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PERFORMANCE OF HIGH-YIELDING AND DISEASE-RESISTANT KASTURI TOBACCO GENOTYPES WITH ENHANCED LEAF QUALITY FOR SUSTAINABLE PRODUCTION

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SUMMARY

Kasturi tobacco (*Nicotiana tabacum* L.) is a sun-cured aromatic cultivar prized for its unique flavor and economic potential in premium blends. However, in Indonesia its cultivation constraints come from genetic degradation and susceptibility to various diseases, such as *Phytophthora nicotianae*, *Ralstonia solanacearum*, and Cucumber Mosaic Virus (CMV). This study sought to develop high-yielding, disease-resistant, and quality-consistent Kasturi genotypes through the integration of cytoplasmic male sterility (CMS)-based hybridization and recurrent bulk selection. Nine elite genotypes and two check cultivars entailed evaluation during 2020–2022 across three agroecological zones in Jember Regency, Indonesia. The tobacco genotypes Dark CK, Dark BK, and Dark AK exhibited considerable improvement in cured leaf yield (2.037 t ha⁻¹), cured leaf quality index (78.90), and crop index (151.68). Most tobacco genotypes enunciated remarkable resistance to *P. nicotianae* and *R. solanacearum*, though CMV susceptibility remains a challenge. Stability analysis identified four genotypes with consistent performance through genotype-by-environment interaction across diverse environments. The results provide considerable genetic basis and support for the development of export-oriented Kasturi cultivars and contribute to reducing dependency on tobacco imports in Indonesia.

Keywords: Kasturi tobacco (*N. tabacum* L.), recurrent selection, hybridization, genotype-by-environment interaction, disease resistance, cured leaf quality, yield stability

Key findings: The integration of CMS-based hybridization and recurrent selection successfully produced Kasturi tobacco (*N. tabacum* L.) genotypes with superior yield, better leaf quality, and disease resistance. Four tobacco genotypes revealed broad environmental adaptability, while one genotype showed specific adaptation. These genetic resources will enhance the productivity and export potential of sun-cured aromatic tobacco.

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INTRODUCTION

Indonesia is the homeland of a diverse array of tobacco ecotypes shaped by centuries of adaptation across varied agroecological zones (Djajadi, 2015). The genotype diversity underpins the development of region-specific cultivars such as Kasturi and Bondowoso types. Kasturi tobacco (*Nicotiana tabacum* L.) is a sun-cured aromatic cultivar cultivated in Indonesia, China, Turkey, India, and several African and American countries. In Indonesia, growing Kasturi tobacco primarily occurs in East Java before processing into 'krosok' for blending in premium 'kretek' cigarettes. Krosok refers to sun-cured sliced tobacco commonly used in premium kretek blends, a traditional Indonesian cigarette.

Despite its economic importance, Kasturi tobacco production faces various critical challenges. These constraints include genetic degradation due to the continued use of farmer-saved seeds, declined soil fertility, and increasing disease pressure, as observed in other sliced tobacco types, i.e., Banyuwangi tobacco (Rochman and Heliyanto, 2024). Moreover, recent Kasturi cultivars (BEI-301S and BEI-302S), released between 2019 and 2020, have shown inconsistent agronomic performance and limited acceptance by the industry due to quality concerns.

Indonesia's persistent tobacco trade deficit further underscores the urgency of strengthening domestic production. During 2020 and 2021, the tobacco imports reached USD 548.08 million and USD 586.68 million, respectively, while the exports remained below USD 74 million (Statistics Indonesia, 2022). This imbalance and import pressure highlight the need for developing high-performing and export-oriented cultivars that can reduce import dependency and compete in the global market.

Addressing these constraints, the former Research Institute for Tobacco and Fiber Crops, now integrated into BRIN, initiated a well-planned breeding program in 2006 in partnership with PT Benih Emas Indonesia, a private tobacco R&D company in Indonesia.

The program integrates cytoplasmic male sterility (CMS)-based hybridization and recurrent bulk selection strategies, proven to be effective in enhancing genetic uniformity and yield potential with better quality in flue-cured and oriental tobacco (Nanda *et al.*, 2022; Santos *et al.*, 2025). Recent advances in molecular breeding, including marker-assisted selection (MAS) and RNA interference (RNAi), have also shown promise in boosting disease resistance breeding, particularly against viral pathogens such as CMV, or the cucumber mosaic virus (Kakar *et al.*, 2020).

The novelty of the presented study lies in the integration of CMS-based hybridization with conventional selection to develop the stable and high-yielding Kasturi tobacco genotypes adapted to diverse agroecological zones of Indonesia. This approach directly supports Indonesia's strategic goals of reducing tobacco imports and expanding export capacity. The detailed objectives of this study were to a) develop high-yielding and better-quality Kasturi tobacco genotypes, b) obtain information on their resistance to major diseases, such as *P. nicotianae*, *R. solanacearum*, and CMV, and c) gather information on their stability across multiple locations.

MATERIALS AND METHODS

Genetic material

Tobacco pure lines, such as Dark AK, Dark FK, Dark GK, Dark HK, and Dark IK derivatives, resulted from biparental crossing, followed by multi-generational pedigree selection from F₂ to F₉ generations. Meanwhile, the CMS lines and hybrids (e.g., Dark BK, CK, Dark DK, and Dark EK) reached development via controlled backcrossing using *Nicotiana suaveolens* cytoplasm and elite donor lines, followed by six generations of backcrossing to restore all the agronomic traits. By the end of 2019, nine tobacco elite genotypes comprising pure lines, CMS lines, and hybrids entailed selection in comparison with two check cultivars (BEI-301S and BEI-302S) for multilocation trials.

Experimental sites and study duration

Field trials ran from 2020 to 2022 across three agroecological zones in Jember Regency, East Java, namely, Pakusari (lowland and sandy loam), Kalisat (mid-elevation and clay loam), and Summersari (upland and volcanic soil).

Experimental design

The experiments, laid out in a randomized complete block design, had three replications at all locations. Each plot consisted of 150–200 plants, with spacing at 110 cm × 90 cm × 50 cm. Standard fertilization treatment included 250 kg urea + 600 kg ZA + 100 kg SP-36 + 100 kg ZK per hectare.

Studied parameters

The data recording on traits included cured leaf yield (t ha⁻¹), cured leaf quality index (based on aroma, color, texture, and market grade), crop index (yield × quality), and nicotine content. The cured leaf quality index (QI) calculation used the following equation (Yulaikah *et al.*, 2015; 2022):

$$QI = \frac{\sum_{i=1}^n (a_i \times b_i)}{\sum_{i=1}^n b_i}$$

Where *QI* is the cured leaf quality index, *a_i* is the price index of the *i*-th treatment, *b_i* is the weight assigned to the quality of the *i*-th treatment, and *n* is the number of quality grades considered.

The calculation for crop index (CI) employed the following formula:

$$\text{Crop index} = \text{cured leaf quality index} \times \text{cured leaf yields (t ha}^{-1}\text{)}$$

Nicotine analysis relied on the titrimetric and gravimetric methods, which are reliable for alkaloid quantification in plant matrices (Qureshi *et al.*, 2022).

Disease resistance

Disease resistance assessment proceeded through artificial inoculation, followed by

systematic observation and classification, as described by Korubin-Aleksoska *et al.* (2015). For *Phytophthora nicotianae* and *Ralstonia solanacearum*, inducing infections used the root-dip inoculation method. The carefully uprooted seedlings had their roots immersed in a pathogen suspension (10⁶ cfu/mL) for 10–15 minutes. Post-inoculation continued with seedlings transplanted into sterilized soil to facilitate disease development under controlled conditions. This approach simulates natural root infection and has wide adoption for evaluating resistance to root rot and bacterial wilt.

In the case of cucumber mosaic virus (CMV), mechanical inoculation took place. The inoculum preparation ensued by grinding infected leaf tissue in phosphate buffer (pH 7.0). The resulting sap's application continued to the upper surface of young leaves pre-dusted with carborundum powder (silicon carbide) to induce micro-wounding. Leaves received gentle rubbing with a soft applicator to promote viral entry before rinsing with sterile water to remove excess abrasives. This method ensures uniform infection and is standard for screening viral resistance.

Disease symptom monitoring was at regular intervals, with resistance levels classified based on symptom severity, incidence, and progression, following the scoring criteria outlined by Korubin-Aleksoska *et al.* (2015). Genotypes attained categorization as resistant, moderately resistant, or susceptible groups, enabling comparative evaluation of disease response across treatments.

Data analysis

Analysis of variance (ANOVA), followed by the honestly significant difference (HSD) test at 5% significance, served for means comparison and separation. Stability analysis followed the Eberhart and Russell (1966) model, using regression coefficient (*b_i*) to assess the responsiveness to environmental change and deviation from regression (*S*²_{di}) to evaluate the stability. This model has been widely applicable in tobacco breeding to assess the genotype-by-environment interaction effects and

adaptability (Sowmya *et al.*, 2018; Nanda *et al.*, 2025).

RESULTS AND DISCUSSION

Cured leaf yield

According to analysis of variance, the Kasturi tobacco genotypes revealed significant variability for cured leaf yield. The genotype Dark CK produced the highest cured leaf yield (2.037 t ha⁻¹), followed by Dark BK (1.943 t ha⁻¹) and Dark AK (1.891 t ha⁻¹), showing a 15%–20% enhancement over the check cultivar (BEI-302S). The results confirmed the effectiveness of combining recurrent selection and CMS-based hybridization in improving tobacco productivity (Table 1). Applying similar approaches has been successful with better results in flue-cured tobacco breeding programs (Nanda *et al.*, 2022; Santos *et al.*, 2025).

Yield fluctuations were also noticeable across the growing seasons, likely influenced by climatic variables, such as ENSO (El Niño–Southern Oscillation) and IOD (Indian Ocean Dipole) events, known to affect crop performance in tropical growing regions (Muttaqin *et al.*, 2019). Tobacco genotypes that maintained consistent performance across the growing seasons demonstrate enhanced genetic resilience and adaptability.

Cured leaf quality index and nicotine content

Among the evaluated tobacco genotypes, significant differences were evident for the cured leaf quality index. The genotype Dark AK led in the index value (78.90), followed by Dark CK and Dark BK, and outperformed the check cultivar (BEI-302S) (Table 2). High index scores indicated superior aroma, texture, leaf maturity, and visual grading attributes. These improvements reflect the influence of the additive gene expression and hybrid vigor resulting from recurrent selection and CMS-based hybridization. Past studies also reported comparable improvement in cured leaf characteristics in flue-cured tobacco hybrids

(Ahmed *et al.*, 2019), underscoring the relevance of the present breeding strategies for quality-oriented selection.

Among the tobacco genotypes, the nicotine levels ranged from 1.21% (Dark HK) to 2.18% (Dark AK), and their obtained values were within acceptable commercial standards for oriental and flue-cured tobacco types. Elevated nicotine content showed general alignment with higher leaf quality index scores, supporting its role as a key chemical indicator in grading and market classification. Nicotine concentration usually has gained influences from genotypic variations, curing conditions, and soil nutrient dynamics (El-Hellani *et al.*, 2018). Previous reports also highlighted that nicotine content ranging between 1.5% and 2.3% was preferable for maintaining sensory balance and meeting export quality benchmarks (Shah *et al.*, 2018; Alsarahe and Sanad, 2021).

Crop index

Crop index values varied markedly among the tobacco genotypes, reflecting differences in economic potential based on yield and quality integration. The genotype Dark BK recorded the highest crop index (151.68), followed by Dark AK and Dark EK, and these genotypes surpassed the check cultivar BEI-302S (Table 3). These results indicated a balanced combination of productivity and cured leaf quality, as both variables are essential for market competitiveness. Tobacco genotypes with higher crop indexes offer greater profitability under conventional and contract-based production systems.

The crop index has become a comprehensive parameter that accounts for agronomic performance and grading outcomes. The crop index utilization in genotype selection has successful documentations in previous tobacco breeding programs targeting commercial deployment (Tang *et al.*, 2020; Zhu *et al.*, 2024). In the presented study, tobacco genotypes with moderate nicotine content and high-quality leaves contributed positively to crop index, suggesting the importance of trait integration during early-generation evaluation.

Table 1. Mean cured leaf yield (t ha⁻¹) of Kasturi tobacco genotypes during 2020–2022 across three locations.

Genotype	2020			Means	2021			Means	2022			Means	Means (years)
	Pakusari	Kalisat	Sumbersari		Pakusari	Kalisat	Sumbersari		Pakusari	Kalisat	Sumbersari		
Dark AK	1.773	2.001	2.225	1.999	1.704	1.769	1.878	1.784	1.710	1.445	2.518	1.891	1.891
Dark BK	1.858	2.126	2.125	2.037	1.884	1.748	2.058	1.897	1.970	1.250	2.469	1.896	1.943
Dark CK	2.050	2.154	2.297	2.167	2.005	1.950	2.019	1.991	2.269	1.033	2.553	1.952	2.037
Dark DK	2.040	1.576	2.085	1.900	0.920	0.815	1.784	1.173	1.755	0.712	2.036	1.501	1.525
Dark EK	1.749	1.831	1.957	1.846	1.202	0.889	2.234	1.441	1.861	1.359	2.183	1.801	1.696
Dark FK	1.700	1.872	1.956	1.843	0.897	1.718	0.753	1.122	1.710	1.134	1.804	1.549	1.505
Dark GK	1.629	2.212	2.275	2.038	1.481	1.712	0.767	1.320	1.661	1.128	1.856	1.548	1.636
Dark HK	1.648	1.919	2.024	1.864	1.286	0.849	1.815	1.317	1.532	0.915	2.266	1.571	1.584
Dark IK	1.872	1.916	2.087	1.958	1.833	1.663	1.756	1.751	1.843	1.171	2.186	1.733	1.814
BEI 301S	1.654	1.926	1.834	1.804	0.886	1.380	1.247	1.171	1.623	1.147	2.091	1.620	1.532
BEI 302S	2.130	2.172	2.174	2.159	1.095	1.239	1.474	1.269	1.785	1.130	2.014	1.643	1.690
HSD 5%	0.692	0.692	0.692	0.399	0.692	0.692	0.692	0.399	0.692	0.692	0.692	0.399	0.230

Note: BEI 301S: Check cultivar 1, BEI 302S: Check cultivar 2.

Table 2. Mean cured leaf quality index of Kasturi tobacco genotypes during 2020–2022 across three locations.

Genotype	2020			Means	2021			Means	2022			Means	Means (years)
	Pakusari	Kalisat	Sumbersari		Pakusari	Kalisat	Sumbersari		Pakusari	Kalisat	Sumbersari		
Dark AK	80.37	85.92	80.73	82.34	68.77	73.39	75.60	72.58	75.13	86.72	83.50	81.78	78.90
Dark BK	82.49	89.02	82.95	84.82	65.71	76.23	73.16	71.70	77.36	79.91	76.55	77.94	78.15
Dark CK	65.81	75.66	75.33	72.26	52.19	53.61	68.10	57.97	72.66	79.08	74.49	75.41	68.55
Dark DK	33.11	53.05	65.00	50.39	35.57	52.88	64.50	50.98	60.64	50.67	82.26	64.52	55.30
Dark EK	67.85	68.07	74.75	70.22	54.82	54.59	65.08	58.17	66.18	60.15	82.88	69.73	66.04
Dark FK	59.44	65.55	81.38	68.79	42.37	58.65	51.46	50.82	63.88	62.85	68.08	64.93	61.52
Dark GK	65.25	77.68	77.68	73.54	52.86	60.06	51.91	54.94	63.34	65.19	75.52	68.02	65.50
Dark HK	63.05	67.67	78.74	69.82	54.48	56.44	68.94	59.95	61.74	62.75	86.04	70.18	66.65
Dark IK	59.85	70.11	76.56	68.84	60.67	58.90	72.24	63.93	68.19	68.72	82.97	73.29	68.69
BEI 301S	60.43	56.54	73.99	63.65	61.80	63.73	66.70	64.08	70.12	62.62	77.98	70.24	65.99
BEI 302S	48.14	55.39	76.14	59.89	53.39	46.95	60.87	53.74	62.52	65.32	83.72	70.52	61.38
HSD 5%	18.81	18.81	18.81	10.86	18.81	18.81	18.81	10.86	18.81	18.81	18.81	10.86	6.27

Note: BEI 301S: Check cultivar 1, BEI 302S: Check cultivar 2.

Table 3. Mean crop index of Kasturi tobacco genotypes during 2020–2022 across three locations.

Genotype	2020			Means	2021			Means	2022			Means	Means (years)
	Pakusari	Kalisat	Sumbersari		Pakusari	Kalisat	Sumbersari		Pakusari	Kalisat	Sumbersari		
Dark AK	141.81	171.87	180.78	164.82	117.69	130.18	143.09	130.32	129.15	126.61	210.07	155.28	150.14
Dark BK	149.93	188.22	176.33	171.49	123.77	132.41	150.67	135.62	152.62	99.90	191.30	147.94	151.68
Dark CK	136.16	162.72	174.44	157.78	104.58	103.69	137.54	115.27	164.01	82.21	190.71	145.64	139.56
Dark DK	67.69	83.07	136.46	95.74	32.68	42.93	118.63	64.75	106.83	37.81	167.80	104.15	88.21
Dark EK	119.18	124.48	145.90	129.85	65.89	48.61	149.64	88.04	122.52	81.78	180.58	128.29	115.40
Dark FK	100.78	122.53	159.00	127.44	39.23	101.28	38.86	59.79	108.52	72.13	122.22	100.96	96.06
Dark GK	104.70	171.30	176.55	150.85	75.99	103.00	39.33	72.77	106.08	73.80	140.98	106.95	110.19
Dark HK	106.86	129.89	159.11	131.96	70.75	47.92	125.12	81.26	94.38	57.31	195.51	115.73	109.65
Dark IK	113.20	134.41	160.02	135.88	112.03	98.75	127.75	112.85	127.98	81.47	181.26	130.23	126.32
BEI 301S	102.48	110.13	135.56	116.06	54.53	87.62	83.43	75.19	114.89	70.37	162.47	115.91	102.39
BEI 302S	102.61	120.25	165.37	129.41	58.54	57.66	89.77	68.66	111.73	79.12	168.54	119.80	105.95
HSD 5%	61.34	61.34	61.34	35.41	61.34	61.34	61.34	35.41	61.34	61.34	61.34	35.41	20.45

Note: BEI 301S: Check cultivar 1, BEI 302S: Check cultivar 2.

Disease resistance

The selected Kasturi tobacco genotypes revealed distinct patterns of disease resistance, shaped by their breeding background. CMS-based hybrids—namely, Dark BK, Dark CK, Dark DK, and Dark EK—exhibited moderate to high resistance against *Phytophthora nicotianae* and *Ralstonia solanacearum*, with Dark EK showing consistent resistance across both pathogens (Table 4). These results reinforce the utility of CMS-based hybridization in enhancing soil-borne disease resilience, echoing findings from flue-cured tobacco studies (Kakar et al., 2020; Nanda et al., 2022).

In contrast, pure line genotypes, such as Dark AK, Dark FK, and Dark IK, displayed variable resistance profiles. Dark IK stood out with high resistance to *Phytophthora* and CMV, while Dark FK was highly susceptible across all pathogens. These

discrepancies suggest that while certain pure lines may carry innate resistance traits, CMS-based hybrids offer more consistent protection against soil-borne diseases.

However, CMV remains a major vulnerability. Despite some genotypes showing resistance to fungal and bacterial pathogens, nearly all lines—including CMS hybrids and pure lines—exhibited high susceptibility to CMV, with infection rates exceeding 60%. This highlights the absence of effective viral resistance mechanisms in the current breeding pool. Previous studies have reported similar limitations in conventional lines lacking virus-specific defense traits (Kakar et al., 2020). In addressing this, molecular breeding approaches—marker-assisted selection and RNA interference—should be priorities to develop CMV-resistant tobacco genotypes and ensure the long-term sustainability of Kasturi tobacco cultivation.

Table 4. Development rate (DR) and disease incidence (%) of black shank (*Phytophthora nicotianae*), bacterial wilt (*Ralstonia solanacearum*), and cucumber mosaic virus (CMV) in selected Kasturi tobacco.

Genotype	<i>Phytophthora nicotianae</i>			<i>Ralstonia solanacearum</i>			Cucumber Mozaic Virus		
	DR (r)	DI (%)	Category	DR (r)	DI (%)	Category	DR (r)	DI (%)	Category
Dark AK	0.014	40.00	MR	0.0079	16.67	HR	0.0566	75.00	HS
Dark BK	0.003	18.33	HR	0.0080	18.33	HR	0.0574	75.00	HS
Dark CK	0.023	51.67	S	0.0053	11.67	HR	0.0442	67.33	S
Dark DK	0.012	36.67	MR	0.0105	21.67	R	0.0374	64.00	S
Dark EK	0.009	26.67	R	0.0023	10.00	HR	0.0412	66.08	D
Dark FK	0.122	96.67	HS	0.0241	46.67	MS	0.0531	73.67	HS
Dark GK	0.056	78.33	HS	0.0201	38.33	MR	0.0526	72.75	HS
Dark HK	0.009	26.67	R	0.0031	11.67	HR	0.0539	73.33	HS
Dark IK	0.005	16.67	HR	0.0040	13.33	HR	0.0592	75.00	HS
Control Susceptible	0.169	98.33	HS	0.0291	55.00	S	0.0548	74.33	HS
Control Resistant	0.006	16.67	HR	0.0030	8.33	HR	0.0021	4.92	HR

Note: Disease Resistance Classification was based on Korubin-Aleksoska *et al.* (2015); 0% (Immune), 0 - ≤20% (Highly Resistant = HR), 20% - ≤ 30% (R = Resistant), 30% - ≤ 40% (Moderate Resistant = MR), 40% - ≤ 50% (Moderate susceptible = MS), 50% - ≤ 70% (Susceptible = S), and >70% (Highly Susceptible = HS).

Table 5. Regression coefficient (b_i) and deviation from regression (S^2_{di}) for cured leaf yield and crop index based on Eberhart and Russell's Model during 2020–2022 adaptation trials.

No.	Genotype	Cured leaf yield (t ha ⁻¹)				Crop index			
		b_i	t value	S^2_{di}	F value	b_i	t value	S^2_{di}	F value
1	Dark AK	0.786 ^{ns}	0.293	-6.967.3 ^{ns}	0.804	0.829 ^{ns}	0.200	-30.731 ^{ns}	0.817
2	Dark BK	0.831 ^{ns}	0.286	6.631.4 ^{ns}	0.813	0.810 ^{ns}	0.210	-19.877 ^{ns}	0.881
3	Dark CK	1.023 ^{ns}	0.354	18.927.8 ^{ns}	1.533	1.012 ^{ns}	0.179	-34.378 ^{ns}	0.795
4	Dark DK	1.407 ^{ns}	0.357	40.493.5 [*]	2.140	1.242 ^{ns}	0.299	290.243 [*]	2.732
5	Dark EK	0.928 ^{ns}	0.539	78.763.6 [*]	3.217	1.065 ^{ns}	0.343	349.825 [*]	3.088
6	Dark FK	0.885 ^{ns}	0.569	86.160.3 [*]	3.425	0.860 ^{ns}	0.471	620.361 [*]	4.703
7	Dark GK	0.916 ^{ns}	0.606	107.312.3 [*]	4.021	0.982 ^{ns}	0.512	893.061 [*]	6.330
8	Dark HK	1.264 ^{ns}	0.295	11.101.5 ^{ns}	1.312	1.320 ^{ns}	0.229	117.297 ^{ns}	1.700
9	Dark IK	0.737 ^{ns}	0.242	-17.148.5 ^{ns}	0.517	0.825 ^{ns}	0.186	-50.318 ^{ns}	0.700
10	BEI 301S	1.019 ^{ns}	0.272	-3.605.9 ^{ns}	0.899	0.914 ^{ns}	0.173	-54.740 ^{ns}	0.673
11	BEI 302S	1.204 ^{ns}	0.268	1.280.4 ^{ns}	1.036	1.141 ^{ns}	0.149	-63.103 ^{ns}	0.623

Note : t table 5% : 1,833; F table 5% : 2,056, BEI 301S: Check cultivar 1, BEI 302S: Check cultivar 2, ns = not significant.

Stability analysis

Tobacco genotypes' performance across multiple environments obtained analysis using the Eberhart and Russell (1966) model to determine the yield stability and adaptability. Regression coefficient near unity ($b_i \approx 1.0$) and low deviation from regression (S^2_{di}) succeeded their recording for four genotypes, Dark AK, Dark BK, Dark CK, and Dark IK, indicating consistent productivity under varied agroecological conditions (Table 5). The observed stability refers to the effectiveness of CMS-based hybridization combined with recurrent selection, which promotes the fixation of adaptive traits. Incorporating stability parameters early in the selection process enables identification of the genotypes suitable for diverse and marginal growing regions.

Similar stability findings have also received documentation in flue-cured tobacco hybrids developed through multi-environment trials (Gotami, 2021; Nanda *et al.*, 2025). Furthermore, the application of the Eberhart and Russell model in sugarcane (Heliyanto *et al.*, 2020) and Burley tobacco (Nirmal *et al.*, 2019; Raj *et al.*, 2019) breeding programs supports the relevance of this approach in evaluating genotypes reliability across the climatic and soil variations.

The promising study successfully demonstrated the effectiveness of recurrent selection combined with CMS-based hybridization in improving key traits of the Kasturi tobacco genotypes. Four tobacco genotypes, Dark AK, Dark BK, and Dark CK, consistently exhibited superior cured leaf yield with elevated leaf quality index, acceptable nicotine levels, and high crop index values. Stability analysis confirmed their broad adaptability across diverse environmental conditions. The disease screening revealed considerable resistance among the tobacco genotypes to major soil-borne pathogens, although susceptibility to CMV remains a limitation. These outcomes align with the study's objectives by identifying elite hybrids suited for sustainable cultivation under marginal growing conditions. Overall, the integrated breeding approach provides a robust

framework for advancement and improvement in Kasturi tobacco genotypes.

Environmental and agronomic considerations

The Kasturi genotypes' performance on marginal soils, particularly sandy loam conditions found in Pakusari, aligns with broader findings on sliced tobacco productivity in suboptimal environments (Zhao *et al.*, 2021). The presented study sites—Pakusari, Kalisat, and Summersari—represent sandy loam, clay loam, and volcanic soils, respectively, providing useful context with regosol comparison from Garut (Dianawati and Hamdani, 2022). Increased rainfall and shifting seasonal patterns have forced farming communities in East Java to adopt adaptive strategies, such as adjusting planting schedules and enhancing field drainage, with the same also documented in Temanggung Regency, Indonesia (Setiawan *et al.*, 2022). The study results underscore the importance of breeding not only for genetic resilience across the environments but also for practical adaptability aligned with farmer needs. Environmental factors, such as rainfall variability and temperature fluctuations, have a greater impact on yield and quality stability, and therefore, several agronomic adaptation measures require recommendations for Kasturi tobacco cultivation. Adjusting planting dates to avoid periods of excessive rainfall or drought can help synchronize crop growth with favorable weather conditions. The use of organic amendments and mulching are vital to improve soil moisture retention and nutrient availability, particularly on sandy loam soils (Zhu *et al.*, 2024). Site-specific fertilization and split fertilizer applications can further improve nutrient use efficiency and reduce losses. Deploying genotypes with proven stability and broad adaptability, as identified in this study, will help maintain consistent yields under diverse environmental conditions. Integrating these practices with improved Kasturi tobacco genotypes will enhance the resilience and productivity in the face of climate threats.

Supporting the sustainable cultivation of Kasturi tobacco, targeted agronomic

interventions have reached their recommendations. Practices, such as improved drainage systems and optimizing water and fertilizer management, can help mitigate the adverse effects of environmental variability on yield performance (Zhu *et al.*, 2024). Notably, tobacco leaves may serve a dual function by acting as a natural pesticide, thereby contributing to ecologically sound farming approaches (Andjani *et al.*, 2019). This multifunctional role enhances the economic value of Kasturi tobacco while reinforcing sustainable production systems suited for marginal growing conditions.

CONCLUSIONS

Five Kasturi tobacco (*N. tabacum* L.) genotypes (Dark AK, Dark BK, Dark IK, Dark CK, and Dark EK) surpassed the present standard cultivars in yield, grade, and disease resistance, though all remained susceptible to the Cucumber Mosaic Virus. The first four genotypes showed broad adaptability; meanwhile, Dark EK was environment-specific. The integration of CMS-based hybridization and recurrent selection effectively produced the high-performing and export-oriented genotypes for sustainable tobacco production.

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REFERENCES

Ahmed Q, Mohammad F, Ahmed S, Jadoon SA, Ali I, Din A (2019). Comparative genetic analysis for yield and quality traits in flue-cured tobacco. *Sarhad J. Agric.* 35(2): 500-512.

- <https://doi.org/10.17582/journal.sja/2019/35.2.500.512>.
- Alsarahe ATA, Sanad BNM (2021). Determination of nicotine in domestic and imported cigarettes in Aden (Yemen) markets. *Electr. J. Univ. Aden Basic Appl. Sci.* 2(3): 131-138.
- Andjani HN, Sentosa Y, Yati K, Jufri M, Fauzantoro A, Gozan M (2019). Determination of LC₅₀ value of *Nicotiana tabacum* L. extract against *Gryllus bimaculatus* imago and *Galleria mellonella* larvae. *AIP Conf. Proc.* 2193(1): 030024. <https://doi.org/10.1063/1.5139361>.
- Dianawati M, Hamdani KK (2022). Production of several local tobacco varieties on regosol soil in Garut Regency. *J. Bioindustry* 4(2): 84-92. <https://doi.org/10.31326/jbio.v4i2.1294>.
- Djajadi (2015). Tobacco diversity in Indonesia. *J. Biol. Res.* 20(2): 27-32. <https://doi.org/10.23869/106>.
- Eberhart SA, Russell WA (1966). Stability parameters for comparing varieties. *Crop Sci.* 6(1): 36-40.
- El-Hellani A, Salman R, El-Hage R, Talih S, Malek N, Baalbaki R, Saliba NA (2018). Nicotine and carbonyl emissions from popular electronic cigarette products: Correlation to liquid composition and design characteristics. *Nicotine Tob. Res.* 20(2): 215-223. <https://doi.org/10.1093/ntr/ntw280>.
- Gotami SJ (2021). Stability and adaptation of new tobacco varieties to three growing areas under rainfed conditions in Zimbabwe. *Agric. Sci. Dig.* 41(1): 81-84. <https://doi.org/10.18805/ag.D-232>.
- Heliyanto B, Djumali, Abdurrakhman, Syakir M, Sugiyarta E, Cholid M (2020). Development of high-yielding sugarcane varieties for rainfed areas: Yield multilocation trial of promising sugarcane clones. *IOP Conf. Ser.: Earth Environ. Sci.* 418: 012065. <https://doi.org/10.1088/1755-1315/418/1/012065>.
- Kakar KU, Nawaz Z, Cui Z, Zhu J, Xing B, Jin Y, Ren X, Khan S, Ali E, Ali M, Wang S, Luo L (2020). Molecular breeding approaches for disease-resilient tobacco. *Brief. Funct. Genomics* 19(1): 10-25. <https://doi.org/10.1093/bfpg/elz038>.
- Korubin-Aleksoska A, Arsov Z, Miceska G, Gveroska B, Aleksoski J (2015). Detection of resistance to Black Shank (*Phytophthora parasitica* var. *nicotianae*) in a trial with diallel crosses of tobacco. *Scien. Tobacco Instt. Prilep* 35: 19-28.
- Muttaqin AS, Suarma U, Nurjani E, Kurniadhini F, Prabaningrum R, Wulandari R (2019). The

- impact of climate variability on tobacco productivity over Temanggung Regency, Indonesia. *E3S Web Conf.* 76: 04003. <https://doi.org/10.1051/e3sconf/20197604003>.
- Nanda C, Saha S, Sahu S, Sahu PK, Sahoo BB, Panda P, Sahoo S, Sahoo SK, Sahoo BB, Mishra N (2022). Heterosis and character association studies in CMS hybrids of FCV tobacco. *Emerg. Life Sci. Res.* 8(2): 104–112. <https://doi.org/10.31783/elsr.2022.82104112>.
- Nanda C, Saha S, Sahu S, Sahu PK, Sahoo BB, Panda P, Sahoo S, Sahoo SK, Sahoo BB, Mishra N (2025). Assessment of CMS-based FCV tobacco hybrids for yield stability. *Indian J. Genet. Plant Breed.* 85(1): 157–164. <https://doi.org/10.5958/0975-6906.2025.00023.2>.
- Nirmal RR, Devi CPR, Gokulakrishnan J (2019). G×E interaction and stability analysis of maize hybrids using Eberhart and Russell model. *Int. J. Agric. Environ. Biotechnol.* 12(1): 1–6. <https://doi.org/10.30954/0974-1712.01.2019.1>.
- Qureshi A, Vyas J, Upadhyay U (2022). Determination of solubility by gravimetric method: A brief review. *Natl. J. Pharm. Sci.* 2(1): 1–3. <https://doi.org/10.5281/zenodo.6983325>.
- Raj RN, Devi CP, Gokulakrishnan J (2019). G×E interaction and stability analysis of maize hybrids using Eberhart and Russell model. *Int. J. Agric. Environ. Biotechnol.* 12(1): 1–6. <https://doi.org/10.30954/0974-1712.01.2019.1>.
- Rochman F, Heliyanto B (2024). Yield and quality of several Banyuwangi sliced-tobacco genotypes for sustainable kretek cigarette production. *IOP Conf. Ser.: Earth Environ. Sci.* 1413: 012023. <https://doi.org/10.1088/1755-1315/1413/1/012023>.
- Santos MP, Silva RM, Carvalho RF, Figueiredo DD, Soares AM, Almeida J, Silva F, Oliveira AC, Souza GM (2025). Recent advances in genetic improvement of tobacco. *Euphytica* 221: 66. <https://doi.org/10.1007/s10681-025-03516-5>.
- Setiawan AB, Pratama BR, Sabtiningtias N, Fatriasari W (2022). Impact of climate change on farmer adaptation and tobacco productivity in Temanggung regency. *Songklanakarini J. Sci. Technol.* 44(1): 128–135. <https://doi.org/10.14456/sjst-psu.2022.19>.
- Shah VV, Panchal H, Patel S, Agarwal R, Shah VK, Patel MM (2018). Estimation of nicotine content in commercial brands of bidis and cigarettes by non-aqueous titration. *Tob. Control* 10(2): 181–183.
- Sowmya HH, Kamatar MY, Shanthakumar G, Brunda SM, Shadakshari TV, Babu BS, Rajput SS (2018). Stability analysis of maize hybrids using Eberhart and Russell model. *Int. J. Curr. Microbiol. App. Sci.* 7(2): 3336–3343. <https://doi.org/10.20546/ijcmas.2018.702.401>.
- Statistics Indonesia (2022). Indonesia Tobacco Trade Statistics. Jakarta, Indonesia: Statistics Indonesia. (In Indonesian: Statistik Perdagangan Tembakau Indonesia).
- Tang Z, Chen L, Chen Z, Fu Y, Sun X, Wang B, Xia T (2020). Climatic factors determine the yield and quality of Honghe flue-cured tobacco. *Sci. Rep.* 10: 19868. <https://doi.org/10.1038/s41598-020-76919-0>.
- Yulaikah S, Herwati A, Djajadi D (2015). Varietas unggul tembakau Bondowoso. *Buletin Industri Tanaman Manis. Serat dan Minyak Nabati* 7(2): 102–113. <https://doi.org/10.21082/bulitf.v7n2.2015.p102-113>.
- Yulaikah S, Rochman F, Djajadi D, Herwati A, Hamida R, Ridhawati A, Supriyono (2022). Yield potential and adaptability of several introduced Burley tobacco genotypes across development areas. *IOP Conf. Ser.: Earth Environ. Sci.* 974: 012037. <https://doi.org/10.1088/1755-1315/974/1/012037>.
- Zhao W, Sun GW, Sun JG, Feng J, Chen SW, Chen ZG, Yang Y (2021). Climatic characteristics of Hubei tobacco area and its influence on the quality of upper leaves. *Agric. Sci.* 12(8): 863–874. <https://doi.org/10.4236/as.2021.12805>.
- Zhu R, He S, Ling H, Liang Y, Wei B, Yuan X, Cheng W, Peng B, Xiao J, Wei J, He Y, Xiao H, Wang Z (2024). Optimizing tobacco quality and yield through the scientific application of organic-inorganic fertilizer in China: A meta-analysis. *Front Plant Sci.* 2024 Dec 20; 15:1500544. doi: 10.3389/fpls.2024.1500544. PMID: 39759237; PMCID: PMC11697594.