenly distributed. Worldwide cultivation spans over 440,000 hectares with an annual production approaching 4.9 million tons, dominated by countries such as India, Nigeria, and China (9). In stark contrast, Pakistan contributes a negligible share to global production, ranking far behind major producers and relying heavily on imports to satisfy an estimated annual domestic demand of 85,000 tons (10,11). This dependency places a substantial financial burden on the national economy, with import expenditures exceeding ten billion PKR annually (12). Agronomic challenges, including climatic sensitivity, narrow genetic diversity due to vegetative propagation, and the lack of improved cultivars, further constrain local production. In Pakistan, ginger is cultivated only as a minor crop under specific agro-climatic conditions, requiring warm temperatures, high humidity, well-drained fertile soils, and carefully managed inputs of organic matter and fertilizers. Although research institutions have demonstrated that ginger can be successfully grown under protected conditions using drip irrigation and shading nets, open-field cultivation remains vulnerable to climatic variability and disease pressure. The recent development of an advanced ginger line (VGC-19005; AARI Ginger-23) with moderate resistance to fungal and bacterial diseases represents a promising step toward addressing these constraints, yet empirical evidence on its agronomic performance and potential contribution to reducing import dependence remains limited. Against this backdrop, a critical research gap exists regarding the integration of ginger's agronomic potential with its well-documented medicinal value, particularly within the Pakistani context. There is a need for systematic evaluation of locally adaptable cultivation strategies and improved lines that can enhance yield, quality, and sustainability while supporting the growing demand for ginger as both a dietary and therapeutic agent. Therefore, the objective of the present study is to rationally assess ginger cultivation under local conditions with a focus on productivity, adaptability, and health-relevant attributes, thereby generating evidence that can inform agricultural practices and contribute to national food and medicinal security.

METHODS

The study was conducted as a structured, multi-year agronomic evaluation under the ginger research program of the Vegetable Research Institute (VRI), Faisalabad, which has been actively engaged in ginger improvement since 1971. The research followed an experimental field trial design aimed at developing and validating a high-performing ginger advance line suitable for local agro-climatic conditions. Germplasm collection constituted the initial phase of the study, wherein ginger genotypes of diverse geographical origins—including China, Thailand, India, Burma, and Turkey—were assembled from vegetable markets across Punjab, as well as through imported rhizomes sourced from India and Turkey. All collected materials were subjected to clonal selection procedures, considering ginger's vegetative mode of propagation and absence of true botanical seed. Following initial screening, a promising advance line was developed in 2019 through a clonal selection pathway from exotic material. Seven selected genotypes, including the candidate advance line, were included in preliminary yield evaluation trials conducted during the 2020 growing season at VRI, Faisalabad. Inclusion criteria for genotypes comprised healthy, disease-free rhizomes with uniform size and vigor, while genotypes showing poor sprouting, visible disease symptoms, or severe morphological abnormalities were excluded. Standard agronomic practices recommended for ginger cultivation were uniformly applied across all experimental plots to minimize management-related variability. Subsequently, the superior-performing advance line was further evaluated through preliminary and station yield trials over three consecutive growing seasons (2020–2022) at VRI, Faisalabad. To assess yield stability and adaptability, multi-locational/zonal trials were conducted during 2021 and 2022 at three ecologically distinct sites: the Vegetable Research Institute, Faisalabad; Abbas Fruits and Vegetables Farm, Kallar Kahar; and the Barani Agricultural Research Institute, Chakwal. These locations were selected to represent both irrigated and rainfed agro-ecological zones. Each trial followed a randomized complete block design with appropriate replications, and quantitative traits such as total rhizome yield and average rhizome weight per plant were recorded at physiological maturity using standardized field measurement protocols. Data collection focused exclusively on agronomic performance parameters, and no human or animal subjects were involved. Consequently, formal institutional review board (IRB) approval and informed consent procedures were not applicable, as the study fell under routine agricultural field experimentation and varietal evaluation. Nevertheless, all experimental activities were conducted in compliance with institutional research guidelines and national agricultural research standards. Statistical analysis was performed using second-order statistical procedures to compute sums, means, variance estimates, and treatment comparisons. Analysis of variance (ANOVA) was applied to determine significant differences among genotypes for quantitative traits, and treatment means were separated using the least significant difference (LSD) test at the 5% level of significance. All statistical analyses were conducted using Statistix software version 8.1, following standard procedures described by Steel et al. (1997).

RESULTS

Across replicated varietal yield trials at Faisalabad, the candidate advance line VGC-19005 (AARI Ginger-23) consistently ranked among the top-performing entries for rhizome yield and average rhizome weight. In 2020, VGC-19005 ranked first with an average rhizome weight of 313 g and a yield of 6.68 T/ha, followed by VGC-18003 (215 g; 6.54 T/ha) and VGCTc-19007 (324 g; 6.50 T/ha). VGC-17001 produced 163 g average rhizome weight with 6.30 T/ha yield, whereas lower-performing genotypes included VGI-17002 (77 g; 0.89 T/ha), VGB-17000 (71 g; 0.62 T/ha), and VGT-18004 (104 g; 0.60 T/ha). The least significant difference values reported for 2020 were 0.16 for average rhizome weight and 0.02 for yield. In 2021 station yield evaluation at Faisalabad, VGC-19005 again ranked first with an average rhizome weight of 331 g and yield of 9.78 T/ha. VGC-18003 followed closely (330 g; 9.6 T/ha), while VGC-17001 ranked third (266 g; 8.3 T/ha) and VGTy-19006 ranked fourth (258 g; 7.8 T/ha). Additional genotypes recorded yields of 6.6 T/ha with 238 g (VGC-21011), 5.9 T/ha with 194 g (VGC-21010), 4.3 T/ha with 164 g (VGT-18004), and 4.2 T/ha with 130 g (VGI-17002). The least significant difference values for 2021 were 5.62 for average rhizome weight and 0.13 for yield. In 2022 at Faisalabad, eight genotypes were evaluated; yields and average rhizome weights were 9.60 T/ha and 375 g (VGC-21011), 8.87 T/ha and 350 g (VGC-19005), 8.78 T/ha and 380 g (VGC-21010), 8.45 T/ha and 335 g (VGTY-19006), 6.44 T/ha and 140 g (VGT-18004), 5.58 T/ha and 95 g (VGI-17002), 3.75 T/ha and 300 g (VGC-17001), and 3.53 T/ha and 225 g (VGC-18003). The least significant difference value reported for 2022 yield was 0.23, while no least significant difference value was reported for average rhizome weight. In 2023 at Faisalabad, AARI Ginger-2023 (check) produced 8.3 T/ha with 270 g average rhizome weight, followed by VGC-17001 (7.8 T/ha; 268 g), VGC-18003 (6.9 T/ha; 238 g), VGT-18004 (6.3 T/ha; 165 g), VGC-21011 (6.2 T/ha; 179 g), VGTy-19006 (6.1 T/ha; 205 g), VGC-21010 (5.4 T/ha; 237 g), and VGI-17002 (4.3 T/ha; 155 g). The least significant difference values reported for 2023 were 1.3 for yield and 13.5 for average rhizome weight.

Multi-location testing demonstrated substantial variation in performance across sites. In 2021 across Faisalabad, Kallar Kahar, and Chakwal, VGC-19005 recorded 9.80 T/ha and 334 g at Faisalabad, 19.93 T/ha and 1120 g at Kallar Kahar, and 11.37 T/ha and 448 g at Chakwal, resulting in an average of 13.70 T/ha and 634 g. Over the same locations and year, VGTy-19006 recorded 8.28 T/ha and 312 g at Faisalabad, 16.33 T/ha and 992 g at Kallar Kahar, and 10.22 T/ha and 430 g at Chakwal, averaging 11.61 T/ha and 578 g. VGI-17002 recorded 5.92 T/ha and 110 g at Faisalabad, 13.78 T/ha and 498 g at Kallar Kahar, and 6.78 T/ha and 198 g at Chakwal, averaging 8.82 T/ha and 268 g. Least significant difference values reported for 2021 included 0.04 (Faisalabad yield), 3.05 (Kallar Kahar yield), and 0.93 (Chakwal yield), while least significant difference values for average rhizome weight were not consistently reported. In 2022 across Faisalabad, Kallar Kahar, and Chakwal, VGC-19005 recorded 8.92 T/ha and 350 g at Faisalabad, 19.89 T/ha and 1180 g at Kallar Kahar, and 11.64 T/ha and 455 g at Chakwal, averaging 13.48 T/ha and 661 g. VGTy-19006 recorded 8.54 T/ha and 345 g at Faisalabad, 16.27 T/ha and 1030 g at Kallar Kahar, and 10.50 T/ha and 420 g at Chakwal, averaging 11.77 T/ha and 598 g. VGI-17002 recorded 5.78 T/ha and 100 g at Faisalabad, 14.33 T/ha and 520 g at Kallar Kahar, and 6.50 T/ha and 195 g at Chakwal, averaging 8.87 T/ha and 271 g. Additional entries averaged 7.71 T/ha and 435 g (VGC-22014; site-wise: 4.64/285, 12.69/675, 5.82/345) and 7.09 T/ha and 310 g (VGT-22015; site-wise: 3.52/190, 12.48/455, 5.29/285). Least significant difference values reported for 2022 yields were 0.89 (Faisalabad), 0.85 (Kallar Kahar), and 1.58 (Chakwal), while least significant difference values for average rhizome weight were not provided. In 2023 across Faisalabad, Kallar Kahar, Chakwal, and Islamabad, AARI Ginger-2023 (check) recorded 8.0 T/ha and 225 g at Faisalabad, 20.8 T/ha and 913 g at Kallar Kahar, 16.9 T/ha and 428 g at Chakwal, and 20.0 T/ha and 901 g at Islamabad, averaging 16.4 T/ha and 617 g. VGC-21010 recorded 5.4 T/ha and 186 g (Faisalabad), 18.0 T/ha and 843 g (Kallar Kahar), 13.7 T/ha and 330 g (Chakwal), and 15.6 T/ha and 683 g (Islamabad), averaging 13.2 T/ha and 510 g. VGI-17002 recorded 5.5 T/ha and 121 g (Faisalabad), 15.6 T/ha and 510 g (Kallar Kahar), 5.0 T/ha and 120 g (Chakwal), and 14.7 T/ha and 501 g (Islamabad), averaging 10.2 T/ha and 313 g. VGC-21011 recorded 4.9 T/ha and 210 g (Faisalabad), 17.9 T/ha and 816 g (Kallar Kahar), 8.7 T/ha and 208 g (Chakwal), and 17.9 T/ha and 806 g (Islamabad), averaging 12.3 T/ha and 510 g. VGTy-19006 recorded 3.6 T/ha and 205 g (Faisalabad), 18.4 T/ha and 836 g (Kallar Kahar), 15.6 T/ha and 376 g (Chakwal), and 17.0 T/ha and 863 g (Islamabad), averaging 13.5 T/ha and 570 g. Least significant difference values were reported for 2023 by location as 1.3 (Faisalabad yield) and 19.0 (Faisalabad average rhizome weight), 2.7 (Kallar Kahar yield) and 82.5 (Kallar Kahar average rhizome weight), 1.2 (Chakwal yield) and 33.3 (Chakwal average rhizome weight), and 3.8 (Islamabad yield) and 71.2 (Islamabad average rhizome weight).

Nutritional profiling in 2021 across breeding lines, candidate lines, and a market sample demonstrated variability in composition. Dry matter ranged from 24.7% (VGC-18003) to 32.8% (VGI-17002) with moisture from 67.2% to 75.3%. Ash ranged from 5.07% (VGI-17002) to 6.5% (VGC-21010). Crude fat ranged from 4.02% (Ginger China market) to 5.34% (VGTy-21006), while crude protein ranged from 8.4% (VGC-21010 and VGC-22013) to 10.06% (VGC-17001). Crude fiber ranged from 3.11% (Ginger Thailand) to 4.53% (VGC-19005 candidate line). Antioxidant activity by DPPH ranged from 55.9% (VGT-18004) to 77.3% (VGTy-21006), with VGC-19005 recording 74.8% and VGTY-19006 recording 73.3%. Carbohydrate/NFE ranged from 74.5% (VGC-19005) to 78.2% (Ginger China market). In 2022, crude protein ranged from 8.9% (VGT-22015 and VGTy-19006 TCR-23) to 10.52% (VGC-17001); crude fat ranged from 4.01% (VGT-22015) to 5.97% (VGC-19005 candidate line); crude fiber ranged from 3.15% (VGC-08-23023) to 4.64% (VGC-19005 candidate line); ash ranged from 5.39% (VGTy-19006) to 6.95% (VGTy-06-22017); NFE ranged from 73.62% (VGC-22012) to 77.35% (VGT-22015); and moisture ranged from 61.81% (VGC-22013) to 77.94% (VGI-17002). Morphological characterization of AARI Ginger-23 (VGC-19005) described an exotic origin and selection-based development, with adaptation to Faisalabad conditions and a February–March sowing window. Plants exhibited an erect growth habit, 70–80 cm height, medium stem number with 60–70 cm stem length, and absent stem anthocyanin. Leaves were semi-erect, green, approximately 20 cm long and 2 cm wide, with 8–10 leaves on the main stem. Rhizomes were straight with yellowish white skin and light-yellow flesh, medium smooth surface, weak bud anthocyanin, 2–3 sections of medium size, medium sprouting time, and medium harvest time, with a reported yield range of 3500–4000 kg/acre under the described production context. Pathological and entomological observations reported that no serious pathological disease or serious insect/pest attack was recorded on AARI Ginger-2023 (VGC-19005) during the stated evaluations.

Table 1: Performance of Ginger Advance Lines at VRI, Faisalabad (2020–2023)

Year	Rank	Genotype	Average Rhizome Weight (g)	Yield (T/ha)
2020	1	VGC-19005	313	6.68
	2	VGC-18003	215	6.54
	3	VGCTc-19007	324	6.50
	4	VGC-17001	163	6.30
	5	VGI-17002	77	0.89
	6	VGB-17000	71	0.62
	7	VGT-18004	104	0.60

Year	Rank	Genotype	Average Rhizome Weight (g)	Yield (T/ha)
		LSD	0.16	0.02
2021	1	VGC-19005	331	9.78
	2	VGC-18003	330	9.60
	3	VGC-17001	266	8.30
	4	VGTy-19006	258	7.80
	5	VGC-21011	238	6.60
	6	VGC-21010	194	5.90
	7	VGT-18004	164	4.30
	8	VGI-17002	130	4.20
		LSD	5.62	0.13
2022	1	VGC-21011	375	9.60
	2	VGC-19005	350	8.87
	3	VGC-21010	380	8.78
	4	VGTY-19006	335	8.45
	5	VGT-18004	140	6.44
	6	VGI-17002	95	5.58
	7	VGC-17001	300	3.75
	8	VGC-18003	225	3.53
		LSD	–	0.23
2023	1	AARI Ginger-2023 (Check)	270	8.30
	2	VGC-17001	268	7.80
	3	VGC-18003	238	6.90
	4	VGT-18004	165	6.30
	5	VGC-21011	179	6.20
	6	VGTy-19006	205	6.10
	7	VGC-21010	237	5.40
	8	VGI-17002	155	4.30
		LSD	1.3	13.5

Table 2: Multi-Location Performance of Ginger Advance Lines at Faisalabad, Kallar Kahar, and Chakwal (2021–2022)

Year	Sr. No.	Genotype	Faisalabad Yield (T/ha)	Faisalabad ARW (g)	Kallar Kahar Yield (T/ha)	Kallar Kahar ARW (g)	Chakwal Yield (T/ha)	Chakwal ARW (g)	Average Yield (T/ha)	Average ARW (g)
2021	1	VGC-19005	9.80	334	19.93	1120	11.37	448	13.70	634
	2	VGTy-19006	8.28	312	16.33	992	10.22	430	11.61	578
	3	VGI-17002	5.92	110	13.78	498	6.78	198	8.82	268
		LSD	0.04	–	3.05	–	0.93	–	–	–
2022	1	VGC-19005	8.92	350	19.89	1180	11.64	455	13.48	661
	2	VGTy-19006	8.54	345	16.27	1030	10.50	420	11.77	598
	3	VGI-17002	5.78	100	14.33	520	6.50	195	8.87	271
	4	VGC-22014	4.64	285	12.69	675	5.82	345	7.71	435
	5	VGT-22015	3.52	190	12.48	455	5.29	285	7.09	310
		LSD	0.89	–	0.85	–	1.58	–	–	–

Table 3: Performance of Ginger advance line at Faisalabad, Kallar Kahar & Chakwal during 2023

Sr. No.	Genotypes	Faisalabad		Kallar Kahar		Chakwal		Islamabad		Average	
		Yield (T/ha)	ARW (gm.)	Yield (T/ha)	ARW (gm.)	Yield (T/ha)	ARW (gm.)	Yield (T/ha)	ARW (gm.)	Yield (T/ha)	ARW (gm.)
1	AARI Ginger-2023 (Check)	8.0	225	20.8	913	16.9	428	20.0	901	16.4	617
2	VGC-21010	5.4	186	18.0	843	13.7	330	15.6	683	13.2	510
3	VGI-17002	5.5	121	15.6	510	5.0	120	14.7	501	10.2	313
4	VGC-21011	4.9	210	17.9	816	8.7	208	17.9	806	12.3	510
5	VGTy-19006	3.6	205	18.4	836	15.6	376	17.0	863	13.5	570
LSD 0.05		1.3	19.0	2.7	82.5	1.2	33.3	3.8	71.2	-	-

Table 4: Nutritional Analysis of Ginger advance line during 2021

Sample Description	Dry matter %	Moisture %	Ash %	Crude fat %	Crude protein %	Crude fiber %	Antioxident % DPPH	Carbohydrate/ NFE %
VGC-17001	27.5	72.5	5.54	4.48	10.06	4.11	57.3	75.8
VGI-17002	32.8	67.2	5.07	5.02	8.75	3.71	60	77.4
VGC-18003	24.7	75.3	6.28	4.29	9.19	3.13	64.1	77.1
VGT-18004	30.2	69.8	5.24	4.09	9.98	4.01	55.9	76.7
VGC-19005 (Candidate line)	28.2	71.8	5.9	5.28	9.8	4.53	74.8	74.5
VGTY-19006	30.9	69.1	5.47	4.6	9.98	3.42	73.3	76.5
VTGA-19007 (Torch Ginger)	31.2	68.8	6	4.81	9.98	3.94	60	75.3
VGC-20008	28.4	71.6	5.75	4.69	9.45	4.25	73.8	75.9
VGTy-21006 (TCR)	26.2	73.8	5.35	5.34	9.63	3.91	77.3	75.8
VGC-21010	28.4	71.6	6.5	4.93	8.4	3.51	66.9	76.7
VGC-21011	28.2	71.8	6.21	4.65	9.8	4.43	62.6	74.9
VGC-22012	30.5	69.5	5.57	5.13	9.28	3.15	59.2	76.9
VGC-22013	29.8	70.2	6.06	4.4	8.4	4.28	57.9	76.9
Ginger China (market)	31.2	68.8	5.22	4.02	8.93	3.67	63.6	78.2

Table 5: Nutritional Analysis of Ginger advance line during 2022

Sr No	Sample/Description	Crude Protein (%)	Crude Fat (%)	Crude Fiber (%)	Ash (%)	NFE (%)	Moisture (%)
1	VGC-17001	10.52	4.78	4.01	5.87	74.82	73.13
2	VGI-17002	9.12	5.72	3.6	6.19	75.37	77.94
3	VGC-18003	9.8	4.43	3.24	6.62	75.91	72.7
4	VGT-18004	10.05	4.06	4.15	6.56	75.18	64.95
5	VGC-19005 (Candidate Line)	9.96	5.97	4.64	5.44	73.99	69.15
6	VGTy-19006	10.21	4.69	3.68	5.39	76.03	69.29
7	VGC-21010	9.62	5.33	3.27	5.71	76.07	76.01
8	VGC-21011	9.7	4.67	3.54	6.43	75.66	70.46
9	VGC-22012	10.44	5.21	4.04	6.69	73.62	67.47
10	VGC-22013	9.85	5.31	4.38	5.94	74.52	61.81

Sr No	Sample/Description	Crude Protein (%)	Crude Fat (%)	Crude Fiber (%)	Ash (%)	NFE (%)	Moisture (%)
11	VGC-22014	9.78	5.61	4.26	5.55	74.8	75.8
12	VGT-22015	8.9	4.01	3.78	5.96	77.35	69.15
13	VGC-22016	10.22	5.74	4.57	5.42	74.05	67.67
14	VGTy-06-22017 (TCR-22)	9.78	4.17	3.28	6.95	75.82	68.31
15	VGTy-19006 (TCR-23)	8.9	5.52	4.41	6.1	75.07	74.63
16	VGTy-06-23022 (TCR-23)	9.2	4.72	3.89	6.22	75.97	63.32
17	VGC-20008 (TCR-23)	9.6	4.86	3.26	6.83	75.45	70.09
18	VGC-08-23023 (TCR-23)	10.2	4.23	3.15	5.52	76.9	70.71

Table 6: Production Technology of Variety

Parameter	Specification
Seed rate (ha)	2000–2500 kg
Sowing for sprouting	3rd week of February for plains & 1st week of March for Pothohar
Transplanting	3rd week of March for plains & 1st week of April for Pothohar
Tunnel height	7–14 feet
Shading net (Black or Green)	70% for Plains & 50% for Pothohar
Row to Row distance	60 cm
Plant to plant distance	20 cm for plains & 30 cm for Pothohar
Fertilizers (N:P:K) Kg/ha	75:50:50
Irrigation	Drip Irrigation System
Harvesting	December

Table 7: Botanical Description of AARI Ginger-23 (VGC-19005)

Parameter	Description
Origin	Exotic
Breeding method	Selection
Areas of adaptation	Faisalabad
Sowing time	Feb–March

Parameter	Description
Maturity duration	Long
PLANT CHARACTERISTICS	
Growth habit	Erect
Plant height (cm)	70–80 cm
STEM CHARACTERISTICS	
Number of stems	Medium
Stem length (cm)	60–70
Stem anthocyanin	Absent
LEAF CHARACTERISTICS	
Leaf attitude	Semi erect
Leaf color	Green
Leaf length/width (cm)	20/2
No. of leaves on main stem	8–10
RHIZOME CHARACTERISTICS	
Rhizome shape	Straight
Rhizome skin color	Yellowish white
Rhizome surface	Medium smooth
Bud anthocyanin	Weak
No. of sections	2–3
Size of sections	Medium
Flesh color	Light yellow
Sprouting time after planting	Medium
Harvest time	Medium
Yield (kg/acre)	3500–4000

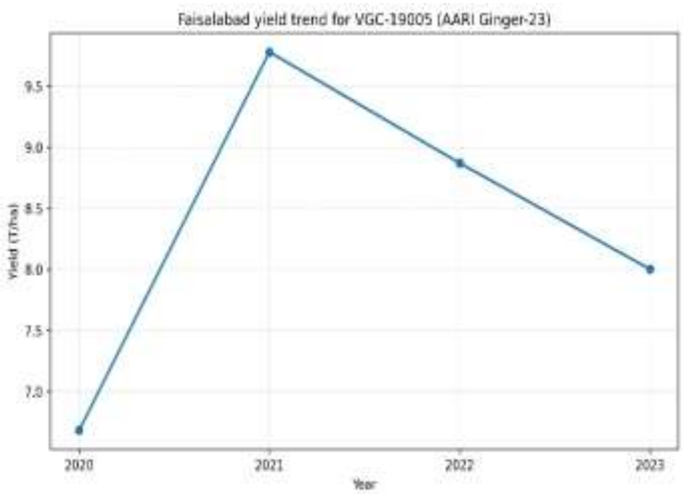


Figure 2 Faisalabad yield trend for VGC-19005 (AARI Ginger-23)

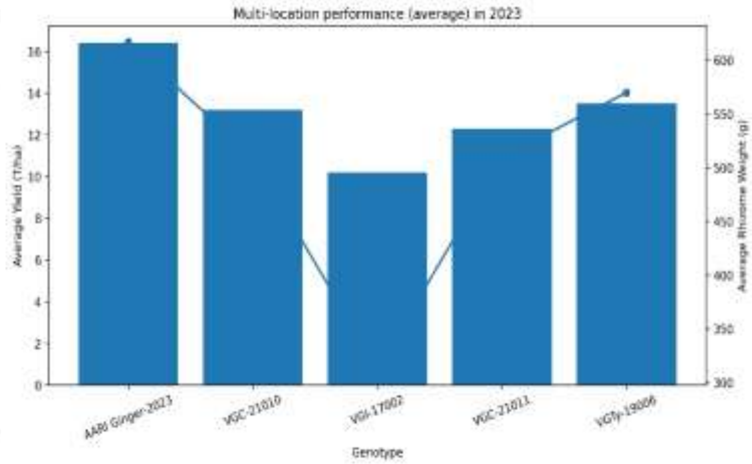


Figure 2 Multi-Location Performance (Average) in 2023

DISCUSSION

The present work contributed evidence that a clonally selected ginger line could be advanced toward varietal use under Pakistani conditions where ginger production remained constrained by narrow genetic diversity, inconsistent field performance, and strong dependence on protected cultivation. The overall pattern of observations aligned with the long-recognized reality that ginger, as a vegetatively propagated crop, often expressed limited genetic recombination but marked phenotypic variability when introduced germplasm was exposed to contrasting environments. This helped explain why performance trends were better understood through multi-season and multi-location evaluation rather than single-site screening, a principle that has also been emphasized in broader crop adaptation research where stability was as important as productivity (13,14). A key implication of these findings was that the candidate line demonstrated characteristics generally regarded as desirable for commercial ginger cultivation, including rhizome traits linked to market acceptability and post-harvest handling. Straight rhizome architecture has been described as advantageous for harvesting efficiency and reduced physical damage during cleaning, grading, and storage, which can translate into lower post-harvest losses in value chains where handling is largely manual (15-17). Similarly, a medium-smooth rhizome surface has been associated with easier cleaning and potentially lower attachment of soil and contaminating material, which may influence storability and perceived quality in fresh markets (18). The yellowish-white skin and light-yellow flesh profile also resembled consumer-preferred appearances in several regional markets, where visual uniformity often determined price premiums and processing suitability (19). These market-facing traits strengthened the practical relevance of the selection pathway, since yield improvements alone rarely resulted in adoption if post-harvest and appearance traits were weak. From a nutritional and functional-food perspective, the observed diversity across biochemical traits reinforced the idea that "high-yielding" and "high-quality" were not always synonymous in ginger breeding lines. Prior work on ginger quality profiles documented wide ranges in dry matter, ash, fat, protein, and fiber among genotypes, with meaningful implications for processing yield, palatability, and dietary value (20). The observed variability in antioxidant potential, commonly measured by DPPH radical scavenging assays, remained consistent with earlier reports that ginger genotypes and related selections could differ substantially in free-radical neutralizing capacity, likely reflecting differences in phenolic content and associated phytochemical composition (21). This supported a trait-based selection logic in which product destination—fresh consumption, drying, or nutraceutical use—should guide breeding priorities rather than relying on a single "best" genotype for all purposes.

The agronomic package proposed for protected cultivation also carried implications for scaling local ginger production in Pakistan. Recommendations such as drip irrigation, specified shade-net intensity, and tunnel structures were consistent with broader protected-cropping strategies used to buffer heat stress, reduce evapotranspiration, and moderate canopy microclimate in sensitive crops. Such approaches were especially relevant for ginger, which generally preferred warm temperatures, high humidity, and stable moisture while remaining susceptible to waterlogging and disease outbreaks in poorly managed conditions. At the same time, protected cultivation introduced cost and management complexity, making adoption uneven among smallholders. This created a practical tension between the promise of improved varieties and the realities of resource-limited farming systems, a debate that remained central to crop intensification efforts in semi-arid regions. A major strength of the work was the multi-year, multi-location trialing approach, which improved confidence that the candidate line's performance was not an artifact of a single season or site. Repeated evaluation under contrasting agro-ecological conditions supported a more credible case for adaptability, and the inclusion of comparative genotypes improved the interpretability of selection outcomes. In addition, the study incorporated morphological characterization and basic nutritional profiling, allowing a broader assessment than yield-only screening. The inclusion of pathology and entomology observations, even as qualitative statements, suggested attention to on-farm feasibility where disease and pest pressure often determined farmer uptake more than performance under ideal conditions.

Several limitations nevertheless restricted the strength of inference and the generalizability of the conclusions. First, the genotype × environment interaction was described as significant, yet the analytical reporting did not include interaction-model outputs, stability statistics, or graphical approaches commonly used to evaluate adaptability across environments. Methods such as AMMI or GGE biplots, alongside variance component estimates, would have clarified whether performance was broadly stable or driven by a small number of favorable sites. Second, replication details, measures of dispersion (e.g., standard errors), and confidence intervals were inconsistently reported, limiting the assessment of precision and the extent to which differences were practically meaningful rather than statistically detectable. Third, disease and pest findings were stated in broad terms without quantitative scoring of incidence or severity; structured plant protection metrics would be essential for varietal positioning, particularly under tunnel and shade-net systems where humidity could raise disease risk. Fourth, the quality evaluation remained incomplete for market and medicinal positioning because direct measures of essential oil yield and key bioactives such as gingerols and shogaols were not reported. Given that the health-related value of ginger largely depended on these compounds, chemical profiling would be necessary to connect agronomic superiority with nutraceutical promise (22,23). Future research would benefit from expanding both the analytical depth and the translational focus. Wider multi-location testing across additional years and farmer fields would better reflect real production constraints and identify management-by-genotype interactions. More rigorous stability analysis should be incorporated to support claims of adaptability across agro-ecological zones (24,25). Chemical and sensory profiling, including gingerol-related markers, essential oil yield, and shelf-life assessment, would allow clearer market segmentation and support value-chain adoption. Disease and pest evaluation should be standardized using incidence/severity scoring, and storage trials should be performed to quantify post-harvest losses under typical supply-chain conditions. Finally, economic analysis comparing protected cultivation costs with yield and quality benefits would strengthen policy relevance and help determine whether the improved line could realistically reduce import dependence in a sustainable manner. Overall, the findings supported the feasibility of advancing a clonally selected ginger line with desirable agronomic and market-aligned traits under Pakistani production systems, while also highlighting the need for deeper stability analytics, standardized plant health evaluation, and bioactive profiling to fully substantiate varietal superiority and guide scaled adoption.

CONCLUSION

VGC-19005 (AARI Ginger-23) demonstrated strong and repeatable agronomic promise under protected and multi-location testing, with desirable rhizome traits and a favorable nutritional profile for both fresh market and processing use. The study supported its suitability for local cultivation systems that aim to improve productivity and reduce reliance on imports. These findings provided a practical foundation for varietal advancement and dissemination, while emphasizing the need for expanded farmer-field validation, standardized disease scoring, and detailed bioactive profiling to strengthen commercialization and health-value positioning.

AUTHOR CONTRIBUTIONS

Author	Contribution
Amir Latif*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Saqib Ali	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing

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	Has given Final Approval of the version to be published
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Ghazanfar Hammad	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Muhammad Iqbal	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Muneeb Munawar	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published
Waseem Abbas	Contributed to study concept and Data collection Has given Final Approval of the version to be published
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