Supplementary Materials

Table S1: Soil Element Content of Yellow-Brown Earth

| Element | Content Range |
| --- | --- |
| **Total Nitrogen (N)** | 0.05% - 0.25% |
| **Available Phosphorus (P)** | 5 - 30 mg/kg |
| **Exchangeable Potassium (K)** | 80 - 200 mg/kg |
| **Calcium (Ca)** | 0.5% - 3.0% |
| **Magnesium (Mg)** | 0.2% - 1.0% |
| **Organic Matter** | 1% - 6% |

Table S2: Chemical Indicators and Coordination of Flue-cured Tobacco Leaves After Curing in Different Regions

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Tobacco-growing County | Nicotine(%) | Total Sugar(%) | Reducing Sugar(%) | Total Nitrogen(%) | Potassium(%) | Chlorine(%) | Starch(%) | Sugar to Nicotine Ratio | Nitrogen to Nicotine Ratio | Reducing Sugar to Total Sugar Ratio | Potassium to Chlorine Ratio |
| Changshun | 2.87±0.04ab | 26.69±0.52a | 19.05±0.24 a | 1.96±0.03a | 2.56±0.09a | 0.11±0.01d | 4.08±0.05ab | 9.31±0.27a | 0.68±0.01a | 0.71±0.02a | 22.6±0.73a |
| Weining | 2.76±0.10ab | 26.68±3.03a | 20.34±3.53a | 1.96±0.05a | 0.38±0.01e | 0.44±0.03a | 3.54±0.62b | 9.68±1.04a | 0.71±0.04a | 0.76±0.06a | 0.89±0.06f |
| Anlong | 2.90±0.11ab | 24.93±2.66a | 19.14±0.61a | 2.03±0.13a | 1.10±0.01d | 0.33±0.02b | 4.34±0.39ab | 8.64±1.18a | 0.70±0.04a | 0.78±0.11a | 3.39±0.25e |
| Pingba | 2.73±0.31ab | 29.25±2.84a | 21.90±3.04a | 1.90±0.21a | 1.08±0.03d | 0.23±0.03c | 4.1±0.46ab | 10.97±2.27a | 0.69±0.01a | 0.75±0.03a | 4.76±0.71cd |
| Jinsha | 3.49±0.76a | 24.74±2.13a | 18.15±0.42a | 2.22±0.33a | 1.22±0.01c | 0.22±0.01c | 3.75±0.16ab | 7.51±1.94a | 0.64±0.05a | 0.74±0.07a | 5.66±0.22b |
| Yinjiang | 3.06±0.15ab | 29.75±2.37a | 20.88±3.30a | 1.98±0.13a | 1.41±0.01b | 0.33±0.02b | 4.67±0.66ab | 9.71±0.31a | 0.65±0.07a | 0.7±0.06a | 4.33±0.29de |
| Bozhou | 2.63±0.33b | 30.48±6.73a | 21.86±4.98a | 1.83±0.36a | 1.40±0.01b | 0.22±0.01c | 5.56±1.92a | 12.14±4.42a | 0.69±0.06a | 0.72±0.01a | 6.46±0.33bc |

Note: Values are presented as means ± standard errors (SE). Different lowercase superscript letters (e.g., a–f) within the same column indicate significant differences in specific chemical composition factors among tobacco-growing counties according to Duncan’s multiple range test (*p* < 0.05).

Table S3: Meteorological Factors Conditions in Different Regions

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Meteorological Factors | Tobacco-growing County | months | | | | |
| April | May | June | July | August |
| Precipitation (mm) | Changshun | 91.4±1.83dE | 277.1±6.08aB | 344±10.31aA | 156.7±0.28 cD | 180.4±0.76bC |
| Weining | 29±1.1fE | 76.8±2.58eD | 155.3±4.63dB | 178.1±3.03bA | 134.5±8.82 cC |
| Anlong | 39.7±0.93eD | 164.8±6.67bC | 218.2±13.93 cB | 220±4.90aB | 369.6±23.58aA |
| Pingba | 118.4±4.79 cD | 280.8±4.11aB | 350±5.64aA | 84.1±0.40eE | 202.2±8.9bC |
| Jinsha | 98±0.78dC | 110.7±3.21 cB | 214.4±11.63 cA | 80.9±3.45eD | 84.6±2.53dCD |
| Yinjiang | 230.1±5.82aA | 103.5±6.59dC | 108±2.59eB | 94.6±1.26dC | 53.9±3.21eD |
| Bozhou | 134±6.59bC | 121±3.7 cD | 243±7.5bA | 228.7±6.9aB | 57.3±1.26eE |
| Average Temperature (℃) | Changshun | 17±0.12aC | 20.5±0.08abB | 21.3±0.36 cB | 23.7±0.09bA | 23.1±0.46abA |
| Weining | 13±0.46bD | 15.9±0.9eC | 16.5±0.16dBC | 19.1±0.49 cA | 17.8±0.53dB |
| Anlong | 17.2±0.79aC | 20.7±0.16abB | 20.7±0.86bcB | 22.7±0.17bA | 21.5±0.9 cAB |
| Pingba | 16.7±1.18aD | 19.8±0.31bcC | 20.9±0.78bcB | 24.1±0.63bA | 22.6±0.41bAB |
| Jinsha | 18.1±1.03aD | 21.4±0.7aC | 22.7±0.54abBC | 26.9±0.45aA | 25±1.44abB |
| Yinjiang | 18.2±0.67aC | 17.9±0.34dC | 21.8±0.33bcB | 23.1±1.23bAB | 24.6±0.42abA |
| Bozhou | 18±0.67aB | 18.9±0.78 cdB | 23.1±0.9aA | 24.6±0.76bA | 25.6±0.48aA |
| Sunshine Duration (h) | Changshun | 127.9±1.97cC | 122.5±0.52dD | 66.8±2.96dE | 153.4±2.91cB | 165.9±2.91bA |
| Weining | 156.9±4.31bB | 172.2±3.27bA | 87.3±1.61bD | 130.7±1.68dC | 136±8.26cC |
| Anlong | 190.4±5.39aB | 216.5±2.22aC | 113.7±4.92aA | 204±9.91abA | 171.4±5.08bB |
| Pingba | 154.9±3.68bC | 154.4±2.67cC | 102.5±2.62aD | 219.1±7.45aA | 193.6±2.72aB |
| Jinsha | 122.1±2.91cC | 120.4±5.13dC | 77.7±0.95cD | 207±1.24bA | 184.6±6.25bB |
| Yinjiang | 68.1±2.41eD | 41.7±1.64eE | 87.6±2.19bC | 131.6±2.35dB | 178±1.15bA |
| Bozhou | 101.9±1.82dC | 37.8±0.88eE | 84.1±2.25bD | 122.5±3.39dB | 182±5.01bA |

Note: Values are presented as means ± standard errors (SE). Different lowercase superscript letters (e.g., a–f) within each column indicate significant differences in meteorological factors among tobacco-growing counties for a fixed month according to Duncan’s multiple range test (*p* < 0.05). Different uppercase superscript letters (e.g., A–E) within each row indicate significant differences in meteorological factors among months for a fixed tobacco-growing county according to Duncan’s multiple range test (*p* < 0.05).

Table S4: Cross-validated predictive performance of random forest models for tobacco chemical constituents

| **Metric** | MSE | RMSE | MAE | R² |
| --- | --- | --- | --- | --- |
| Nicotine | 0.2579 ± 0.417 | 0.3902 ± 0.3426 | 0.3169 ± 0.2556 | 0.9875 ± 0.0397 |
| Total Sugar | 21.7388 ± 16.4473 | 4.3336 ± 1.8132 | 3.6463 ± 1.2942 | 0.9098 ± 0.2853 |
| Reducing Sugar | 18.00 ± 12.29 | 3.83 ± 1.92 | 3.39 ± 1.72 | 0.992 ± 0.026 |
| Total Nitrogen | 0.0935 ± 0.0930 | 0.2689 ± 0.1534 | 0.2284 ± 0.1192 | 0.9357 ± 0.2032 |
| Potassium | 0.0854 ± 0.1195 | 0.2398 ± 0.1759 | 0.2056 ± 0.1748 | 0.8979 ± 0.3156 |
| Chlorine | 0.0026 ± 0.0023 | 0.0458 ± 0.0235 | 0.0398 ± 0.0230 | 0.7993 ± 0.4213 |
| Starch | 1.3344 ± 1.5749 | 1.0160 ± 0.5794 | 0.8427 ± 0.4064 | 0.9000 ± 0.3162 |
| Sugar to Nicotine Ratio | 8.0871 ± 8.9862 | 2.5184 ± 1.3924 | 2.0258 ± 0.9082 | 0.9191 ± 0.2560 |
| Nitrogen to Nicotine Ratio | 0.0034 ± 0.0028 | 0.0525 ± 0.0261 | 0.0467 ± 0.0235 | 0.9059 ± 0.2977 |
| Reducing Sugar to Total Sugar Ratio | 0.0075 ± 0.0075 | 0.0769 ± 0.0420 | 0.0664 ± 0.0363 | 0.9766 ± 0.0740 |
| Potassium to Chlorine Ratio | 0.0684 ± 0.0263 | 0.2567 ± 0.0562 | 0.1898 ± 0.0627 | 0.6337 ± 0.4566 |