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Comparative Analyses of Different Green Pea Varieties of Pakistan

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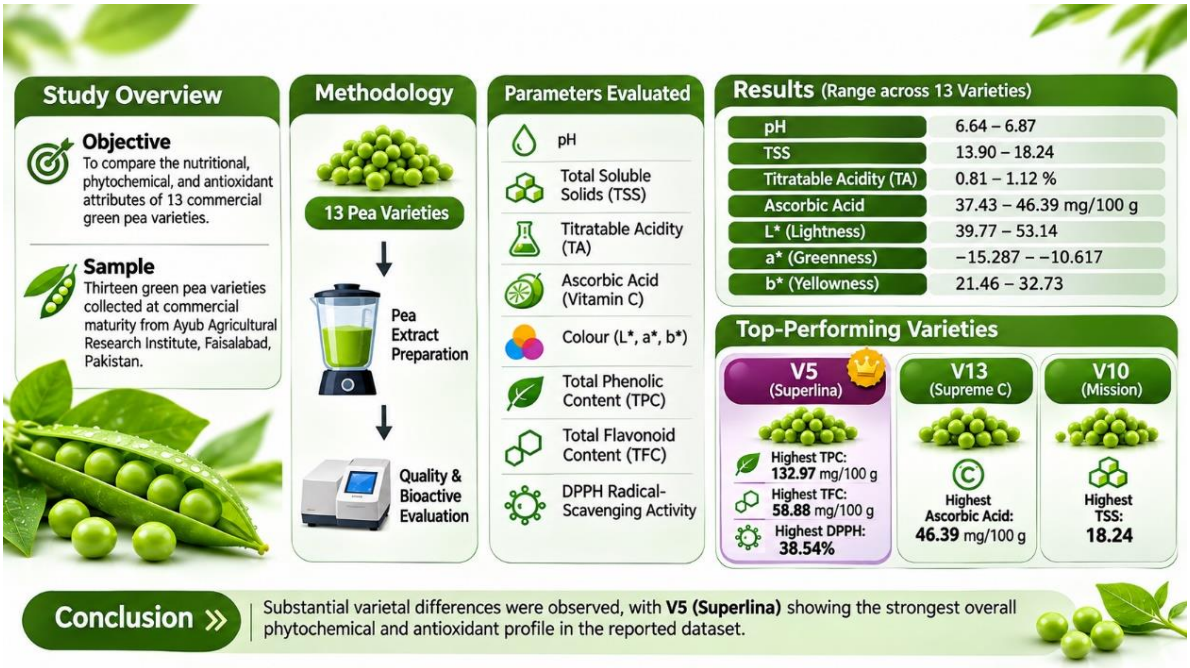
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Abstract

Green pea (Pisum sativum L.) is an important vegetable legume valued for its nutritional composition and bioactive constituents. However, compositional variation among commercially cultivated varieties can influence their nutritional and quality attributes. This study compared thirteen green pea varieties collected at commercial maturity from Ayub Agricultural Research Institute, Faisalabad, Pakistan. Pea extracts were prepared and evaluated for pH, total soluble solids (TSS), titratable acidity (TA), ascorbic acid, instrumental colour (L*, a*, and b*), total phenolic content (TPC), total flavonoid content (TFC), and DPPH radical-scavenging activity. The reported pH values ranged from 6.64 to 6.87, while TSS ranged from 13.90 to 18.24. Titratable acidity ranged from 0.81% to 1.12%, and ascorbic acid ranged from 37.43 to 46.39 mg/100 g. Colour values also varied among varieties, with L* values of 39.77–53.14, a* values of −15.287 to −10.617, and b* values of 21.46–32.73. V5 (Superlina) had the highest reported TPC (132.97 mg/100 g), TFC (58.88 mg/100 g in the detailed table), and DPPH activity (38.54%). V13 (Supreme C) had the highest ascorbic acid concentration (46.39 mg/100 g), whereas V10 (Mission) had the highest TSS (18.24). These findings demonstrate substantial varietal differences across the measured quality attributes. Considering the combined phenolic, flavonoid, and DPPH results, V5 showed the strongest overall phytochemical and antioxidant profile in the reported dataset. The findings may assist in identifying pea varieties with desirable quality characteristics for consumption and further value addition.

Keywords: *Pisum sativum L.*; green pea; varietal variation; physicochemical properties; total phenolic content; flavonoids; DPPH; antioxidant activity

Graphical Abstract



1. Introduction

Vegetables are essential components of a balanced diet and provide vitamins, minerals, dietary fibre, and a range of phytochemicals. Regular consumption of vegetables has been associated with improved health outcomes and a lower risk of several chronic diseases, including cardiovascular disease, diabetes, and certain cancers. Their phytonutrients may contribute antioxidant and anti-inflammatory activities that help protect cells against oxidative damage (Wallace et al., 2020).

Pea (Pisum sativum L.), a member of the Fabaceae family, is an important food legume cultivated in temperate and subtropical regions. In Pakistan, peas are commonly known as matar and are consumed fresh as well as in processed and cooked foods. Pea seeds contain proteins, carbohydrates, dietary fibre, minerals, and vitamins, making them nutritionally important (Hussein et al., 2006; Urbano et al., 2003). The composition of pea seeds varies with genotype, growing environment, maturity, and postharvest handling (Dhaliwal et al., 2021).

Peas are cultivated worldwide for human consumption, animal feed, and commercial processing. Global production and trade have been shaped by major producing countries, including Canada, China, and Russia (Janzen et al., 2014). Production data have also distinguished between dry peas and green peas, reflecting their different market and consumption uses (Tassoni et al., 2020). In Pakistan, pea cultivation is distributed across several provinces, with Punjab accounting for a major share of reported production (Aslam et al., 2019).

Peas provide protein, complex carbohydrates, minerals, and micronutrients and have been discussed as useful food sources in the context of global micronutrient adequacy (Amarakoon et al., 2012). The literature has also associated their nutritional value and bioactive constituents with potential health benefits, including effects relevant to cardiovascular health and metabolic disease (Dahl et al., 2012; Iqbal et al., 2006). However, the nutritional quality of peas is not uniform across genotypes. Differences in seed composition and antinutritional factors can influence their food and feed applications (Danesi and Bordoni, 2008).

Postharvest handling and processing can modify the quality of vegetables. Ascorbic acid and some antioxidant compounds are sensitive to oxygen, light, temperature, and processing conditions, and losses may occur during storage, cooking, and industrial processing (Zhang and Hamauzu, 2004; Roy et al., 2009). Varietal selection is therefore relevant when identifying raw materials with desirable initial nutritional and physicochemical characteristics.

Although multiple pea varieties are cultivated in Pakistan, comparative information on their physicochemical properties and antioxidant-related phytochemicals is limited. The present study therefore evaluated thirteen green pea varieties for selected quality attributes and compared their phytochemical content and DPPH radical-scavenging activity. The objective was to identify varietal differences and highlight varieties with comparatively desirable measured characteristics.

2. Materials and Methods

2.1. Study location and procurement of raw material

The study was conducted in the Fruits and Vegetable Laboratory, National Institute of Food Science and Technology (NIFSAT), University of Agriculture, Faisalabad, Pakistan. Pea (Pisum sativum L.) varieties were manually harvested from Ayub Agricultural Research Institute, Faisalabad, Punjab, and transported to the laboratory. Samples were sorted to remove damaged or deteriorated material, washed with water to remove surface dirt and impurities, and kept in a cool, dry, shaded place before processing.

2.2. Experimental treatments

Table 1. Green pea varieties included in the study.

Treatment	Variety name
V1	Classic
V2	9374
V3	Pea-09
V4	1800-4
V5	Superlina
V6	Moti pak
V7	Green Cross
V8	2000-6
V9	Lina Pak
V10	Mission
V11	Champion
V12	Meteor
V13	Supreme (C)

2.3. Preparation of pea extracts

The pea material was washed with tap water and undesirable portions were removed. Seeds were separated from the pods and juice/extract was obtained from each variety using a juicer. The extracted material was clarified or filtered using filter paper, transferred into glass bottles, and stored under refrigeration until analysis. The source manuscript describes the preparation of a blended drink/extract but does not specify the exact extraction yield, dilution factor, storage duration, or storage temperature.

2.4. Physicochemical analyses

2.4.1. Total soluble solids

Total soluble solids were measured at room temperature using a digital refractometer according to AOAC (2016). The refractometer was rinsed with distilled water before measurement, and readings were recorded in degrees Brix. The original tables label the parameter inconsistently as mg/100 g in one heading; the method indicates refractometric soluble-solids readings, conventionally expressed as °Brix.

2.4.2. pH

The pH of each sample was measured using a calibrated pH meter following AOAC (2016). A 50 mL portion of pea juice was placed in a 100 mL beaker, and the electrode was immersed in the sample. The digital reading was recorded.

2.4.3. Titratable acidity

Titratable acidity was determined using a digital acidity meter as described in AOAC (2016). The calculation formula provided in the source manuscript was: TA (%) = [mL NaOH used × 0.1 N NaOH × 0.064 × 100] / grams of sample. The manuscript does not explicitly state the acid equivalent represented by the factor 0.064.

2.4.4. Ascorbic acid

Ascorbic acid was determined by the 2,6-dichlorophenol-indophenol dye titration method (AOAC, 2016). A standard was prepared using oxalic acid and ascorbic acid and titrated with dye to a persistent light-pink endpoint. Approximately 5 mL of sample was diluted to 100 mL with 0.4% oxalic acid. An aliquot was mixed with oxalic acid and titrated with standard dye until a light-pink colour persisted. The formula reported in the manuscript was: Ascorbic acid = $(1 \times R \times V \times 100)/(R1 \times W \times V1)$, where R is the sample titration reading, R1 is the standard reading, V is the final sample volume, W is sample weight, and V1 is the aliquot volume. Units were reported as mg/100 g.

2.4.5. Colour measurement

Colour was assessed using a Color Tech-PCM spectrophotometer (SN 3001378). Colour was expressed using the CIELAB coordinates L* (lightness), a* (green–red axis), and b* (blue–yellow axis), following the approach cited by Vukić et al. (2018).

2.5. DPPH radical-scavenging activity

Antiradical activity was evaluated using the DPPH method described by Al-Juhaimi and Ghafoor (2013). Four millilitres of sample were mixed with 1 mL of 0.1 mM methanolic DPPH solution and incubated at room temperature for 30 min. Absorbance was measured at 520 nm using a CECIL CE7200 spectrophotometer. Percentage inhibition was calculated using the blank DPPH absorbance (A0) and sample absorbance (Ae): DPPH inhibition (%) = [(A0 − Ae)/A0] × 100.

2.6. Phytochemical analyses

2.6.1. Total phenolic content

Total phenolic content was determined using the Folin–Ciocalteu method as described by Daramola (2013). A 125 µL portion of sample was mixed with 125 µL Folin–Ciocalteu reagent and 500 µL distilled water. After 5 min at 22°C, 4.5 mL of 7% sodium bicarbonate was added. Following 90 min of reaction, absorbance was measured at 765 nm using a CECIL CE7200 UV/visible spectrophotometer against a control. The manuscript reports TPC as mg/100 g; however, the method description also refers to gallic acid equivalents per 100 mL. The exact calibration equation and sample-basis conversion are not supplied in the source.

2.6.2. Total flavonoid content

Total flavonoid content was assessed using the aluminium chloride/potassium acetate procedure described by Escobar et al. (2019). Stock solutions of aluminium chloride and potassium acetate were prepared, and crude extracts were dissolved in DMSO at 4 mg/mL. Twenty microlitres of sample extract were transferred to a 96-well plate, followed by 10 µL aluminium chloride solution, 10 µL potassium acetate solution, and 160 µL distilled water. The mixture was incubated at laboratory temperature and absorbance was measured at 415 nm. Quercetin was used as the positive standard at 40, 20, 10, 5, and 2.5 µg/mL; DMSO served as the negative control. The method states that TFC was expressed as µg quercetin equivalents (QE)/mg extract, whereas the results tables report mg/100 g.

2.7. Statistical presentation

The source manuscript presents treatment means with dispersion values (reported as mean ± value) and letter-based significance groupings. The underlying replicate-level observations, sample size for each assay, statistical test, post-hoc procedure, significance threshold, and statistical software are not documented in the supplied file. Accordingly, this article retains the reported summary statistics and superscript letters without assigning an unreported statistical method or reconstructing raw observations. The authors should insert the verified statistical-analysis details and replicate-level data before journal submission.

3. Results and Discussion

The results show variation among the thirteen pea varieties across physicochemical, colour, and phytochemical parameters. Unless otherwise stated, values below are reproduced from the detailed treatment tables in the source manuscript. Letter groupings are retained as reported and should be interpreted using the original statistical analysis records.

3.1. pH

The pH values ranged from 6.64 to 6.87. V2 and V8 showed the highest reported values (6.87), while V7 had the lowest value (6.64). The variation indicates differences in the acid–base characteristics of the extracts among the tested genotypes. Arif et al. (2020) and Pervin et al. (2017) reported similar varietal differences in pea quality traits.

Table 2. pH values of the thirteen green pea varieties.

Treatment	pH (reported mean ± dispersion; group)
V1	6.67±0.01FG
V2	6.87±0.02AB

V3	6.84±0.01ABC
V4	6.72±0.01DEFG
V5	6.68±0.01EFG
V6	6.75±0.12CDEFG
V7	6.64±0.01G
V8	6.87±0.01A
V9	6.82±0.02ABCD
V10	6.79±0.01ABCDE
V11	6.76±0.01BCDEF
V12	6.77±0.02BCDEF
V13	6.74±0.02CDEFG

3.2. Total soluble solids

TSS ranged from 13.90 to 18.24. V10 (Mission) had the highest value (18.24), followed by V9 (17.91), V8 (17.81), and V13 (17.66). V4 (1800-4) had the lowest value (13.90). TSS reflects soluble constituents, including sugars, organic acids, minerals, and amino acids. Genotypic variation in TSS has also been reported in pea germplasm (Arif et al., 2020).

Table 3. Total soluble solids in the pea varieties.

Treatment	TSS (reported value; group)
V1	15.76±0.33BC
V2	17.51±0.50A
V3	15.57±0.37BC
V4	13.90±0.18D
V5	16.04±0.22B
V6	15.06±0.47C
V7	15.70±0.27BC
V8	17.81±0.15A
V9	17.91±0.17A
V10	18.24±0.16A
V11	16.29±0.24B
V12	15.69±0.21BC
V13	17.66±0.18A

Note: Values are reproduced as presented; the source table labels the unit as mg/100 g, although the described refractometer method normally reports °Brix.

3.3. Titratable acidity

Titratable acidity varied from 0.81% to 1.12%. V13 showed the highest reported acidity (1.12%), followed by V10 (1.10%) and V11 (1.06%), whereas V5 had the lowest value (0.81%). Acidity contributes to flavour balance and may vary with genotype and maturity. The varietal differences are broadly consistent with reports on pea quality and postharvest characteristics (Pervin et al., 2017; Drakula et al., 2021).

Table 4. Titratable acidity of the pea varieties.

Treatment	Titratable acidity (%)
V1	0.89±0.01EF
V2	0.82±0.01G
V3	0.99±0.01C
V4	0.86±0.02FG
V5	0.81±0.01G
V6	0.82±0.02G
V7	0.97±0.01CD
V8	0.93±0.03DE

V9	1.05±0.01B
V10	1.10±0.02AB
V11	1.06±0.01B
V12	0.98±0.02CD
V13	1.12±0.01A

3.4. Ascorbic acid

Ascorbic acid content ranged from 37.43 to 46.39 mg/100 g. V13 had the highest concentration (46.39 mg/100 g), while V6 had the lowest (37.43 mg/100 g). V3 (44.39 mg/100 g) and V10 (43.64 mg/100 g) also showed comparatively high values. Ascorbic acid is sensitive to oxidation and environmental conditions during handling and storage (Ghasemnezhad et al., 2010). Genotypic variation in ascorbic acid and other quality traits has been documented in vegetable crops (Zhang et al., 2021).

Table 5. Ascorbic acid content of the pea varieties.

Treatment	Ascorbic acid (mg/100 g)
V1	39.11±0.60FG
V2	43.26±0.54BC
V3	44.39±0.60B
V4	41.71±0.24CD
V5	39.92±0.40EFG
V6	37.43±0.48H
V7	38.52±0.41GH
V8	40.93±0.43DE
V9	40.18±0.92DEF
V10	43.64±0.30B
V11	41.36±0.53DE
V12	43.02±0.57BC
V13	46.39±0.55A

3.5. Colour characteristics

3.5.1. Lightness (L*)

L* values ranged from 39.77 to 53.14. V11 had the highest reported lightness (53.14), whereas V1 had the lowest (39.77). Lightness is an important instrumental descriptor of sample appearance. Differences among varieties may reflect variation in pigmentation and tissue characteristics. Similar changes in colour parameters have been discussed in pea and vegetable products (Zhang et al., 2021).

Table 6. L* colour values of the pea varieties.

Treatment	L*
V1	39.77±0.65F
V2	40.81±0.17EF
V3	41.59±0.30E
V4	49.19±0.53AB
V5	47.87±0.45BC
V6	44.94±0.69D
V7	46.97±0.30C
V8	47.86±0.28BC
V9	47.41±0.57C
V10	49.45±0.43A
V11	53.14±0.52D
V12	43.81±0.32D
V13	49.31±0.46A

3.5.2. Green–red coordinate (a*)

All varieties showed negative a* values, indicating a position toward the green region of the CIELAB colour space. V5 had the most negative value (−15.287), indicating the strongest measured greenness among the varieties, while V2 had the least negative value (−10.617). The differences may be associated with variation in green pigments and other optical properties. Comparable varietal differences have been reported by Pervin et al. (2017).

Table 7. a* colour values of the pea varieties.

Treatment	a*
V1	−13.383±0.25EF
V2	−10.617±0.14A
V3	−14.520±0.37G
V4	−12.100±0.13BC
V5	−15.287±0.05H
V6	−12.887±0.06D
V7	−12.837±0.05D
V8	−13.017±0.09DE
V9	−13.133±0.05DE
V10	−11.673±0.05B
V11	−12.107±0.04BC
V12	−12.137±0.05C
V13	−13.740±0.03F

3.5.3. Yellow–blue coordinate (b*)

The b* values ranged from 21.46 to 32.73. V5 showed the highest b* value (32.73), while V4 had the lowest value (21.46). Positive b* values indicate a shift toward yellow. Colour is relevant to consumer perception and commercial quality, and varietal differences in colour coordinates have been described in vegetable materials (Zhang et al., 2021).

Table 8. b* colour values of the pea varieties.

Treatment	b*
V1	24.36±0.01E
V2	22.333±0.03H
V3	26.24±0.13C
V4	21.46±0.05I
V5	32.73±0.19A
V6	25.87±0.07D
V7	26.46±0.06C
V8	28.69±0.14B
V9	28.82±0.07B
V10	25.94±0.04D
V11	23.25±0.04G
V12	23.57±0.03F
V13	26.38±0.05C

3.6. Total phenolic content

TPC ranged from 114.07 to 132.97 mg/100 g in the detailed results table. V5 had the highest reported value (132.97 mg/100 g), followed by V1 (128.87 mg/100 g) and V8 (128.40 mg/100 g). V3 showed the lowest value (114.07 mg/100 g). Phenolic compounds are plant secondary metabolites that can contribute to antioxidant capacity. Differences in phenolic content among garden pea genotypes have been reported previously (Devi et al., 2019).

Table 9. Total phenolic content of the pea varieties.

Treatment	TPC (mg/100 g; as reported)
V1	128.87±0.24B
V2	115.27±0.43GH
V3	114.07±0.54H
V4	116.50±0.14F
V5	132.97±0.12A
V6	115.86±0.66FG
V7	126.03±0.54C
V8	128.40±0.20B
V9	124.33±0.42D
V10	122.67±0.66E
V11	124.27±0.20D
V12	124.53±0.24D
V13	126.93±0.31C

3.7. Total flavonoid content

TFC ranged from 50.18 to 58.88 mg/100 g in the detailed table. V5 had the highest value (58.88 mg/100 g), closely followed by V12 (58.79 mg/100 g), while V1 had the lowest value (50.18 mg/100 g). Flavonoids are a diverse group of plant phenolics and may contribute to antioxidant activity. Genotypic variation in phenolic and flavonoid-related traits has been reported in pea and related legumes (Devi et al., 2019; Rybiński et al., 2018).

Table 10. Total flavonoid content of the pea varieties.

Treatment	TFC (mg/100 g; as reported)
V1	50.18±2.00F
V2	50.92±2.93EF
V3	52.03±1.39DEF
V4	52.58±0.84DEF
V5	58.88±0.55A
V6	55.36±0.84BC
V7	57.77±0.96AB
V8	51.29±1.15DEF
V9	52.77±0.96DE
V10	53.51±0.64CD
V11	53.14±1.11CDE
V12	58.79±0.32A
V13	53.32±0.55CDE

3.8. DPPH radical-scavenging activity

DPPH inhibition ranged from 10.38% to 38.54%. V5 exhibited the highest activity (38.54%), followed by V10 (35.76%) and V6 (34.44%). V2 had the lowest activity (10.38%). The pattern is consistent with the comparatively high TPC and TFC reported for V5, although correlation or causal relationships cannot be established without a dedicated statistical analysis. Previous studies have reported variation in antioxidant capacity among pea genotypes and pea-containing food systems (Bashir et al., 2019; Drakula et al., 2021).

Table 11. DPPH radical-scavenging activity of the pea varieties.

Treatment	DPPH inhibition (%)
V1	19.73±0.03I
V2	10.38±0.05L
V3	25.98±0.03F

V4	27.43±0.06E
V5	38.54±0.06A
V6	34.44±0.03C
V7	21.01±0.05H
V8	13.37±0.06J
V9	30.43±0.06D
V10	35.76±0.60B
V11	21.56±0.08G
V12	12.58±0.03K
V13	19.93±0.08I

3.9. Integrated comparison of varietal performance

No single variety ranked highest for every measured parameter. V10 had the highest TSS, V13 had the highest ascorbic acid and titratable acidity, and V11 had the highest L* value. V5 showed the most negative a* value and the highest b*, TPC, TFC, and DPPH activity in the detailed results tables. These findings indicate that selection should be aligned with the intended use: a variety with high antioxidant-related measurements may be preferred for phytochemical-focused applications, whereas other varieties may be selected for soluble solids, vitamin C, or visual attributes. On the basis of the combined TPC, TFC, and DPPH results, V5 (Superlina) showed the strongest overall antioxidant-related profile in this dataset.

4. Future Perspectives

The present comparison provides a useful baseline for identifying variation among thirteen commercially cultivated green pea varieties; however, it represents a single procurement and maturity context and evaluates a defined set of physicochemical and antioxidant-related traits. Future investigations should therefore move from a descriptive varietal comparison toward a multi-environment, multi-season evaluation that can distinguish stable genetic effects from environmental and management-related variation. Replicated field trials across locations, sowing dates, soil types, irrigation regimes, and seasons would help determine whether the comparatively high phenolic, flavonoid, and DPPH values observed for V5 (Superlina), the higher ascorbic acid content of V13 (Supreme C), and the higher soluble-solids reading of V10 (Mission) are reproducible. Such work should also record agronomic traits, including yield, pod number, seed size, maturity duration, and resistance to major biotic and abiotic stresses, so that quality-based selection is not separated from crop performance and production feasibility (Ahmad et al., 2024; Shafeeq et al., 2026).

A priority will be to broaden the compositional assessment beyond total phenolic and flavonoid measurements. These colorimetric assays provide aggregate estimates and do not identify individual compounds or their relative contribution to antioxidant activity. Future studies should use chromatographic and mass-spectrometric methods, such as HPLC-DAD and LC–MS/MS, to profile phenolic acids, flavonoids, carotenoids, tocopherols, and other relevant metabolites. Targeted and untargeted metabolomics could establish whether the strong DPPH response of V5 is associated with particular chemical constituents, while antioxidant assays based on different reaction mechanisms would provide a more complete assessment than DPPH alone. The relationship among TPC, TFC, individual metabolites, and antioxidant responses should be tested using correlation analysis and multivariate methods only after adequate biological replication and transparent statistical reporting. Research on antioxidant variation in pea germplasm and plant-derived functional ingredients provides a foundation for this approach (Devi et al., 2019; Rybiński et al., 2018; Riaz et al., 2026a).

The nutritional characterization should also be expanded to include protein quantity and amino-acid composition, dietary fibre, starch fractions, sugars, minerals, vitamins, and antinutritional factors such as phytate, tannins, and trypsin inhibitors. This is important

because selection for a high antioxidant-related profile does not necessarily identify a variety with the best overall nutritional quality or protein bioavailability. Previous work on pea proteins, legume nutritional quality, and naturally low-phytate field peas indicates the value of considering nutrient density and antinutritional components together (Dhaliwal et al., 2021; Iqbal et al., 2006; Amarakoon et al., 2012). A more complete nutrient profile would help establish whether the varieties identified in this study offer complementary advantages for fresh consumption, ingredient development, or specialized food formulations.

Postharvest research is another essential direction. The measured values were obtained from fresh extracts, and they do not establish how the varieties behave during commercial storage, blanching, freezing, drying, canning, or cooking. Follow-up experiments should quantify changes in ascorbic acid, phenolics, flavonoids, colour, soluble solids, texture, and antioxidant activity under controlled time–temperature and packaging conditions. Particular attention should be paid to oxygen exposure, light, moisture, blanching intensity, and cold-chain management because these factors can alter quality and nutrient retention. Earlier work on pea blanching and storage, vegetable freezing and cooking, and radio-frequency blanching of green peas demonstrates the importance of processing conditions in determining final product quality (Pervin et al., 2017; Danesi and Bordoni, 2008; Zhang et al., 2021).

The varieties should subsequently be evaluated in product-development trials. V5 may be a candidate for formulations in which phenolic content and in-vitro radical-scavenging activity are desirable, whereas V13 may warrant attention where ascorbic acid retention is a key selection criterion and V10 may be useful in formulations where soluble-solids characteristics are relevant. These are hypotheses for testing rather than established processing recommendations. Trials could examine pea-based beverages, soups, purees, snacks, bakery products, protein-rich foods, and plant-based patties, with assessment of sensory acceptance, colour stability, texture, cooking behaviour, nutrient retention, and microbial safety. Studies on plant-based functional foods and pea-enriched food systems provide relevant starting points for such product-oriented investigations (Riaz et al., 2026a; Drakula et al., 2021; Adnan et al., 2026).

A further opportunity is the valorization of pea-processing residues, including pods, seed coats, and rejected or undersized material. These streams may contain dietary fibre, phenolic compounds, and other recoverable components, but their composition and safety must be established before commercial use. Extraction conditions, solvent choice, recovery yield, stability, contaminant levels, and the functionality of recovered ingredients should be investigated. Research on the valorization of agricultural processing by-products and plant-derived bioactive compounds offers a broader framework for developing circular food-processing systems (Tassoni et al., 2020; Fordos et al., 2023; Butt et al., 2026c).

Finally, subsequent studies should strengthen experimental transparency. The present manuscript contains summary statistics but not the replicate-level observations or complete statistical-analysis record. Future work should report the number of independent biological samples and technical replicates, randomization, sample preparation, calibration equations, analytical recovery, limits of detection where relevant, statistical tests, post-hoc comparisons, and exact units. The TSS, TPC, and TFC units and calculation bases identified in the current manuscript must be verified against laboratory records before comparison across studies. These steps will improve reproducibility and support the development of reliable quality benchmarks for Pakistani pea germplasm.

5. Integration with Other Sciences and Research Domains

The quality variation observed among green pea varieties is influenced by interconnected biological, environmental, analytical, and technological factors. Accordingly, future research should integrate food science with plant genetics, agronomy, analytical chemistry, microbiology, nutrition, data science, and

environmental assessment. This multidisciplinary approach would allow varietal selection to move beyond isolated measurements and toward a more complete understanding of how genotype, growing conditions, composition, processing, and consumption determine the value of green pea as a food crop.

Combining physicochemical and phytochemical phenotyping with molecular characterization could help explain the genetic basis of the observed differences. Genotyping, genome-wide association studies, transcriptomics, and metabolomics could be used to identify markers and pathways associated with phenolic accumulation, flavonoid biosynthesis, ascorbic acid content, pigment formation, and stress tolerance. These data could support marker-assisted selection or genomic selection, provided that sufficiently large and genetically diverse pea populations are evaluated. Genome-editing research in crop improvement, including CRISPR-based approaches to stress tolerance and disease resistance, illustrates the potential of molecular tools to complement conventional breeding; such methods would require pea-specific validation and appropriate regulatory and biosafety assessment before application (Jabeen et al., 2025; Fatima et al., 2026).

Food quality is partly established in the field. Soil fertility, water availability, temperature, salinity, pest pressure, and crop management can influence plant development and seed composition. Linking varietal trials with soil analysis, weather records, irrigation data, and precision-agriculture tools would help identify genotype-by-environment interactions and improve recommendations for different production regions. Smart agriculture approaches, including sensor-based monitoring, remote sensing, and data-supported crop management, may improve the consistency of field experiments and resource-use efficiency (Ahmad et al., 2024). Research on salinity mitigation in vegetable crops also highlights the need to assess quality traits alongside stress adaptation rather than treating yield as the only breeding outcome (Shafeeq et al., 2026). Environmental assessment should additionally consider water use, fertilizer inputs, energy demand, greenhouse-gas emissions, and the fate of processing residues when comparing production and processing options.

Analytical chemistry is required to move from bulk estimates to compound-specific evidence. Chromatographic profiling, spectroscopy, microscopy, and validated antioxidant assays could be combined with instrumental colour and texture measurements to establish links between chemical composition and functional performance. Food engineering can then examine how unit operations—including blanching, thermal treatment, freezing, drying, extrusion, and non-thermal processing—affect those compounds and the structure of pea-based products. Work on ultrasound-assisted modification of plant proteins and ultrasound-enabled protein remodelling demonstrates how processing technologies can alter ingredient functionality, although the effects must be directly tested in pea matrices rather than assumed from other protein systems (Butt et al., 2026b; Riaz et al., 2026b).

The development of pea-based beverages and fermented foods requires integration with food microbiology. Starter cultures and probiotic organisms may influence acidification, flavour, texture, metabolite formation, and product stability; however, each formulation must be assessed for microbial quality, pathogen control, and shelf-life under intended storage conditions. Research on probiotic fermentation and AI-supported fermentation optimization provides relevant concepts for monitoring microbial dynamics and controlling processing parameters (Ahmed et al., 2024; Khan et al., 2025). Safety evaluation should include hygienic handling, microbial enumeration, and, where relevant, screening for contaminants and adulterants. The use of processing by-products as ingredients should likewise be accompanied by microbiological and chemical safety assessment rather than relying solely on their bioactive potential.

The present study measured in-vitro antioxidant activity and selected compositional attributes; it did not investigate digestion, nutrient bioavailability, physiological effects, or clinical outcomes. Integration with nutrition science should therefore begin with

simulated gastrointestinal digestion and assessment of the bioaccessibility of selected nutrients and phenolic compounds. Subsequent cell-based, animal, and appropriately designed human studies may be considered where justified by the evidence. Protein quality, amino-acid adequacy, mineral bioavailability, and the contribution of dietary fibre should be evaluated alongside phytochemical composition. Research connecting functional foods with gut microbial composition and inflammatory or metabolic pathways offers possible future questions, but these health-related effects cannot be inferred from the DPPH results in the current study (Nawaz et al., 2026; Shazif et al., 2026; Butt et al., 2026a; Butt et al., 2026a).

The multi-parameter dataset generated in this study could be expanded into a decision-support framework when additional varieties, locations, seasons, and replicate-level observations become available. Principal component analysis, hierarchical clustering, and supervised learning could help identify groups of varieties with similar quality profiles and predict quality traits from environmental or molecular variables. Artificial intelligence should be used as an analytical aid, not as a substitute for sound experimental design, transparent data provenance, and independent validation. Smart-agriculture research and AI-guided food-process optimization provide examples of how data-driven approaches can support crop and processing decisions (Ahmad et al., 2024; Khan et al., 2025).

The practical value of varietal selection depends on more than laboratory composition. Collaboration among plant breeders, growers, food processors, nutrition researchers, and supply-chain stakeholders is needed to assess market demand, affordability, consumer acceptance, processing losses, and the feasibility of using secondary biomass. Life-cycle assessment and techno-economic analysis could compare alternative routes for fresh-market distribution, freezing, drying, ingredient extraction, and residue valorization. This systems perspective is consistent with research on pea and legume value chains and the recovery of agro-industrial residues (Tassoni et al., 2020; Fordos et al., 2023). For Pakistan, linking local germplasm evaluation with postharvest infrastructure and processor requirements may help translate varietal differences into practical opportunities while avoiding unsupported claims about commercial or health benefits.

Taken together, these interdisciplinary approaches could establish a pathway from varietal characterization to validated crop improvement, safe processing, nutritionally informed product development, and more sustainable utilization of pea resources. The immediate priority is to validate the analytical units and statistical record of the present dataset, followed by replicated field and processing studies. Only after these steps should specific varieties be recommended for defined food applications or broader nutritional claims.

6. Conclusion

The comparative evaluation of thirteen green pea varieties demonstrated substantial variation in physicochemical, colour, and phytochemical attributes. V10 (Mission) recorded the highest TSS (18.24), V13 (Supreme C) recorded the highest ascorbic acid content (46.39 mg/100 g), and V11 (Champion) had the highest L* value (53.14). V5 (Superlina) showed the highest reported TPC (132.97 mg/100 g), TFC (58.88 mg/100 g in the detailed table), and DPPH radical-scavenging activity (38.54%), indicating a comparatively strong antioxidant-related profile. Therefore, V5 may be considered a promising candidate when selection is based primarily on the measured phenolic, flavonoid, and DPPH parameters. The findings also show that varietal selection involves trade-offs among quality traits rather than one universally superior variety.

The study provides comparative baseline information that may support further evaluation of Pakistani pea germplasm for fresh consumption and value-added food applications. However, claims regarding export suitability, shelf-life superiority, or health effects cannot be established from the measured parameters alone. Further work should include replicated field trials across locations and seasons, validated unit

reporting, detailed statistical analysis, sensory assessment, processing performance, and storage studies. Improving postharvest handling and processing infrastructure may also help reduce losses and improve the value chain for vegetables in Pakistan.

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