Sensitive Optical Authentication of Honey: Probing 5% Adulteration with Laser-Induced Speckle Textures

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Abstract—This study employs the Dynamic Laser Speckle Technique (DLST) with grey-level co-occurrence-matrix analysis to detect 5 % burra-sugar adulteration across eight commercial honeys. A spatially filtered He–Ne laser beam interacted with liquid samples, producing speckle images captured at 64 fps by a CMOS sensor. Seven statistical textural metrics were extracted from the speckle images using MATLAB software. Average absolute percentage change in metrics such as cluster prominence, variance, and contrast changes by 12.4 %, 6.2 %, and 5.5 % respectively. The average change in inertia moment (IM) and absolute value difference (AVD) is −7.64 % and −5.39 %, respectively. DLST costs < $1 per sample, offering an economical safeguard for honey quality.

The issue of honey adulteration is a significant concern for both the health industry and beekeepers' livelihoods. Honey has been cherished for its medicinal properties, particularly for wound healing and alleviating cold symptoms. In India, the honey market is experiencing growth, offering profitable opportunities for beekeepers. However, they face challenges due to rising honey adulteration and difficulties in selling their product despite increasing demand. Currently, numerous well-established procedures exist for detecting honey adulteration. 1D and 2d NMR spectra had detected adulteration in honey up to 10% [1], and $\Delta\delta^{13}C$ differences reliably detected C3 and C4 sugars at 1-10% levels [2]. Differential scanning calorimetry has been used to identify adulteration in honey by syrups at levels as low as 5% [3]. FTIR spectroscopy correctly identifies adulterated honey up to 7% [4]. GC-MS detected DFAs at a concentration of 5% [5]. However, these methods and their sample preparation are costly. We identified 5% sugar adulteration in honey using the Dynamic Laser Speckle Technique (DLST). DLST proved effective across various analyses, including natural zeolites [6], blood flow imaging [7, 8], and epoxy resin curing [9]. Our lab has initially detected up to a 20% level of adulteration in honey using DLST [10]. We improved accuracy by adding an advanced digital image processing algorithm. Combining DLST with digital image processing allows us to reliably detect 5% adulteration in commercial honey for under $1 per sample.

This study probes the optical scattering of eight commercial honeys—Apis, Indigenous, Organic, Saffola, Dadev, Zandu, Patanjali, and Baidyanath adulterated at 5% with Burra Sugar (BS) (see Table 1). A 633 nm, 15 mW He–Ne laser was spatially filtered via a 40× microscope objective and 10 µm pinhole combination (kept 36.8 cm from the laser), then passed through an iris, at a distance of 2.7 cm downstream to produce a 0.5 cm-radius Gaussian beam. Sequentially, 4 mL of the samples were transferred into a quartz cuvette (10 mm optical path, 4.5 cm³ volume) placed 10 cm from the iris. After a five-minute settling period, each sample was uniformly exposed to the Gaussian beam. Speckle patterns were recorded at 30° with respect to the path of the laser beam using a CMOS sensor (Genie Nano 5G), placed 35.4 cm from the cuvette, and captured 15 frames at 64 frames per second (fps); each measurement was repeated three times. Post-acquisition, seven statistical and textural features were extracted in MATLAB to characterize adulteration (schematic setup is shown in Figure 1).

Table 1. Composition and Sample names of honey and 5% adulterated honey sample across all eight honeys.

Sample	Composition
A	5 gm Apis Honey + 20 ml diH_2O
A5	(4.75 gm Apis Honey: 0.25 gm BS) + 20 ml diH_2O
I	5 gm Indigenous Honey + 20 ml diH_2O
I5	(4.75 gm Indigenous Honey: 0.25 gm BS) + 20 ml diH_2O
O	5 gm Organic Honey + 20 ml diH_2O
O5	(4.75 gm Organic Honey: 0.25 gm BS) + 20 ml diH_2O
S	5 gm Saffola Honey + 20 ml diH_2O
S5	(4.75 gm Saffola Honey: 0.25 gm BS) + 20 ml diH_2O
D	5 gm Dadev Honey + 20 ml diH_2O
D5	(4.75 gm Dadev Honey: 0.25 gm BS) + 20 ml diH_2O
Z	5 gm Zandu Honey + 20 ml diH_2O
Z5	(4.75 gm Zandu Honey: 0.25 gm BS) + 20 ml diH_2O
P	5 gm Patanjali Honey + 20 ml diH_2O
P5	(4.75 gm Patanjali Honey: 0.25 gm BS) + 20 ml diH_2O
B	5 gm Baidyanath Honey + 20 ml diH_2O
B5	(4.75 gm Baidyanath Honey: 0.25 gm BS) + 20 ml diH_2O

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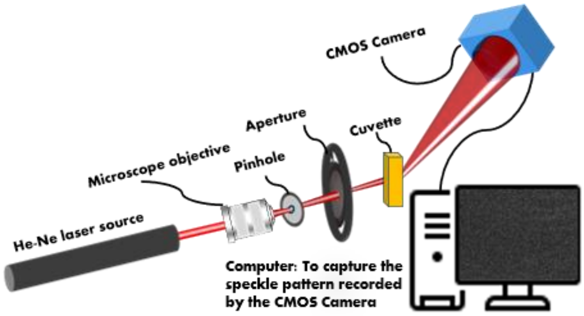

Fig. 1. Illustration of experimental setup for capturing speckle images produced by a scattered He-Ne laser beam after it interacts with liquid samples.

The value of brix (sugar content) and pH of the solution were measured using a handheld refractometer and a pH meter, respectively [11]. We have calculated two features (Mean and Variance), and five textures (Contrast, Autocorrelation, Angular Second Moment, Cluster Prominence, and Maximum Probability) using all 15 frames [12]. Inertia Moment (IM) sums each normalized COM element weighted by the squared index difference, while Absolute Value Difference (AVD) sums each weighted by the absolute index difference [13, 14].

Co-occurrence Matrix (COM) plots, shown in Fig. 2, reveal a slight qualitative change, with the COM plots indicating a modest reduction in diagonal and edge spread for the 5% adulterated honey compared to the pure sample.

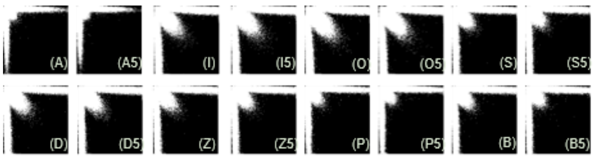

Fig. 2. Co-occurrence matrix (COM) plot of scattering images for pure and 5% adulterated honey, with each sample labelled with its respective sample name.

Across eight commercially available honey samples adulterated with 5% Burra sugar, we averaged each feature and texture measurement over three repeated experimental runs.

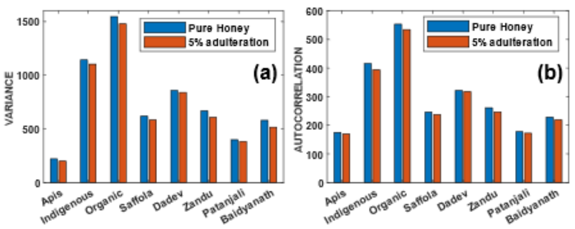

Fig. 3. Bar charts comparing pure and 5% adulterated honey across all samples for (a) variance and (b) autocorrelation.

Figure 3 presents two bar charts of Variance and Autocorrelation, in which the peaks of the honey sample are more prominent than those of 5% adulterated honey across all eight honey brands.

Table 2. Values of two features (Mean and Variance) and five textures (Contrast, Autocorrelation, Angular Second Moment (ASM), Cluster Prominence (CP), and Maximum Probability (MP)) obtained from the speckle image are calculated below.

Sample	Mean	Contrast	CP	ASM	MP
A	13.6	852.3	1607392.8	0.00325	0.0125
A5	13.1	809.9	1374698.3	0.00351	0.0134
I	27.3	2944.2	18782615.3	0.00097	0.0040
I5	26.2	2789.4	20179186.3	0.00102	0.0044
O	32.0	4030.9	28304291.2	0.00076	0.0032
O5	31.5	3873.5	25447012.3	0.00080	0.0034
S	20.2	1561.8	7081749.2	0.00157	0.0067
S5	19.9	1483.6	5847145.9	0.00162	0.0068
D	23.0	2129.7	14695378.8	0.00124	0.0055
D5	22.8	2087.9	13834696.3	0.00128	0.0057
Z	20.3	1641.1	9859085.1	0.00153	0.0068
Z5	19.8	1509.5	7582051.3	0.00162	0.0069
P	16.8	1009.3	2836223.6	0.00216	0.0090
P5	16.6	971.0	2506120.9	0.00223	0.0093
B	19.4	1456.2	6501219.3	0.00166	0.0071
B5	18.8	1300.0	4934556.2	0.00180	0.0076

After calculating the absolute average percentage change for all eight honeys from Table 2, the most sensitive feature was cluster prominence, which exhibited an average change of 12.41%, indicating a marked shift in texture. This was closely followed by variance (6.18%) and contrast (5.46%), all of which reflect increasingly pronounced textural changes as sugar is added. Angular second moment rose by 5.21 %, maximum probability by 4.59 %, suggesting modest gains in uniformity measures, and autocorrelation by 3.58 %. An intermediate shift was observed in the mean (2.24%), indicating that global disorder metrics are least affected by low-level adulteration.

Table 3. The table below lists IM, AVD, pH, and Brix values for pure and 5% adulterated honey samples.

Sample Name	IM	AVD	pH	BRIX
A	1815000	15599	4.24	16.2
A5	1109800	11261	4.27	16.2
I	4846700	30266	3.92	14.0
I5	4837600	30228	3.92	14.0
O	4844600	30235	3.98	16.0
O5	4839200	30229	4.04	16.0
S	4856300	30308	4.16	17.0
S5	4852100	30307	4.22	17.0
D	4832900	30208	3.94	16.0
D5	4823600	30189	4.05	16.2
Z	4837600	30225	4.05	16.2
Z5	4771000	29979	4.19	16.4
P	4326700	28012	4.29	16.6
P5	3469900	24099	4.45	16.6
B	4862200	30329	4.02	17.4
B5	4838900	30245	4.03	17.4

From Table 3, for 5% Burra-sugar adulteration, Apis honey's inertia moment plunged by 38.66% and its absolute value difference by 27.73%, whereas Indigenous honey showed almost no change (IM −0.19%, AVD −0.13%). Organic and Saffola honeys experienced slight IM declines of 0.11% and 0.09%, respectively, alongside AVD shifts of 0.02% and 0.003%. Dadev's IM fell by 0.19% with a 0.06% AVD decrease, and Zandu registered a 0.81% drop in AVD. Patanjali proved more vulnerable, losing 19.81% of its IM and 13.73% of its AVD. In terms of acidity, the pH rose modestly by 0.71% in Apis and 1.51% in Organic honey, while Dadev, Zandu, and Patanjali saw increases of 2.79%, 3.44%, and 3.73%, respectively. Indigenous remained steady at pH 3.92. Brix values remained stable at 16.2 (Apis), 14.0 (Indigenous), 16.0 (Organic), 17.0 (Saffola), 17.4 (Baidyanath), and 16.6 (Patanjali), with Dadev and Zandu exhibiting slight sweetening (+1.25% and +1.11%, respectively). These results highlight each brand's unique resilience and susceptibility to adulteration.

The dynamic laser speckle method with gray-level co-occurrence matrix analysis effectively detects 5% burra-sugar adulteration in all eight varieties of commercially available honey. We enhanced precision by incorporating an advanced digital image processing system. While the inertia moment and absolute value difference fall by 38.7% and 27.7% for Apis honey, the average change in inertia moment and absolute value difference is −7.64 % and −5.39 %, respectively. Key textural measures show prominent changes: cluster prominence (−12.4%), variance (−6.2%), and contrast (−5.5%). Conventional quality checks, on the other hand, are insensitive: pH increases by at most 3.7%, and Brix values remain essentially unchanged, thereby failing to highlight adulteration. For ordinary honey verification, DLST provides a better, sub-minute, <$1 sample preparation cost that offers producers and regulators quick, low-cost protection against economically driven fraud.

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