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Interpretable Non-Destructive Discrimination of Japanese Bast Fibers via Micro-Hyperspectral Imaging

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INTRODUCTION & AIM

- **Background:** Conservation repairs need fiber-compatible materials — a species mismatch causes secondary damage at the repair interface. Yet the standard JIS P8120 iodine-staining test is destructive and unsuitable for heritage objects.
- **Gap:** Macroscopic HSI / AI screening reads only surface morphology and offers little physicochemical interpretability; intrinsic single-fiber spectral signatures remain uncharacterized.
- **Aim:** Assess the feasibility of micro-hyperspectral imaging (Micro-HSI) with chemometrics for non-destructive, interpretable, species-level discrimination of three Japanese bast fibers — Kozo, Mitsumata, and Gampi.

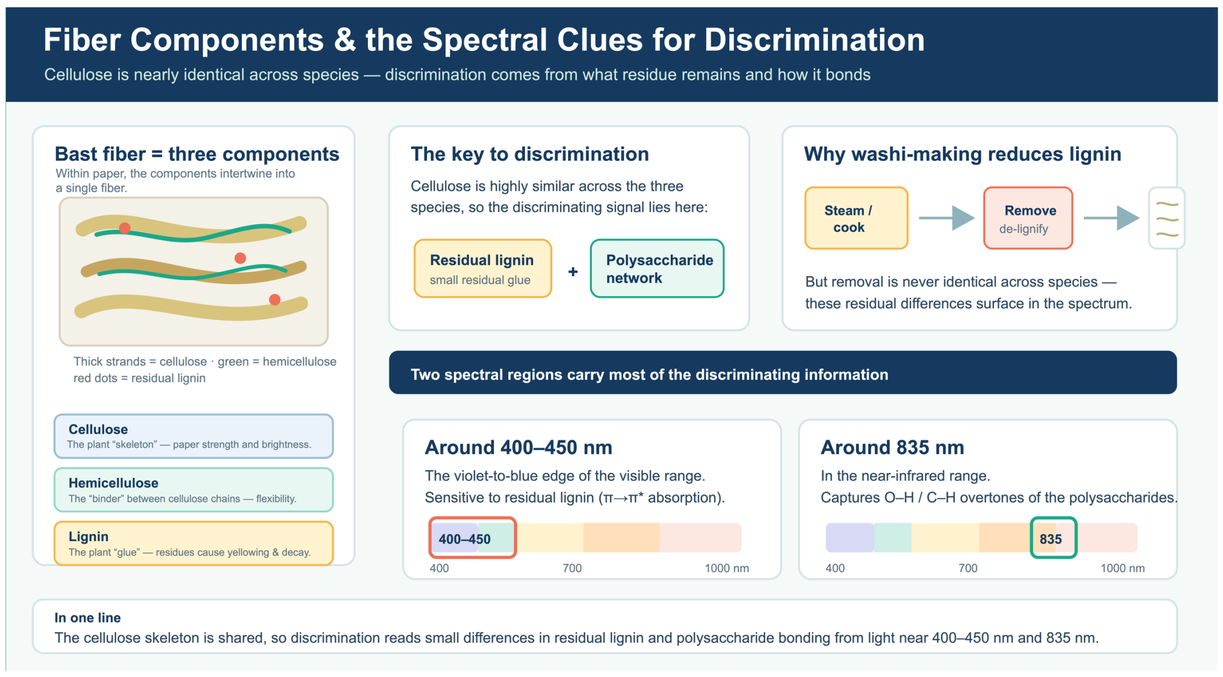


Fig. 1. Physicochemical basis and spectral interpretability for the discrimination of Japanese bast fibers. Fiber identification is based on two key diagnostic spectral regions: residual lignin absorption (≈400–450 nm) and polysaccharide overtone bands (≈835 nm). Although Kozo, Mitsumata, and Gampi share a common cellulose skeleton, subtle variations in residual lignin content and polysaccharide network structure, arising from species-specific chemical composition and processing, provide the spectral basis for their discrimination.

METHOD

- **Samples:** 3 bast fibers × 6 pure, additive-free specimens from an authenticated 1973 reference archive; 10 ROIs per specimen = 60 ROI spectra per class (18 specimens total).
- **Acquisition:** Push-broom HSI camera (NH-9) on an upright microscope, 50× objective, 350–1100 nm, 5 nm resolution.
- **Pre-processing:** Dynamic normalization → Savitzky–Golay 1st derivative → CV-based window (400–1000 nm) → Z-score.
- **Chemometrics:** PCA (unsupervised structure) and LDA (supervised discrimination), validated by Leave-One-Specimen-Out CV — one whole specimen held out per fold to avoid ROI data leakage.

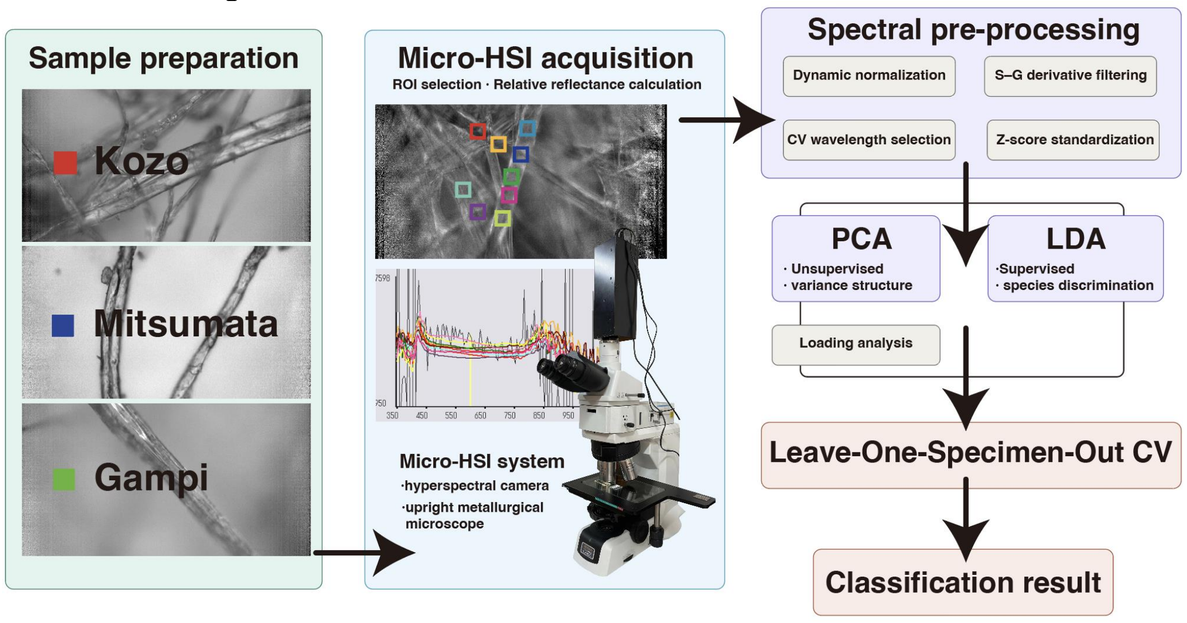


Fig. 2. Schematic overview of the analytical workflow. Three Japanese bast fibers—Kozo (red), Mitsumata (blue), and Gampi (green)—were analyzed using a Micro-HSI system consisting of a hyperspectral camera and an upright metallurgical microscope. Reflectance spectra were extracted from selected ROIs, followed by spectral pre-processing (dynamic normalization, Savitzky–Golay first derivative, CV-based wavelength selection, and Z-score standardization). Chemometric analyses were then performed using PCA and LDA, and classification performance was evaluated by Leave-One-Specimen-Out Cross-Validation (LOSO-CV).

RESULTS & DISCUSSION

- **PCA:** 95% confidence ellipses overlap heavily (PC1–3 = 62.5% variance) — the shared cellulose matrix masks species differences.
- **LDA:** Resolves all three fibers into distinct clusters (LD1 73.2%, LD2 26.8%).
- **Diagnostic bands:** Lignin π→π* transition (400–450 nm) and NIR O–H / C–H polysaccharide overtones (~835 nm).
- **Accuracy:** LOSO-CV = 77.8%; Kozo classified error-free (F1 = 1.00); Mitsumata and Gampi F1 = 0.67 each.
- **Confusion:** All errors fall within the chemically similar, low-lignin Mitsumata–Gampi pair.

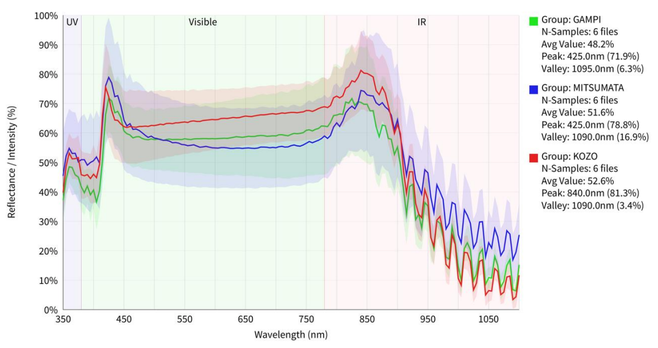


Fig. 3. Dynamically normalized reflectance spectra of the three bast fibers.

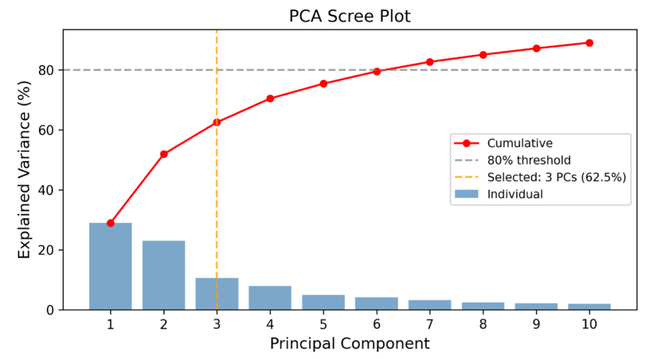


Fig. 4. PCA Scree plot.

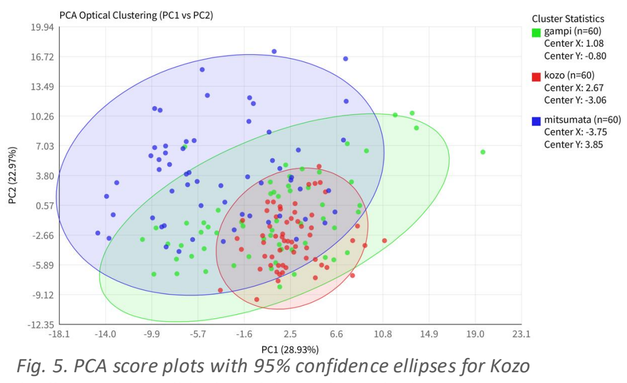


Fig. 5. PCA score plots with 95% confidence ellipses for Kozo (red), Mitsumata (blue), and Gampi(green):PC1 vs. PC2

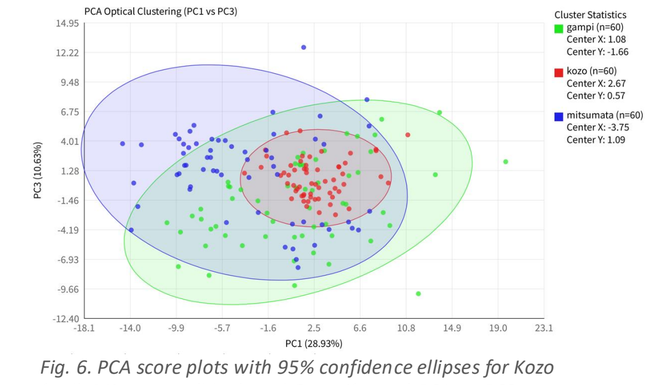


Fig. 6. PCA score plots with 95% confidence ellipses for Kozo (red), Mitsumata (blue), and Gampi(green):PC1 vs. PC3

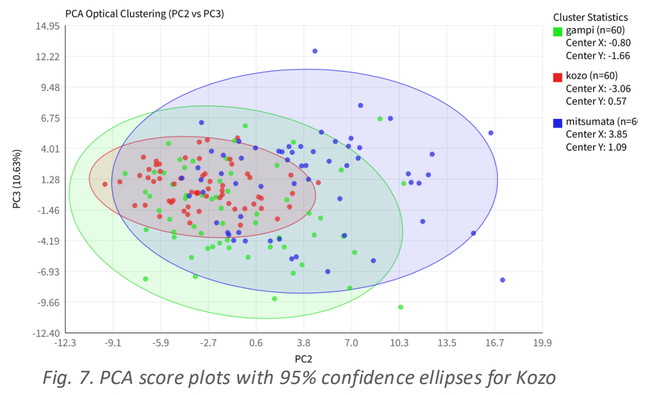


Fig. 7. PCA score plots with 95% confidence ellipses for Kozo (red), Mitsumata (blue), and Gampi(green):PC2 vs. PC3

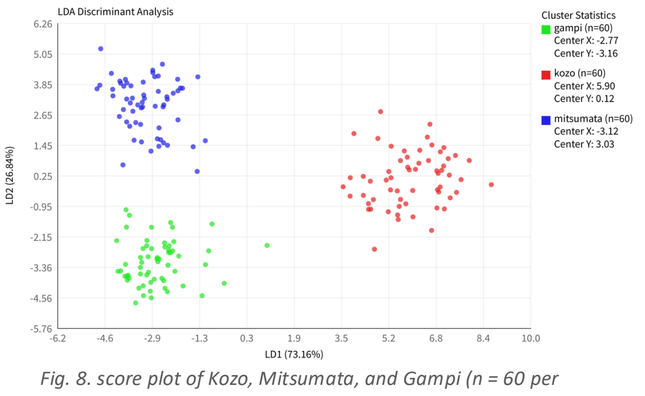
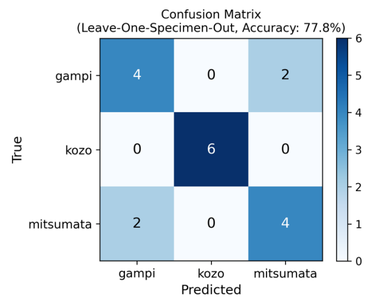


Fig. 8. score plot of Kozo, Mitsumata, and Gampi (n = 60 per class). All three fiber types form distinct clusters, with LD1 (73.16%) and LD2 (26.84%) providing effective species-level discrimination.



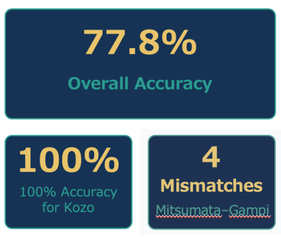


Fig. 9. LOSO-CV confusion matrix.

Error Analysis

Perfect Detection for Kozo: 100% correctly identified with zero errors.
Confined Misclassifications: All remaining errors (4 cases) occurred exclusively between Mitsumata and Gampi.
Chemical Consistency: This misclassification is highly plausible, as Mitsumata and Gampi share very similar chemical profiles and traditional preparation methods.

CONCLUSION

- Micro-HSI + chemometrics enables non-destructive, physicochemically interpretable fiber discrimination at the single-fiber scale.
- Establishes a controlled microscopic spectral reference to support future analysis of historical paper.

FUTURE WORK / REFERENCES

Future work

- Extend to naturally aged and historical specimens.
- Spectral unmixing for mixed-pulp documents; expanded reference datasets.
- Adapt acquisition for bound volumes and fragile artifacts.

References

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