Research Article

doi:10.25081/jpc.2021.v49.i3.7450
Journal of Plantation Crops, 2021, 49(3): 168-175

# Bean and beverage quality - Prospects of four $F_1$ hybrids of coffee (*Coffea arabica* L.) in India

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*(Manuscript Received: 30-09-2021 , Revised: 25-10-2021, Accepted: 02-11-2021)*

## Abstract

In coffee, both physical quality attributes as assessed by the colour and size of the beans and cup quality of the beverage rated based on sensory analysis are the important criteria for determining market price. In general, quality is dependent on genotype and also influenced by the growing conditions. The bean and beverage quality of pure *C. arabica* varieties is far superior to diploid introgressed arabica genotypes developed for improved host resistance. Thus, integrating the host resistance without affecting quality parameters is very imperative in arabica coffee breeding. Four $F_1$ hybrids (S.5083, S.5084, S.5085 & S.5086) developed from reciprocal crosses between the most popular semi-dwarf arabica variety 'Chandragiri' and Sln.10, an auto-tetraploid of a diploid inter-specific hybrid, used as a donor for rust resistance, were evaluated for physical quality traits for four seasons and cup profiles for two seasons. Among the four hybrids, S.5085 and S.5086 recorded bold bean size with 70.05 per cent and 69.75 per cent of mean 'A' grade beans, respectively. The 'B' grade ranged from 9.5 per cent to 10.4 per cent in hybrids as against 16.8 per cent in Chandragiri. The Pea berry ranged from 10.1 per cent to 12.5 per cent, indicating high fertility in hybrids. The cup qualities of S.5085 and S.5086 were also found superior with a cumulative average score of 80.3 and 78.3 respectively, compared to parents; 71.6 in Chandragiri and 77.3 in Sln.10. The present study established the superiority of S.5085 and S.5086 in quality parameters and therefore has potential implications in the commercial exploitation of these two $F_1$ hybrids that also manifested high levels of field tolerance to coffee leaf rust.

***Keywords:*** Bean density, bean grades, coffee quality, cup profile, $F_1$ hybrids

## Introduction

Coffee is a largely consumed natural beverage across the continents and is preferred for its stimulating properties. The coffee beverage comes from the beans of the plant that belong to the genus *Coffea* of the family Rubiaceae. Among the vast diversity of over 100 species of the *Coffea* genus, only two species, *Coffea arabica* and *Coffea canephora* are commercially cultivated. Of the two commercial species, *C. arabica,* popularly called Arabica coffee, is regarded as high-quality coffee with good flavour, distinctive aroma, mild taste and medium acidity in the cup. On the other hand, the second commercial species of coffee, popularly known as robusta coffee, gives relatively harsh brew and liquor quality often rated as neutral in taste, with light to fair acidity. The caffeine content of arabica coffee is around 1.2 - 1.5 per cent, while that of robusta is relatively high (2.2% to 2.7%). Because of such contrasting attributes in cup characteristics, Robusta coffee is used to blend with Arabica to meet consumer preferences. In general, besides the genetic attributes, the growing conditions and meticulous on-farm processing contribute to the delicious flavours and intrinsic stand-alone quality of the cup. It is well established that coffee quality is also influenced by Genotype and Environment (G x E) interaction (Geneti, 2019). In coffee, physical qualities, as assessed by the colour and size of the coffee beans, defined as a grade of the sieves, and sensory analysis of the cup quality are the key criteria for price determination

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in the coffee market. The bold size beans are considered premium grades and fetch higher prices.

Therefore, the improvement of bean and beverage quality has been considered one of the important objectives of coffee breeding worldwide. Nevertheless, in *C. arabica* (only tetraploid species of the genus *Coffea* originated from spontaneous hybridisation of two diploid species, *C. canephora* and *C. eugenioides*), breeding for disease and pest resistance has been the prime objective because of the high susceptibility of this species to major diseases and pests. Interestingly, some of the diploid species, including *C. canephora,* form the major sources of disease and pest resistance genes. Hence, transfer of disease and pest resistance from diploid species to tetraploid Arabica, without compromising bean and beverage quality, has been the priority of arabica breeding. In this context, the development of tetraploid inter-specific hybrids by using diploid species as donors of resistance becomes imperative. Accordingly, introgressive breeding using spontaneous tetraploid inter-specific hybrids with introgression of diploid genes as resistance donors has high practical relevance. This approach is more relevant to India, where diseases and pest flare-ups are very high on arabica coffee varieties due to ideal climatic conditions. However, because of the single flowering season for coffee in the Indian conditions and long breeding cycles, pyramiding or transferring resistance genes into outstanding arabica cultivars by conventional breeding approaches is a time-consuming process. To overcome this limitation, $F_1$ breeding strategy has been gaining significance in the recent past, wherein the genetically distant donor parents are crossed with proven commercial cultivars of Arabica. The resultant $F_1$s are used for commercial exploitation by scaling up propagation through tissue culture. This strategy not only reduces the time frame for the integration of resistance genes but also gains an advantage from the expression of resistance genes of dominant nature in $F_1$ progenies. With this background, the development of $F_1$ hybrids of Arabica has been undertaken in India with the main objective of evolving heterotic $F_1$ hybrids of Arabica for crop yield coupled with durable resistance to coffee leaf rust disease. As part of this programme, four $F_1$ hybrids were developed from reciprocal crosses between the most popular semi-dwarf arabica variety 'Chandragiri', and Sln.10, a diploid introgressed line as a donor for rust resistance and superior beverage quality, were established in the field during 2012. The present communication details the agronomic performance of these $F_1$ hybrids with respect to bean and beverage quality and their commercial prospects.

## Materials and Methods

### Experimental material

The plant material evaluated in the present study comprised of four $F_1$hybrid progenies *viz.,* S.5083, S.5084, S.5085 and S.5086 developed from reciprocal crosses between two arabica genotypes, '*Chandragiri*', a popular semi-dwarf arabica variety and Sln.10, a double-cross hybrid involving a dwarf mutant 'Caturra' of arabica variety (Bourbon); Ethiopian arabica (*Cioccie*) and S.795 (diploid - *C. liberica* introgressed line and donor for $S_H3$ gene for rust resistance) Two elite plants of Sln.10, characterised as homozygous and heterozygous for $S_H3$ gene for rust resistance were used in hybridisation as pollen donors to study the differences in performance of the hybrids if any (Table 1).

**Table 1. Cross combinations of the $F_1$ hybrids included in the study**

| Sl. No. | Accession No. | $F_1$ cross combination |
|---|---|---|
| 1. | S.5083 | Chandragiri x Sln.10 |
| 2. | S.5084 | Sln.10 x Chandragiri |
| 3. | S.5085 | Sln.10 x Chandragiri |
| 4. | S.5086 | Chandragiri x Sln.10 |
| 5. | S.5103 | Sln.10 } parent |
| 6. | S.5104 | Chandragiri } progenies |

### Experimental location and trial plot design

The field trial was conducted at Central Coffee Research Institute, Balehonnur, Karnataka, India (13º 22' N, 75º 25' E). The four hybrid progenies included in the study were planted during the year 2012 in a compact plot. The elevation of the experimental location is 2787 ft MSL and receives average annual precipitation of 2200 mm, while temperature and relative humidity were recorded to be 23.17º C and 82.16 per cent, respectively. The plant material was planted in a conventional square design at a spacing of 5'x5', and a total of 60 plants per progeny were established. The recommended two-tier shade pattern, the top cover of evergreen natural forest trees and the lower canopy comprising of fast-growing leguminous trees were maintained for the trial plot. Single stem training was adopted for canopy management of individual plants, and all standard cultural operations recommended for semi-dwarf arabica genotypes were followed. The hybrids were evaluated for all agronomic characters covering growth parameters, yield component characters, crop yield, tolerance to pests and diseases and bean and beverage quality profiles. In the present communication, the data with respect to physical quality traits for four consecutive cropping seasons (2017-18 to 2020-21) and cup profiles for two seasons (2018-19 and 2019-20) were considered for analysis.

**On-farm processing of coffee fruits - Preparation of clean coffee samples**

Coffee fruits are generally processed at the estate level by two methods. The first method is the 'wet method', where well-ripened fruits are subjected to pulping using the pulping machines, and the extracted beans are allowed to ferment 24-30 hours depending on temperature and then washed and dried to the specified moisture standards. The second method is the 'dry method', where the ripened fruits or the matured green fruits are harvested and directly dried in drying platforms to the prescribed moisture levels. The on-farm processed product by wet method is known as 'parchment", while the dry method is called 'cherry'. Both the 'parchment' and 'cherry' samples are subjected to secondary processing at curing factories to obtain clean coffee beans.

As the wet-processed coffees give rise to high-quality brew, all the samples from the trial plot were processed by wet method using a simple disc hand pulper. For each sample, a total of six kilograms of ripened fruit were taken from the pooled harvest of each replication and used for pulping. The wet parchment was collected and subjected to fermentation for 24-30 hours. After fermentation, the coffee beans were subjected to thorough washing with clean water and washed samples were sundried on the drying racks to the moisture level of 10 to 11 per cent. The moisture of the individual sample was tracked using the Dickey John multigrain digital moisture meter. The dried 'Parchment' samples were hulled using mini hullers, and clean coffee samples were prepared to assess bean quality parameters and cup profiles.

**Analysis of physical coffee quality parameters**

The dried parchment was hulled using a manual huller to assess physical quality, and clean coffee samples were obtained. These clean coffee samples were subjected for grading using standard sieves of Mckinnon India Pvt. Ltd., designated as 'A', 'B' & 'C' grades for sieve sizes No. 17, 15 and 14 respectively and the bean grade percentages were worked out. For assessing the average bean weight, 100 randomly selected 'A-grade beans were measured using Sartorius digital weighing balance. The length, breadth, thickness of the beans was measured from 20 beans in each replication using digital Vernier Calipers.

**Cup quality analysis**

The cup profiles of the individual samples were evaluated at the Coffee Quality Division, Coffee Board, Bengaluru. The parameters such as fragrance/aroma, flavour, acidity, body, the balance of the cup, uniformity, sweetness were analysed, and the score was given as per a 10 point scale. Sensory evaluation was conducted by a panel of four cupping specialists, including a certified 'Q grader' and SCAA protocol for Cupping Specialty Coffee (2015) was broadly followed for the analysis. The cumulative score of individual parameters was considered for data analysis.

**Data analysis**

Analysis of variance (ANOVA) was computed for each quality parameter to identify the variability among the different hybrid progenies. Pearsons correlation coefficient analysis was computed to illustrate the relationship between sensory attributes and bean grades following the procedures described by Gomez and Gomez (1984).

## Results and Discussion

The visual assessment of the clean coffee samples as assessed by the colour revealed no colour variations. All four hybrids and parental samples reflected the usual bluish-green colour of wet-processed coffee. The second criteria of visual quality being the bean size, the clean coffee samples prepared from all the harvests of four consecutive years were subjected to grading by using standard sieves and consolidated mean data of the four years with respect to four important commercial grades (AA, A, B and Pea berry) is furnished in Table 2.

The pooled data show that the per cent of 'AA' grade varied from 41 (S.5083) to 50 (S.5086), 'A' grade beans varied from 19.7 to 28.5, and 'B' grade ranged from 9.6 to 10.47. The per cent Pea berry characterised by single round seed ranged from 10 to 12.5 in different hybrid progenies. Among the two parental lines, the Chandragiri parent is known to produce bold beans among the different commercially cultivated coffee varieties of India also reflected a similar trend with 44 per cent (AA), 25 per cent (A), 16.8 per cent (B), and 5.5 per cent (Pb) in the bean grades and the differences between the hybrids and Chandragiri parent are not significant. However, significant differences were found among the bean grades of the hybrids and the second parent Sln.10, which was characterised by 27.8 per cent (AA), 31.4 per cent (A), 23.8 per cent (B) and 10.1 per cent (Pb) bean grades. Among the hybrids, the pooled 'A' grade percentage, including 'AA' and 'A' grade, ranged from 66.27 per cent to 70.05 per cent. As the variety 'Chandragiri' is known for value addition for bean size, stabilising this trait in F1 hybrids is considered important.

The data on bean dimensions of coffee beans is furnished in Table 3. The maximum bean length (10.71 mm), thickness (4.25 mm) and 100 bean weight (19.80g) were recorded in S.5086, followed by the $F_1$ hybrid, Chandragiri (10.71 mm, 7.02 mm, 4.10mm and 19.26 g). The maximum bean breadth (7.60 mm) was found in the Sln.10, followed by Chandragiri and S.5086 (7.02 mm). The maximum bean thickness (4.25 cm) was found in S.5086, followed by S.5083 (4.15 cm). The highest 100 bean weight (19.80 g) was found in cultivar S.5086, followed by S.5084 (19.73 g). As the Chandragiri variety produces bold and elongated beans, all the F1 hybrids also reflected a similar tendency.

Further, the Sln.10, characterised by roundish beans, recorded maximum bean breadth. In the $F_1$ hybrids generated from the cross involving Sln.10 as the female parent, there is no improvement in bean breadth, whereas, in reciprocal combinations, there is an increase in bean breadth. As a result, the hybrids recorded higher values for bean density as measured by the 100 'A' grade bean weight that ranged from 19.23 g to 19.80 g as against 19.26 in Chandragiri and 17.63 g in Sln.10 (Table 3). From the data generated on physical quality parameters in the present study, it is apparent that all the $F_1$ hybrids, especially S.5085 and S.5086, are either superior or on par to both the parents for most of the parameters except for bean breadth, which recorded maximum in Sln.10 parent because of the round shape of the beans in this variety.

In the green coffee trade, the physical characteristics of the green beans are still the primary quality criteria to determine the value. Generally, the beans of larger size are marketable as ''Specialty Coffee grades'' and fetch higher prices. It is well considered that bigger beans give more aroma though there is a conflicting opinion on this aspect. (Gonzalez-Rios *et al.* 2007; Kathurima *et al.* 2009). Nevertheless, DaMatta *et al.* (2018) reported that the smaller beans of the same variety designated as lower grades realise low prices. As cup quality of coffee also depends on

**Table 2. Mean data on the percentage of bean grades of $F_1$ hybrids and parent lines over four years**

| Genotypes | Bean grades in percentage | | | | | |
|---|---|---|---|---|---|---|
| | 'AA' | A | Total 'A' | B | C | PB |
| S.5083 | 41.00 | 25.25 | 66.27 | 10.47 | 0.37 | 12.57 |
| S.5084 | 41.00 | 28.50 | 69.50 | 9.60 | 0.25 | 11.35 |
| S.5085 | 46.40 | 27.37 | 70.05 | 9.51 | 0.22 | 10.17 |
| S.5086 | 50.00 | 19.75 | 69.75 | 9.60 | 0.62 | 11.55 |
| Chandragiri | 44.12 | 25.30 | 69.50 | 16.80 | 3.00 | 5.50 |
| Sln.10 | 27.85 | 31.47 | 59.25 | 23.87 | 1.13 | 10.12 |

**Table 3. Mean data on bean dimensions of the $F_1$ hybrids and parent lines**

| Genotypes | Bean Length (mm) | Bean Breadth (mm) | Bean Thickness (mm) | 100 bean weight (g) 'A' grade |
|---|---|---|---|---|
| S.5083 | 10.31 | 7.04 | 4.15 | 19.58 |
| S.5084 | 10.45 | 6.78 | 4.14 | 19.73 |
| S.5085 | 10.42 | 6.90 | 4.11 | 19.23 |
| S.5086 | 10.71 | 7.02 | 4.25 | 19.80 |
| Sln.10 | 10.18 | 7.60 | 3.99 | 17.63 |
| Chandragiri | 10.77 | 7.02 | 4.10 | 19.26 |
| General Mean | 10.47 | 7.06 | 4.12 | 19.20 |
| C.V. | 19.49 | 20.30 | 14.44 | 17.75 |
| SEm± | 1.02 | 0.72 | 0.30 | 1.70 |
| CD @ 5% | NS | NS | NS | NS |

roasting, uniform bean size is preferable, giving uniform roast and thereby tastes better (Wintgens, 2012). Similar findings were reported by Leroy *et al.* (2006) that the uniform size of beans is ideal for roasting rather than the uneven size of the beans as the roasting of uneven sized beans results in charring/over roast of small-sized ones and under roasting of the larger beans, which affects the visual appearance and cup quality.

Further, in the global market, coffee quality is determined not only by the size of the green beans but also by the number of defects. However, in some studies, the weight of 100 beans (stands on screen 17) has been used as an indirect indicator of bean density which depends on the quality of seed filling during the development and ripening of the fruit (Bertrand *et al*. 2005; Tran *et al*. 2017). Lison *et al*. (2020) studied the bean size and the weight of 100 healthy green beans in new arabica $F_1$ hybrid clones *viz.,* Centroamericano-H1 and Starmaya in comparison with conventional Central American varieties and interpreted that the genotypes that have a higher 100 bean weight (W100) are also the genotypes with the best sensory qualities. Based on the lower W100 value and lower sensory notes, it was possible to distinguish the conventional variety, 'Caturra', from the new hybrids and inferred that W100 is a good cup quality predictor.

The second important criteria for assessing quality in coffee is the assessment of organoleptic properties of the beverage by sensory evaluation. Therefore, in the present study, the cup quality of the $F_1$ hybrids was assessed in comparison with the parent lines for two consecutive years. The scores are given by the panel of cup tasters to each of the attributes, *viz*., flavour, after-taste, acidity balance *etc.,* on a 10 point scale that was considered for calculating the cumulative score. Comparative analysis of the data on quality attributes for two consecutive years revealed that the mean cumulative score ranged from 76.3 to 80.3 among the $F_1$ hybrids and S.5085 recorded the maximum mean scores in both the years (79.75 and 81.0) followed by S.5086,

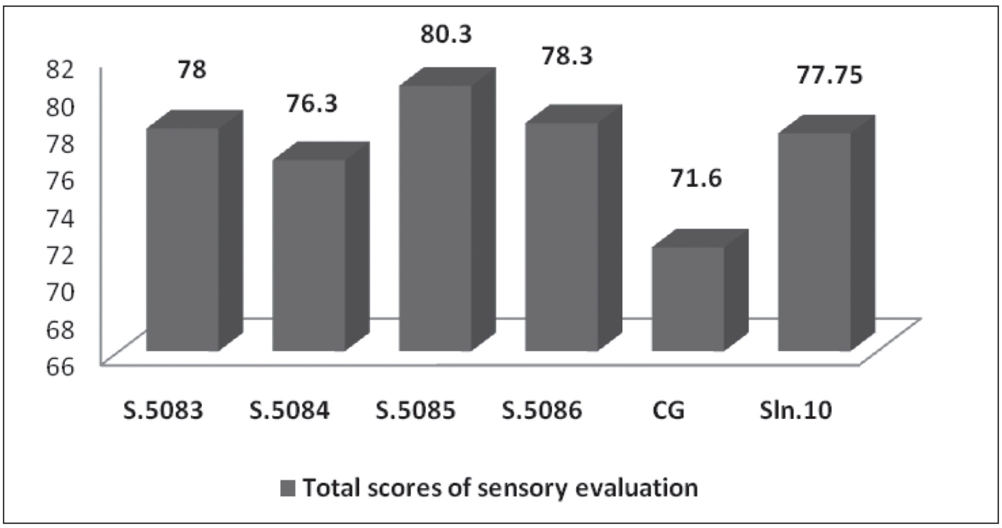


**Fig.1. Cumulative scores of sensory evaluation in $F_1$ hybrids and parent lines**

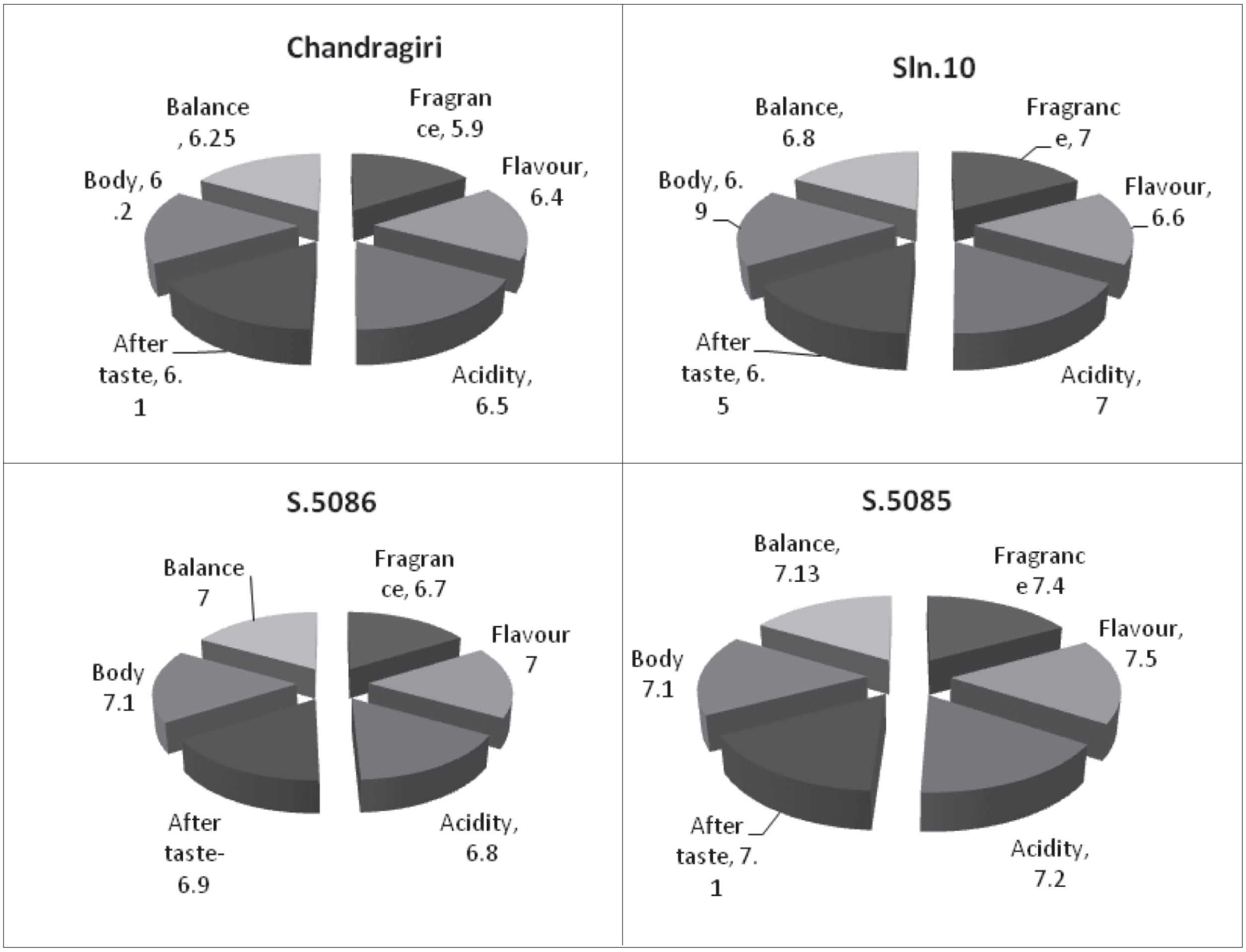


**Fig. 2. Quality profiles covering six important sensory notes of two promising $F_1$ hybrids (S.5085&S.5086) in comparison with the parent lines**

that scored 80.5 and 76.25 out of the total score of 100 (Fig. 1). The cup quality of S.5085 was characterised by 'Intense, sweet, pleasant aroma, sweet citrusy, chocolaty flavours and 'green apple-like taste'. Similarly, in S.5086, the quality note recorded was similar to S.5085. Thus, all the major sensory traits such as fragrance, flavour, body, acidity, balance and after taste values were recorded to be maximum in the $F_1$ hybrid S.5085, followed by S.5086.

Among the two parents, the cumulative score of different quality parameters was 77.6 in Sln.10 and 71.6 in Chandragiri. A total score above 70 denotes a very good cup while 80 and above is considered a fine cup that suits 'speciality coffee grade'. Thus, the sensory evaluation revealed a 'very good' to 'fine' cup quality note in $F_1$ hybrids. These quality attributes are on par with the Sln.10, known for its superior cup quality (Fig. 2).

The correlation coefficients for the physical quality and sensory traits of the hybrids and their parents are presented in Table 4. From the data, it is apparent that there is a positive significant correlation between all the sensory traits amongst the genotypes. Fragrance was positively correlated with acidity (r=0.76), balance (r=0.66), overall (r=0.65), flavour (r=0.63) and aftertaste. Flavour had highly significant association with after taste (r=0.82), balance (r=0.79), overall (r=0.79), acidity (r=0.74) and body (r=0.673). Whereas, acidity had strong positive correlation with overall (r=0.853), balance(r=0.72), after taste (r=0.71) and body (r=0.63). The body of the cup was positively correlated with balance (r=0.91) and overall (r=0.76).

**Table 4. Correlation coefficients between sensory variables and physical parameters of green beans**

| | Flavour | Acidity | After-taste | Body | Balance | Overall | AA | 'A'grade | 100BW |
|---|---|---|---|---|---|---|---|---|---|
| Fragrance | 0.634* | 0.769** | 0.625* | 0.639* | 0.665* | 0.651* | 0.283NS | -0.159NS | -0.083NS |
| Flavour | | 0.742** | 0.821** | 0.673* | 0.791** | 0.795** | 0.315NS | -0.204NS | -0.004NS |
| Acidity | | | 0.717** | 0.639* | 0.720** | 0.853** | 0.213NS | -0.248NS | -0.182NS |
| After-taste | | | | 0.924** | 0.885** | 0.724** | 0.445NS | -0.186NS | -0.044NS |
| Body | | | | | 0.916** | 0.763** | 0.276NS | -0.128NS | -0.224NS |
| Balance | | | | | | 0.845** | 0.142NS | -0.009NS | -0.379NS |
| Overall | | | | | | | 0.045NS | -0.244NS | -0.305NS |
| AA | | | | | | | | -0.677* | 0.719** |
| 'A' grade | | | | | | | | | -0.482NS |

* & ** indicates significant at 0.05 and 0.01 respectively, 'AA' grade- beans retained by 18mm, 'A' grade beans retained by 17mm sieve.100BW is the weight of 100 green beans in grams

The balance of the cup was highly correlated with the overall (0.84) score of the cup. However, the sensory traits were not significantly correlated with physical bean parameters. Nevertheless, a strong correlation was found between AA grade beans and 100 bean weight (r=0.71). Thus, all the sensory traits were correlated with each other and similar results were reported by Cheserek (2020) on assessing physical and sensory traits among 19 different coffee genotypes in Kenya.

The main objective of the $F_1$ breeding programme in Arabica was to improve the popular variety Chandragiri towards durable resistance to coffee leaf rust through pyramiding of the $S_H3$ gene but without affecting the yield potential and bean quality attributes. In this context, the findings of the present study are very important as the $F_1$ hybrids exhibited superior performance with respect to physical and organoleptic quality parameters. The quality evaluation data offers scope for selecting the best performing hybrids, S.5085 and S.5086, that is on par with the best parent, Chandragiri, regarding physical quality and Sln.10 in cup quality. It is pertinent to mention that these two hybrids also recorded promising agronomic performance with respect to yield and field tolerance to leaf rust (in press). The $F_1$ hybrid strategy undertaken as a pre-emptive breeding programme for genetic improvement of 'Chandragiri' variety with respect to enhanced vegetative vigour, yield potential, durable resistance to leaf rust and cup quality attributes is found to be promising. This inference has credence as the very objective of pyramiding the $S_H3$ gene for rust resistance could be achieved without affecting the agronomic performance and quality traits in the $F_1$ hybrids. In addition, stability in bean quality and improvement in cup quality in hybrids is a very positive development. In conclusion, the study provided useful insights in establishing the prospects of the $F_1$ breeding strategy in coffee to integrate agronomic interest traits and the production of heterotic $F_1$ hybrids. The two $F_1$ hybrids, S.5085 and S.5086 that exhibited promising performance have potential implications for commercial exploitation by adopting an appropriate multiplication strategy.

## Acknowledgement

The authors are grateful to the Director of Research, Central Coffee Research Institute, Coffee Board for the support and encouragement received throughout the research study. We also extend our sincere thanks to the cup tasting panel of Quality Division, Bengaluru, for the support extended.

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