



Improvising the Traditional Method of Mizo Smoked Pork (*Vawksa rep*) Preparation by Maintaining its Indigenous Sensory Quality- A Hurdle Technology Approach

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ABSTRACT

Background: Vawksa rep (VR), a popular smoked pork product of Mizoram, has a short shelf life and poses potential health risks due to Polycyclic Aromatic Hydrocarbon (PAH) contamination from traditional smoking methods. To address these issues, a modified smoking process using hurdle technology was developed to enhance shelf life and maintain the sensory qualities of traditional VR.

Methods: Fresh pork sourced from the Department of LPM, C.V. Sc, Aizawl, was processed into two variants: traditional Vawksa Rep (TVR) and modified Vawksa Rep (MVR). MVR involved marination with curing agents and spices, followed by smoking in an automatic unit at 75°C for 45 minutes using sawdust. It was then dipped in 2.5% potassium sorbate and sprayed with 75 ppm nisin before packaging. Both TVR and MVR were stored by wrapping with high density polyethylene packets and stored at ambient temperature (23-25°C) and 4±1°C and analysed for PAH levels, physico-chemical, microbiological and sensory characteristics on every 5th day up till 20 days.

Result: MVR showed improved physico-chemical and microbiological profiles, significantly ($p < 0.05$) enhanced shelf life and preserved sensory attributes compared to TVR. These improvements justify the slightly higher production cost. The modified process offers a valuable alternative for safer preservation of VR without compromising its traditional appeal.

Key words: Extended shelf-life, Hurdle technology, Modified vawksa rep (MVR), PAHs, Traditional vawksa rep (TVR).

INTRODUCTION

Meat preservation for extended shelf life is an age-old practice in India, with significant regional variations. Northeast India, home to over 200 tribal communities, has diverse indigenous meat processing methods, often involving drying, smoking (Kadirvel *et al.*, 2025), fermentation, or salting with local herbs, spices and plant extracts. In this region, Mizoram stands out with its predominantly non-vegetarian tribal population, where pork is the most consumed meat, followed by beef, chicken and chevon.

A popular traditional pork product in Mizoram is *Vawksa rep* (VR), meaning “dehydrated pork” in the Mizo language (*Vawk* = pig, *Sa* = meat, *Rep* = dehydrated). It consists of medium-sized smoked pork chunks Deuri *et al.* (2016), consumed regularly across the state. Traditionally, VR is prepared by simply smoking raw pork without any treatment, making it highly susceptible to spoilage due to microbial growth, fat rancidity and poor packaging, which limits its shelf life (Lalchamliani *et al.*, 2015).

To address these challenges, *hurdle technology* offers a promising solution (Kalaikannan *et al.*, 2022). This method combines multiple preservation techniques to create a synergistic effect that inhibits microbial activity by disrupting their homeostasis (Leistner, 2000). Widely used in modern food processing, key hurdles include temperature control, low water activity, pH, redox potential and natural or chemical preservatives.

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Incorporating edible preservatives like salt, vinegar, potassium sorbate and nisin Pawar *et al.* (2010), along with natural condiments such as garlic, ginger and spices, can significantly enhance the microbiological and physico-

chemical stability of VR. These components possess antimicrobial and antioxidant properties that can help extend the shelf life of *Vawksa rep* while preserving its traditional sensory qualities. Therefore, integrating hurdle technology with indigenous practices holds potential for improving both safety and consumer acceptability of this culturally significant meat product.

MATERIALS AND METHODS

Procurement of raw meat and preparation of spice mix

Pig was slaughtered scientifically following electro stunning technique at LPM, C.V. Sc and AH CAU, Aizawl and Ham part of the carcass was collected aseptically and packed in polythene bags and kept chill at $4\pm1^{\circ}\text{C}$ for 12 hrs, then stored at $-20\pm1^{\circ}\text{C}$ at the work place *i.e.* Department of Livestock Product Technology, College of Veterinary Science and Animal Husbandry; Central Agricultural University; Seleshi, Aizawl. A 100g spice mix was prepared following Debnath *et al.* (2020) using 14 spices in specific proportions. Spices were oven-dried at 50°C for 3 hrs, ground, sieved and stored airtight at $4\pm1^{\circ}\text{C}$. The study was carried out for duration of 11 months from September 2021 till July 2022.

Preparation of traditional vawksa rep (TVR)

Pork chunks (1.5-2") were traditionally smoked for 45 mins, then packed in food-grade HDPE. Samples were prepared thrice with six replicates (3 each of T1 and T2) and mean values from all repeats were used for PAH and other evaluations (Table 1).

Preparation of modified vawksa rep (MVR)

In Modified Vawksa rep, 1.5-2" pork chunks were cured with salt (5%), spice mix (1%), garlic (5%), ginger (2.5%) and vinegar (1%) at $4\pm1^{\circ}\text{C}$ for 24 hrs. Smoking was done

in a digital-controlled unit for 45 mins using moistened sawdust, at $85-100^{\circ}\text{C}$ (Ahmad *et al.*, 2003). After cooling at room temperature meat was dipped in 2.5% potassium sorbate, sprayed with 75 ppm nisin and packed. Samples were stored at ambient and $4\pm1^{\circ}\text{C}$. Triplicate batches with six replicates (T3 and T4) (Table 1) were used and mean values from all repeats were analysed for PAH and other parameters.

PAH detection and quantification in TVR and MVR using GC-MS

Homogenized smoked pork (10 g) was extracted with water-acetonitrile, centrifuged, dried with liquid N_2 , reconstituted in acetonitrile and 1 μl was injected into the GC inlet with BaP as internal control.

GC-MS analysis was done using a SHIMADZU QP2010 with an EB-5 column (30 m $\times$ 0.25 mm $\times$ 0.25 μm); 1 μl extract was injected in split less mode with helium (99.999%) at 1 mL/min. Oven was set from 100°C (5/ min) to 300°C at $8^{\circ}\text{C}/\text{min}$ (10/ min hold). Injector, transfer line and ion source temperatures were 250°C , 275°C and 200°C , respectively (EI at 70 eV). PAHs were identified using EPA 525 standards and m/z values (*e.g.*, BaP: 252) and results expressed in $\mu\text{g}/\text{kg}$.

Physio-chemical and microbiological evaluation

Post GC-MS analysis, the modified smoked pork with lowest acceptable PAH and desired sensory quality (3 hrs at 75°C with sawdust) was selected and stored at various temperatures alongside traditional samples (Table 1). pH, TBA (Wilson *et al.*, 1976), tyrosine value 9 (Strange *et al.*, 1977) and proximate composition (moisture, protein, fat) were evaluated using standard AOAC methods at regular intervals (every 5 days) during both refrigerated (0-20 days) and ambient storage ($23-25^{\circ}\text{C}$) until

Table 1: Formulation for preparation of different treatment group of TVR and MVR.

	Treatment-1 (T1)	Treatment-2 (T2)	Treatment-3 (T3)	Treatment-4 (T4)
Ingredients				
Pork	1000 gm	1000 gm	1000 gm	1000 gm
Salt	0	0	5%	5%
Spice-mix	0	0	1%	1%
Vinegar	0	0	1%	1%
Ginger	0	0	2.5%	2.5%
Garlic	0	0	5%	5%
Potassium sorbate	0	0	2.5% of solution	2.5% of solution
Nisin	0	0	75 $\mu\text{g}/\text{g}$	75 $\mu\text{g}/\text{g}$
Preparation parameters				
Smoking temperature ($^{\circ}\text{C}$)	Approx. 100°C	Approx. 100°C	75°C	75°C
Smoking duration (minute)	45 minutes	45 minutes	45 minutes	45 minutes
Smoking material	Charcoal	Charcoal	Saw dust	Saw dust
Storage condition				
Temperature ($^{\circ}\text{C}$)	Ambient temperature ($23 \pm 1^{\circ}\text{C}$)	Refrigerated at $4\pm1^{\circ}\text{C}$	Ambient temperature ($23 \pm 1^{\circ}\text{C}$)	Refrigerated at $4\pm1^{\circ}\text{C}$

T1: TVR at ambient temp, T2: TVR at refrigeration temp, T3: MVR at ambient temp, T4: MVR at refrigeration temperature.

spoilage. Cooking yield was calculated from weight loss after preparation.

TVC (Traditional Vawksa rep) was assessed per APHA (2015) on days 0, 5, 10, 15 and 20 (refrigerated) and every 3 days (ambient) until spoilage. *E. coli* was counted using ISO 16654:2001; *Salmonella* sp. via ISO 6579:2002 on days 0 and 20 (for refrigerated) and every 3 days (for ambient). *Staphylococcus aureus* was detected using ISO 6888-1:2003 and *Listeria monocytogenes* by ISO 11290-1 (Jamali *et al.*, 2013). Halophilic bacteria were enumerated on Sea Water Agar using pour plate method (APHA, 1984) on days 0 and 20 (for refrigerated temp) and days 0 and 9 (for ambient temp, *i.e.* 23-25°C).

Sensory evaluation

Sensory evaluation was conducted thrice by eight semi-trained panellists using an 8-point scale (Keeton, 1983), assessing appearance, flavour, texture, juiciness and overall acceptability for all replicates of TVR (T1, T2) and MVR (T3, T4). Mean scores per session were recorded and final results reported as mean±SD for each parameter per treatment group.

Statistical analysis

Statistical analysis was performed using SPSS version 21.0 (IBM) for the Windows platform (IBM Corp. Armonk, NY, USA). All the categorical variables are presented as numbers or ratios and the continuous variables as mean±SD. A chi-square test was performed to find the differences in nominal data among the different groups. One-way ANOVA was performed to compare the mean difference in continuous variables.

RESULTS AND DISCUSSION

Detection of PAHs in TVR and MVR

GC-MS analysis using EPA 525 standards detected various PAHs in all smoked pork samples, including

Acenaphthylene, Fluorene, Phenanthrene, Anthracene, Pyrene, BaA, CHR, BbF and BaP (Fig 1). Based on IARC classification, BaA, BbF and CHR are group 2B (possibly carcinogenic), while BaP is group 1 carcinogenic, Mali *et al.*, (2025). Other PAHs fall under group 3 (unclassifiable). Therefore, only BaA, BbF, CHR and BaP were quantified for further analysis.

Analysis of impact of smoking temperature and duration on PAH concentration

PAH concentrations increased with rising smoking temperatures, with CHR consistently highest, followed by BaA, BaP and BbF. Total PAHs (PAH4) showed a linear rise, with BaP increasing 3.5-fold from 1.8 to 6.3 µg/kg between 55°C and 95°C. The sharpest BaP spike occurred between 75°C and 85°C. BaA and CHR also rose, notably between 65°C-85°C and 75°C-85°C, respectively. Overall, a 40°C increase (55°C-95°C) caused a 3.5-fold rise in BaP, 2.3-fold in BaA, 2.75-fold in CHR, 5.7-fold in BbF and 3-fold in PAH4. Thus, smoking temperature critically impacts PAH levels, with 75°C using sawdust being the most suitable for *Vawksa rep* preparation (Fig 2).

Smoking duration significantly affects PAH levels, with concentrations rising as duration increases. CHR remained highest across all durations, while BaP rose sharply beyond 45 minutes. From 45 to 90 minutes, BaA nearly doubled, CHR rose 1.5-fold and BbF by 1.49-fold, with similar trends in total PAHs. The optimal duration balancing PAH safety and sensory quality was 45 minutes at 75°C using sawdust (Fig 3).

Analysis of PAHs in TVR and MVR

Traditional Vawksa Rep (TVR) smoked with charcoal showed significantly higher PAH levels than Modified Vawksa Rep (MVR). BaP was 11.3 µg/kg in TVR vs. 3.5 µg/kg in MVR, with BaA, CHR and BbF also markedly higher (39.5, 39.9, 8.01 µg/kg) compared to MVR (5.01, 7.25, 2.1 µg/kg).

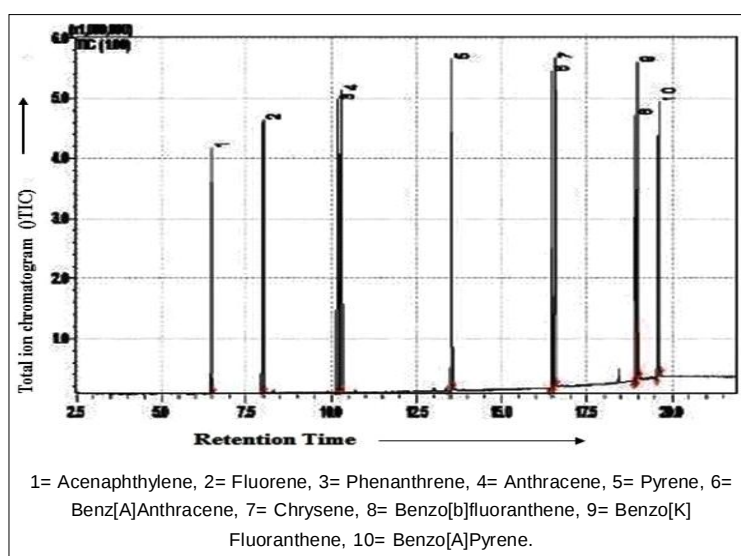


Fig 1: TIC of detected polycyclic aromatic hydrocarbons in EPA 525.

Total PAHs were 94.5/ $\mu\text{g/kg}$ in TVR vs. 22.35 $\mu\text{g/kg}$ in MVR ($p>0.05$), confirming lower PAHs under controlled sawdust smoking (Fig 4).

Optimum conditions for production of modified vawksa Rep (MVR)

Based on GC-MS results obtained, modified Vawksa rep (MVR) was prepared by initial marination of the raw pork meat using the modified marinade composition of (Debnath

et al., 2020) (details in method section) following which the meat samples were smoked for 45 minutes at 75°C using saw dust in an automatic smoking unit by maintaining indigenous sensory quality.

Analysis of physico-chemical parameters of TVR and MVR

pH, TBA, tyrosine value (TV) and proximate properties (moisture, protein, fat) were monitored in Traditional (TVR) and Modified Vawksa Rep (MVR) under refrigerated and

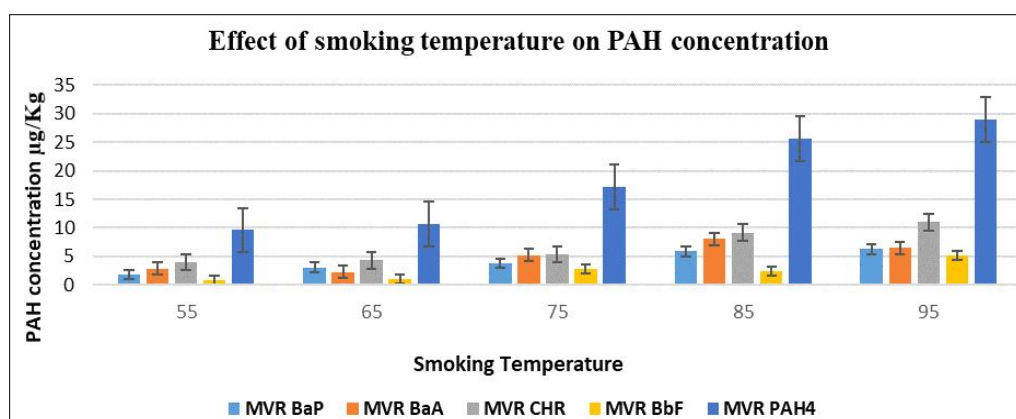


Fig 2: Effect of smoking temperature (°C) on PAH concentration ($\mu\text{g/Kg}$) of modified vawksa rep (MVR).

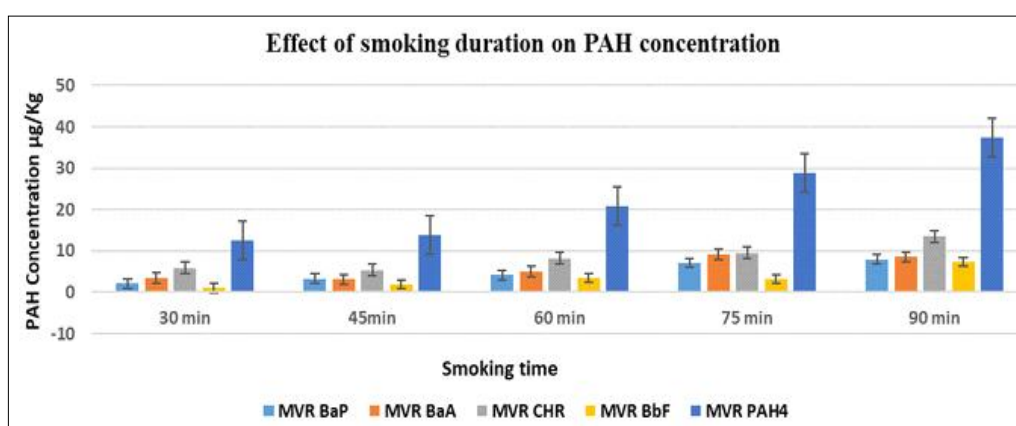


Fig 3: Effect of smoking duration (Minutes) on PAH concentration ($\mu\text{g/Kg}$) of modified vawksa rep (MVR).

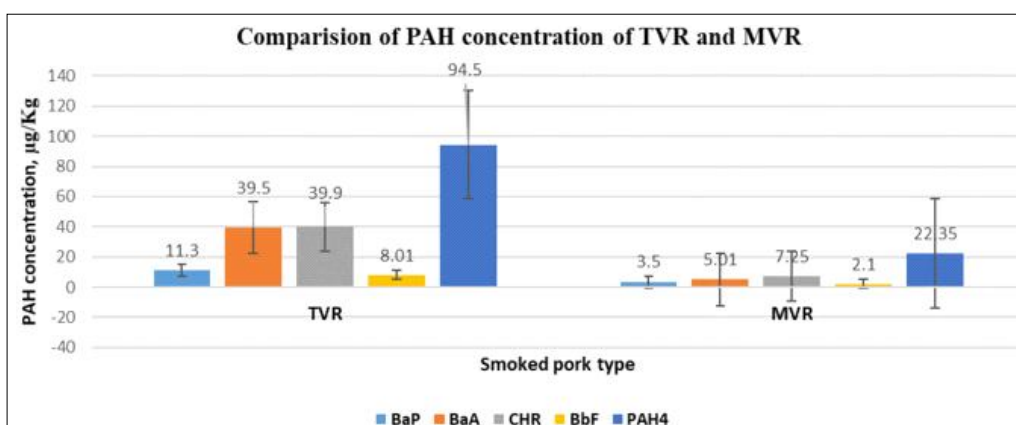


Fig 4: Comparison of PAH concentrations ($\mu\text{g/Kg}$) between modified vawksa rep (MVR) and the traditional vawksa rep (TVR).

Table 2: Analysis of physico-chemical characteristics of modified vawksa rep (MVR) and traditional vawksa rep (TVR) stored at different storage temperature.

Treatment	Storage at 4±1°C (Mean± SD) (T2 and T4)						Storage at room temperature (Mean± SD) (T1 and T3)					
	Period of storage (in days)						Period of storage (in days)					
	0	5	10	15	20	p value	0	5	10	15	p value	
pH value												
TVR (T2 and T1)	5.78±0.01	5.80±0.01	5.85±0.01	5.90±0.01	5.97±0.11	0.045	5.78±0.01	6.40±0.02	7.30±0.01	ND	0.001	
MVR (T4 and T3)	6.21±0.01	6.27±0.01	6.30±0.01	6.32±0.08	6.35±0.06	0.146	6.21±0.01	6.31±0.03	6.37±0.02	7.01±0.01	0.045	
TBA value												
TVR (T2 and T1)	0.18±0.04	0.25±0.01	0.29±0.02	0.30±0.03	0.32±0.02	0.001	0.18±0.04	0.84±0.07	0.92±0.08	ND	0.022	
MVR (T4 and T3)	0.27±0.02	0.28±0.01	0.29±0.01	0.29±0.02	0.31±0.02	0.215	0.27±0.02	0.74±0.03	0.84±0.01	0.924±0.01	0.035	
Tyrosine value (mg tyrosine/100 gm)												
TVR (T2 and T1)	2.92±0.07	3.08±0.05	3.45±0.04	3.82±0.02	4.32±0.01	0.062*	2.92±0.07	13.02±0.3	33.50±0.36	×	0.001	
MVR (T4 and T3)	2.92±0.09	2.9±0.08	3.18±0.08	3.53±0.05	3.99±0.09	0.462	2.92±0.09	9.41±0.11	16.05±0.54	22.50±0.21	0.001	
Proximate analysis												
Moisture content (Per cent mean±S.E.)												
TVR (T2 and T1)	63.25±0.47	62.89±0.28	61.01±0.25	57.9±0.03	59.38±0.75	0.63	62.25±0.47	62.83±0.34	63.68±1.20	ND	0.920	
MVR (T4 and T3)	62.52±1.06	62.48±0.75	59.95±0.26	59.01±0.35	57.67±0.84	1.50	62.52±1.06	61.45±0.35	63.09±1.04	63.85±0.01	0.170	
Crude protein (CP) (Per cent mean±S.E.)												
TVR (T2 and T1)	19.43±0.26	19.51±0.65	19.77±0.31	19.07±0.47	19.94±0.59	0.58	19.43±0.26	19.33±0.25	19.28±0.75	ND	0.210	
MVR (T4 and T3)	19.58±0.64	19.55±0.41	19.79±0.01	19.83±0.21	19.83±0.52	0.09	19.58±0.64	19.45±0.01	19.62±0.41	19.62±0.89	0.290	
Crude fat/ether extract (EE) (Per cent mean±S.E.)												
TVR (T2 and T1)	15.05±0.32	15.05±0.85	15.9±0.45	16.32±0.33	16.81±0.53	0.801	15.05±0.32	15.02±0.31	14.87±1.29	ND	0.135	
MVR (T4 and T3)	15.39±0.99	15.65±0.01	16.45±0.07	16.98±0.28	17.02±0.63	0.820	15.39±0.99	15.33±0.36	15.24±0.37	15.00±1.36	0.23	

Data represented as mean±SD, P<0.05 was considered significant.

Table 3: Analysis of microbiological parameters of modified vawksa rep (MVR) and traditional vawksa rep (TVR) stored at different storage temperature.

Treatment	Storage at 4±1°C (Mean± SD) (T2 and T4)					p value	Storage at room temperature (Mean± SD) (T1 and T3)					p value
	Period of storage (in days)						Period of storage (in days)					
	0	5	10	15	20		0	5	10	15		
Total viable count (TVC) log CFU/gm												
TVR (T2 and T1)	3.93±0.14	4.27±0.08	4.54±0.11	4.79±0.06	4.98±0.09	0.013	3.93±0.14	6.76±0.02	7.12±0.04	ND	0.001	
MVR (T4 and T3)	1.17±0.05	1.33±0.06	1.58±0.44	1.71±0.03	1.88±0.02	0.001	1.17±0.05	3.28±0.04	6.24±0.02	7.18±0.06	0.023	
E. Coli (Present or absent)												
TVR (T2 and T1)	Absent	Absent	Absent	Absent	Absent	N/A	Absent	Absent	Absent	ND	N/A	
MVR (T4 and T3)	Absent	Absent	Absent	Absent	Absent	N/A	Absent	Absent	Absent	Absent	N/A	
Salmonella spp. (Present or absent)												
TVR (T2 and T1)	Absent	Absent	Absent	Absent	Absent	N/A	Absent	Absent	Absent	ND	N/A	
MVR (T4 and T3)	Absent	Absent	Absent	Absent	Absent	N/A	Absent	Absent	Absent	Absent	N/A	
Staphylococcus aureus (Present or absent)												
TVR (T2 and T1)	Absent	Absent	Absent	Absent	Absent	N/A	Absent	Absent	Absent	ND	N/A	
MVR (T4 and T3)	Absent	Absent	Absent	Absent	Absent	N/A	Absent	Absent	Absent	Absent	N/A	
Listeria monocytogenes (Present or absent)												
TVR (T2 and T1)	Absent	Absent	Absent	Absent	Absent	N/A	Absent	Absent	Absent	ND	N/A	
MVR (T4 and T3)	Absent	Absent	Absent	Absent	Absent	N/A	Absent	Absent	Absent	Absent	N/A	
Halophilic bacteria count												
TVR (T2 and T1)	ND	ND	ND	ND	ND	N/A	ND	ND	ND	ND	N/A	
MVR (T4 and T3)	0.59±0.03	0.67±0.01	0.89±0.65	1.12±0.08	1.18±0.04	1.036	0.59±0.03	1.63±0.28	3.05±1.25	4.09±0.16	0.001	

Data represented as mean±SD, P<0.05 was considered significant.

Data represented as mean±SD, P<0.05 was considered significant.

Table 4: Analysis of Sensory characteristics of modified vawksa rep (MVR) and traditional vawksa rep (TVR) stored at different storage temperature.

Treatment	Storage at 4±1°C (Mean±SD) (T2 and T4)						Storage at room temperature (Mean±SD) (T1 and T3)					
	Period of storage (in days)						p value	Period of storage (in days)				p value
	0	5	10	15	20	0		5	10	15		
Odour assessment												
TVR (T2 and T1)	9.07±0.11	9.03±0.09	8.77±0.08	8.44±0.09	8.37±0.10	0.026	9.07±0.11	6.29±0.08	1.22±0.08	×	0.001	
MVR (T4 and T3)	9.01±0.08	8.97±0.09	8.81±0.09	8.48±0.11	8.48±0.09	0.321	9.11±0.08	7.51±0.11	5.62±0.09	2.55±0.09	0.002	
Appearance												
TVR (T2 and T1)	5.59±0.09	5.51±0.11	5.44±0.11	5.37±0.12	5.25±0.12	0.561	5.59±0.09	2.81±0.11	×	×	0.001	
MVR (T4 and T3)	7.29±0.08	7.18±0.09	7.11±0.11	7.03±0.12	6.96±0.09	0.378	7.29±0.08	6.81±0.11	6.44±0.14	×	0.048	
Flavour												
TVR (T2 and T1)	6.25±0.11	6.07±0.11	6.03±0.08	5.96±0.11	5.81±0.09	0.481	6.25±0.11	3.18±0.10	×	×	0.001	
MVR (T4 and T3)	7.22±0.08	7.14±0.08	7.07±0.09	7.00±0.10	6.96±0.09	0.215	7.22±0.08	5.51±0.11	5.29±0.11	×	0.001	
Texture												
TVR (T2 and T1)	4.96±0.64	4.88±0.09	4.85±0.11	4.74±0.12	4.62±0.10	0.581	4.96±0.12	2.03±0.09	×	×	0.061	
MVR (T4 and T3)	7.29±0.46	7.22±0.09	7.11±0.11	7.07±0.10	6.92±0.12	0.356	7.29±0.08	6.66±0.10	5.62±0.09	×	0.051	
Juiciness												
TVR (T2 and T1)	5.00±0.13	4.88±0.12	4.77±0.09	4.70±0.10	4.59±0.09	0.369	5.00±0.11	7.37±0.09	×	×	0.041	
MVR (T4 and T3)	7.25±0.08	7.14±0.10	7.07±0.11	7.03±0.11	6.88±0.12	0.451	7.25±0.09	6.74±0.08	6.92±0.09	×	0.214	
Overall acceptability												
TVR (T2 and T1)	5.55±0.11	5.48±0.11	5.37±0.10	5.25±0.11	5.04±0.11	0.047	5.55±0.11	2.07±0.10	×	×	0.001	
MVR (T4 and T3)	7.04±0.09	7.33±0.10	7.25±0.08	7.18±0.07	6.96±0.11	0.365	7.40±0.09	5.62±0.10	5.40±0.13	×	0.001	

Data represented as mean ± SD, P<0.05 was considered significant.

ambient storage. pH increased steadily in both types with storage time. TVR showed a greater rise, especially at ambient temperature, reaching spoilage by day 10, while MVR remained stable till day 15, indicating better shelf life. TBA values also increased with time; TVR showed faster oxidation, but both stayed below rancidity thresholds. Tyrosine values rose in all samples, with MVR increasing more slowly and remaining lower, especially at ambient temperature, supporting improved storage stability. Moisture content declined slightly in both types over 20 days, with no significant difference. Protein levels remained stable. Fat content rose in both, more so in TVR, but differences were statistically insignificant. Overall, MVR showed enhanced shelf life without compromising indigenous quality (Table 2).

Analysis of microbiological parameters of TVR and MVR

Under refrigerated storage, TVC of traditional smoked pork (T2) increased 1.26-fold from 3.93 ± 0.14 to 4.98 ± 0.09 log CFU/g by day 20 ($p=0.013$), while MVR (T4) showed a slower rise from 1.17 ± 0.05 to 1.88 ± 0.02 ($p=0.061$). At ambient temperature, TVR (T1) remained safe until day 10 (7.12 ± 0.04 log CFU/g), while MVR (T3) was consumable until day 15 (6.24 ± 0.02 log CFU/g), showing extended shelf life. No *E. coli*, *Salmonella*, *S. aureus*, or *L. monocytogenes* were detected in any samples. Halophilic bacteria were absent in MVR (T4) under refrigeration but increased significantly in T3 under ambient conditions ($p=0.001$) (Table 3).

Analysis of sensory quality of TVR and MVR

Sensory quality including odour, appearance, flavour, texture, juiciness and overall acceptability was assessed (Table 4). Under refrigeration, odour scores of TVR (T2) declined significantly ($p=0.026$), while MVR (T4) showed a non-significant change ($p=0.321$). Up to 20 days, both retained freshness, with no significant difference between them (Table 4).

At ambient temperature, TVR (T1) odour dropped sharply by day 10 (1.22 ± 0.08), indicating spoilage; MVR (T3) declined more gradually, remaining acceptable until day 10, spoiling by day 15. Differences between TVR and MVR were highly significant ($p=0.001$), indicating better shelf life for MVR. MVR showed higher appearance scores than TVR at all storage conditions. Changes under refrigeration were non-significant for both ($p>0.05$), but at ambient conditions, both declined significantly (MVR, $p=0.048$). Flavour remained stable under refrigeration ($p=0.481$ for TVR, $p=0.215$ for MVR) but declined significantly at ambient temperature ($p=0.001$), again favouring MVR.

Texture remained stable for both, likely due to the smoking process. Juiciness declined slightly but not significantly. Overall acceptability of MVR (T3, T4) remained consistent under both storage conditions, suggesting better shelf life than TVR.

MVR maintained stable pH (6.28-6.46), aligning with Lalchamlani *et al.* (2015) and Deuri *et al.* (2016), though

our method excluded nitrate/nitrite and still achieved 20-day refrigerated shelf life. Higher cooking yield in MVR (T2 and T4) is attributed to added spices, salt and potassium sorbate, also supported by Deuri *et al.* (2016).

Higher TBA values in MVR were linked to salt and sorbate, which promote fat oxidation but have antimicrobial and tenderizing benefits. Tyrosine value (TV), an indicator of spoilage, increased slowly in MVR compared to TVR, with T4 showing non-significant rise ($p>0.05$) and T3 highly significant rise at ambient temperature. Proximate parameters (moisture, protein, fat) remained stable with storage; minor moisture loss at 4°C possibly due to cold evaporation (Lal *et al.*, 2013), indicating texture preservation.

MVR showed significantly lower TAPC than TVR throughout storage. HBC increased in MVR but remained lower than TVR. *E. coli*, *Salmonella*, *S. aureus* and *L. monocytogenes* were absent in all samples. Smoking contributes to microbial safety through dehydration and bactericidal compounds like phenols and formaldehyde (Singh, 2015; Wendorff *et al.*, 1993; Asita and Campbell, 1990). Salt restricts microbial growth by reducing water activity (Gómez *et al.*, 2020). Combined curing and smoking inhibit *Listeria* (Montero *et al.*, 2007). Nisin, vinegar and potassium sorbate enhance microbial safety (Tompkin *et al.*, 1974; Glass *et al.*, 2007; Niaz and Fatima, 2017).

Condiments like garlic, ginger and turmeric used in MVR have known antimicrobial properties (Fijelu *et al.*, 2014; Bhatwalkar *et al.*, 2021; Kim and Lee, 1995; Abdeldaiem, 2014). TAPC increased with time (Dharmaveer *et al.*, 2007; Debnath *et al.*, 2020), but MVR consistently showed slower microbial growth and better-quality retention.

CONCLUSION

With systematic application of *hurdle technology* involving washing of carcass with chlorinated water, use of sanitized kitchen equipment and knives, curing of meat with salt, ginger, garlic, spice-mix and vinegar, standardized thermal treatment and smoking, dip into potassium sorbate solution, spraying of nisin, sterilization of packaging materials in UV rays exerted positive effect on Physico-chemical, microbiological and sensory properties of Modified Vawksa rep (MVR). Further superior sensory attributes besides extending the shelf-life up to 10 days at ambient temperature and 20 days at refrigeration temperature sufficiently justifies the 6.21% higher cost of production in comparison to TVR.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

Meat samples were collected from Dept of Livestock Product Management, College of veterinary Science and Animal Husbandry, Central Agricultural university, Aizawl and as such informed consent may not be required.

Conflict of interest

The author declares no conflict of interest in this study both financially and non-financially.

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