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Comparison of Starter Spices for Retention of Sensory Attributes, Appearance, and Antioxidants in Red Cabbage Sauerkraut

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Red cabbage finds wide appeal as salad among the health-conscious consumers however it is seasonal and is available for only two months. Conventionally green cabbages are converted to sauerkraut in traditional Oriental cuisines which enjoys wide appeal. The suitability of red cabbage for sauerkraut formulation was evaluated through two formulations, i.e., use of carom seeds and mustard seeds. The two formulations were compared for total anthocyanins, ascorbic acid, colour, texture (hardness), titratable acidity, total phenolic content, antioxidant activity, and sensory evaluation. The study was conducted after 15 days fermentation of red cabbage shreds at 20°C for a period of 75 days while sauerkraut was stored in refrigerated condition. Variation in starter spice caused significant difference in the rate of acidification, and change in total anthocyanins, ascorbic acid, colour, texture, total phenolic content, flavour, and antioxidant activity. While mustard spiced sauerkraut was more acidic and retained colour and texture better, the carom sauerkraut was less tart, softer and lower on colour scores. The antioxidant activity decreased from 7.55 µmol TE/g to 4.43 µmol TE/g on conversion to sauerkraut. Retention of 65.6% total phenolics and 57% ascorbic acid and 57% anthocyanins following 60 days of refrigerated storage of sauerkraut was recorded without use of any preservative, which shows reasonably good way to preserve the red cabbage which otherwise is not amenable for routine Indian culinary preparations. Sensory quality on the basis of taste, colour, odour, texture, and overall acceptance revealed acceptable quality sauerkraut up to 60 days when prepared with mustard seeds.

Keywords: Acidity, Anthocyanins, Carom, Colour, Mustard

Introduction

Cool season crop of red cabbage (*Brassica oleracea* var. *Capitata* F. *rubra*) belongs to the cole vegetables group (*Brassicacea* family). Termed the millenium's functional food, it is a rich source of phytochemicals, flavonoids, antioxidants, vitamins like B-complex (B1: thiamine, B2: riboflavin, and B9: folate), C, E, K, small amount of proteins, and minerals such as calcium, magnesium, iron, and potassium.[1,2] Dominant anthocyanins in red cabbage were identified as cyanidin-3-diglucoside-5-glucoside derivatives that are highly conjugated with sugars (glucose and xylose) and acyl groups (caffeoyl, feruloyl, *p*-coumaroyl, sinapoyl, *p*-hydroxybenzoyl, and oxaloyl).[3] Thus, consumption of cabbage protects us from premature aging, diabetes, ulcer, cancer, Alzheimer's disease and helps in boosting the immune system, weight loss management, improving skin and eye and in detoxifying the body. The glucosinolates present in cabbage breakdown into compounds like indole-3-carbinol, which demonstrate anti-cancerous properties.[1,4]

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Red cabbage being bred nowadays has unique health benefits (higher antioxidants, anthocyanins) and texture which make a sought-after accompanying leaf for salads. However, it's not amenable to conventional Indian cooking owing to heat instability of anthocyanins. Therefore, conversion of red cabbage leaves to sauerkraut can serve two ends, one providing enhanced shelf life to this seasonal produce; and second provide a tasteful and healthy delicacy to be relished with meals.

Sauerkraut is the only traditionally preserved cabbage product and is often consumed in Germany and in many other parts of the world i.e., Southeast Asian countries European, and the United States. Global market of sauerkraut is rising at an annual rate of 6% in forecast period of 2021 to 2029 due to rise in its consumption, with highest consumption in the United States and Canada.[5]

The production of sauerkraut starts with shredding the cabbage and combining with 2–3% salt, which is allowed to ferment spontaneously, that generally involves *Leuconostoc* spp., *Lactobacillus* spp., and *Pediococcus* spp. Store-brought sauerkraut contains

Bifidobacterium dentium, *Lactobacillus delbrueckii*, *Lactobacillus casei*, *Enterococcus faecalis*, *Staphylococcoccus epidermidis*, *Lactobacillus lactis*, *Lactobacillus curvatus*, *Lactobacillus plantarum*, *Lactobacillus brevis*, *Weisella confuse*, and *Enterobacteriaceae*.[6–8] Non standardized procedure for sauerkraut making can lead to long fermentation period and yield product with unstable quality, including undesirable odours, posing delay in industrial production. Sauerkraut fermentation involves several physical, chemical, and microbiological transformations that influence the safety and quality of the product. If unpasteurized, the sauerkraut contains 0.1% sodium benzoate and potassium metabisulphite as preservatives and are stored in refrigerator.[9]

Sauerkraut is also a good source of antioxidants (vitamin C: 14.7 to 75 mg/100 g and phenolic compounds 0.44–1.06 mg gallic acid equivalents/ 100g).[10] Sauerkraut has high amount of vitamin E (0.14 μg/100 g fresh weight), isothiocyanates and other sulphur compounds having therapeutic properties like anti-inflammatory, anti-microbial, and antioxidant properties.[11] Due to antioxidant compounds, sauerkraut neutralizes free radicals, regulate antioxidant enzyme activities, lower oxidative stress, better inflammatory reactions, and increases immunity. Bioactive compounds derived from glucosinolate hydrolysis (indole-3-carbinol, sulforaphane, ascorbigen, and allyl isothiocyanate) are present in higher concentrations in sauerkraut.

Sauerkraut is also rich source of lactic acid bacteria and is considered as probiotic because it increases the natural and acquired immunity, also reduces the inflammation by modifying the gut microflora. Glucosinolates, ascorbigen, and ascorbic acid present in higher quantities in sauerkraut reduces DNA damage and rate of cell mutation in the patients suffering from cancer.[11]

Traditional recipes for sauerkraut involve use of either carom seeds[12] or mustard seeds[13] to prepare sauerkraut. These aid initiating the acidification and fermentation process. Carom seeds and mustard seeds enhance flavour, act as preservative, antibacterial, and antifungal helping in growth of lactic acid bacteria.[14] Thus, this study was conducted with two objectives. One, to identify which spice is better for making sauerkraut from red cabbage; and two, to profile the compositional and textural changes taking place during storage of red cabbage sauerkraut.

Materials and Methods

Preparation of Red Cabbage Sauerkraut

A healthy crop of red cabbage 'Pusa Red Cabbage Hybrid-1' was raised in Vegetable farm, Division of Vegetable Science, ICAR-IARI, New Delhi. Ready-to-harvest heads were harvested, and 2 kg net head weight (after removal of jacket/cover leaves) was taken as sample. The heads were cut into four equal pieces and core of the head was removed with sharp knife. Cabbage was shredded into 0.5 cm strips and washed with distilled water for cleaning and removal of any dirt particles. Then, 2.5% sodium chloride was added to red cabbage shreds and allowed to stand for 10–15 minutes. This helped to withdraw juices from the red cabbage. Salted shreds were divided into two parts. Carom (*Trachyspermum ammi*) seeds (1%) were mixed in first batch (CRCS) and in the other (MRCS), crushed mustard (*Brassica juncea*) seeds (1%) was mixed. The cabbage shreds were filled into separate glass jars and sealed with lid to start reaction. The jars were kept at 20 ± 2°C in incubator for 12 days to allow fermentation.[15] Following fermentation, sauerkraut was refrigerated and studied for compositional and textural changes up to 90 days. Samples in triplicates were analysed on 0^{th}, 15^{th}, 30^{th}, 45^{th}, 60^{th} and 75^{th} day after refrigerated storage. The study entailed analysis for sensory acceptance, colour, texture (hardness), titratable acidity, anthocyanins, ascorbic acid, total phenolic content and antioxidant activity.

Sensory Evaluation

Sensory scores for odour, appearance, taste, texture, and overall acceptance were recorded for both preparations at regular intervals during storage as per the 9-point hedonic scale[16] where, 1 referred to extremely disliked and 9 for extremely liked. A semi-trained test panel of 30 persons (17 females and 13 males aged between 21 and 35) were asked in this study for sensory evaluation of carom seed and mustard seed red cabbage sauerkraut.

Colour Measurement

The colour analysis of red cabbage sauerkraut was done using Hunter colorimeter (Hunter lab instruments, Colourflex EZ, USA). The instrument was first calibrated with black and white plate calibration standards and L* set at 0 and 100, respectively. Readings were displayed as L*, a*, and b* colour parameters. The a* value ranged from +100 (red hue) to −100 (green hue), the b* value ranged from −100 (blue

hue) to +100 (yellow hue). Measurement of colour was done in triplicates in a glass bottom container provided with the machine.

Texture Analysis

Hardness of sauerkraut was determined by Texture Analyzer-Stable Microsystem, TA XT-Plus, UK. The HDP/BSK blade set with knife with 5 kg load cell was used to determine the hardness of sauerkraut shreds. The test settings used were: pre-test speed as 2 mm/s; test speed as 3 mm/s post-test speed as 10 mm/s, and distance 35 mm. At least 5 samples of each treatment were tested at each interval.[17] The hardness of shreds was expressed in Newton (N).

Titratable Acidity

In a 100 mL volumetric flask 5 g ground sample was taken and volume was made up to 100 mL with distilled water.[18] Activated charcoal (1%) was added to depigment the sample. An aliquot of 10 ml was titrated against 0.1 N sodium hydroxide using phenolphthalein indicator.

$$\text{Acidity (\%)} = \frac{Titrated\ value \times N_{NaOH}\,(0.1)\ Volume\ made\ up \times Equivalent\ weight\ of\ acid \times 100}{Weight\ of\ sample \times Volume\ of\ aliquot \times 1000}$$

Total Anthocyanin Content

Total anthocyanin content (TAC) was determined by pH-differentiation method spectrophotometrically.[19] Briefly, 0.5 g sample was ground with 80% methanol/ ethanol and volume made up to 20 mL in centrifuge tube and centrifuged at 10,000 rpm at 4°C. In two separate test tubes 1 mL supernatant was taken and 4 mL of KCl buffer (pH 1.0) and acetate buffer (pH 4.5) were added and kept for 15 minutes. Absorbance was measured at 510 and 700 nm using distilled water as blank.

$$\text{Total anthocyanin (mg/ L)} = \frac{A \times Molecular\ weight\ of\ anthocaynin \times Dilution\ factor \times 10^3}{\varepsilon \times Path\ length \times weight\ of\ sample}$$

where, $A = (A_{510} - A_{700})_{pH1.0} - (A_{510} - A_{700})_{pH4.5}$; $\varepsilon = 26900 cm^{-1}mg^{-1}$ was used.

Ascorbic acid

Ascorbic acid was determined by titration method with 2,6-dichloroindophenol as indicator.[20] To 100 ml volumetric flask 5 g ground sample was added and final volume was made up using 3% metaphosphoric acid. The solution was filtered with Whatman paper and 10 mL of filtered solution was titrated against dye solution.

$$\text{Ascorbic acid (mg/100 g)} = \frac{Titrated\ value \times dye\ factor \times volume\ made\ up \times 100}{Aliquot\ taken \times sample\ weight}$$

Total Phenolic Content

Total phenolic content of the sample was determined by Folin-Ciocalteu method spectro-photometrically.[21] Briefly, 1 g ground sample was extracted with 20 ml 80% ethanol and centrifuged for 10 minutes at 10,000 RPM at 4°C. To 0.1 ml supernatant, 2.9 mL distilled water, 0.5 mL of Folin-Ciocalteu reagent were added and allowed to stand for 3 minutes. After addition of 2 mL of 20% sodium carbonate, the volume was made up to 10 mL with distilled water. Absorbance was measured at 750 nm (Thermoscientific Genesys UV visible spectrophotometer).

$$\text{Total phenol (mg GAE/ 100g)} = \frac{Absorbance \times volume\ made\ up \times 100}{0.02 \times weight\ of\ sample \times aliquot\ taken \times 1000}$$

Antioxidant Activity

Antioxidant activity was determined by spectrophotometric "Cupric ion reducing antioxidant capacity" (CUPRAC)assay.[22] Ground sample of 1 g was extracted with 20 mL 80% ethanol and centrifuged for 10 minutes at 10,000 rpm at 4°C. And 1 mL each of copper chloride, neocuprine, and ammonium acetate buffer was added and to this mixture, 0.1 methanolic extract of sample was added followed by 1 mL distilled water and made up to 4 mL. It was then kept in dark place for 30 minutes. The absorbance was recorded at 460 nm.

$$\text{Antioxidant activity (µmol Trolox equivalents/g)} = \frac{Absorbance \times 4.1 \times volume\ made\ up \times 100}{1.67 \times 10^4 \times aliquot\ taken\ (0.1) \times weight\ of\ sample}$$

Statistical Analysis

All tests were performed in triplicates. Data was expressed in mean ± standard deviation. Statistical analysis was performed by the SPSS software version 19 for significant difference in the means using confidence intervals.

Results and Discussion

In this study, carom and mustard seeds were used in preparation of sauerkraut to enhance aroma and flavour. While carom seeds contribute a distinctive, thyme-like taste, mustard seeds add a tangy, spicy note, creating a more complex and interesting flavour profile. This practice also aligns with traditional methods of spicing fermented foods, which impart additional health benefits such as digestive support

Table 1 — Colour and texture of red cabbage sauerkraut

Day of storage	CRCS			MRCS		
	Colour		Hardness (N)	Colour		Hardness (N)
	L^*	a^*		L^*	a^*	
Fresh	40.13 ± 0.02^a	36.46 ± 0.01^a	6577.71 ± 1.17^a	40.13 ± 0.02^a	36.46 ± 0.01^a	6577.71 ± 1.17^a
0	31.75 ± 0.16^a	24.25 ± 0.13^a	4663.25 ± 1.55^a	33.12 ± 0.15^b	31.75 ± 0.41^b	5917.36 ± 1.12^b
15	28.91 ± 0.87^a	21.37 ± 0.38^a	4158.06 ± 1.84^a	31.61 ± 0.17^b	29.42 ± 0.33^b	4168.38 ± 0.92^b
30	27.98 ± 0.30^a	20.81 ± 0.13^a	3868.23 ± 0.86^a	31.31 ± 0.24^b	28.51 ± 1.05^b	3596.38 ± 1.54^b
45	26.59 ± 0.65^a	16.37 ± 0.09^a	2123.94 ± 1.65^a	30.46 ± 0.45^b	26.87 ± 0.88^b	2893.73 ± 0.33^b
60	26.18 ± 0.36^a	14.56 ± 0.04^a	1162.08 ± 0.75^a	29.17 ± 0.18^b	26.81 ± 0.13^b	2344.56 ± 1.45^b
75	24.18 ± 0.81^a	12.35 ± 0.30^a	1038.49 ± 0.49^a	28.57 ± 0.20^b	23.55 ± 0.44^b	1244.55 ± 1.04^b

*different letter of superscript indicates significant level of difference in means

and antimicrobial properties, although their primary role is to enrich the sensory qualities of the pickle.

The red cabbage shreds filled to the brim in glass containers took 15 days to yield sauerkraut. This was judged by the peculiar smell characteristic of pickle, acidity and softening of shreds. In terms of percent acidity, the MRCS showed higher titratable acidity (33.48% higher) compared to CRCS which was perceptible during sensory trials. While fresh cabbage had an ascorbic acid content of 49.84 ± 0.78 mg/100g, the sauerkraut prepared with carom seeds (CRCS) showed 55.79% decrease, MRCS retained ascorbic acid better with lesser decrease of 45.58% (Table 1). On similar lines, the MRCS shreds were much brighter in appearance (Fig. 1) with higher anthocyanins retention (only 0.14% decrease from fresh cabbage) while the CRCS showed 14.77% decrease. The Hunter scale 'a' values were 33.12 and 24.25 for MRCS and CRCS, respectively (Table 2). The texture and mouthfeel of MRCS was also different. The hardness of fresh MRCS sauerkraut shreds was 5917 N compared to 4663 N of CRCS. Sensory evaluation results indicated clear preference to MRCS over CRCS. However, there was a preference of some panellists towards CRCS owing to delicate and characteristics aroma associated with carom seeds. Crunchier mouth feel was percepted by the panellists in MRCS. Both preparations were liked well by panellists with overall acceptance ratings above 7 (liked moderately).

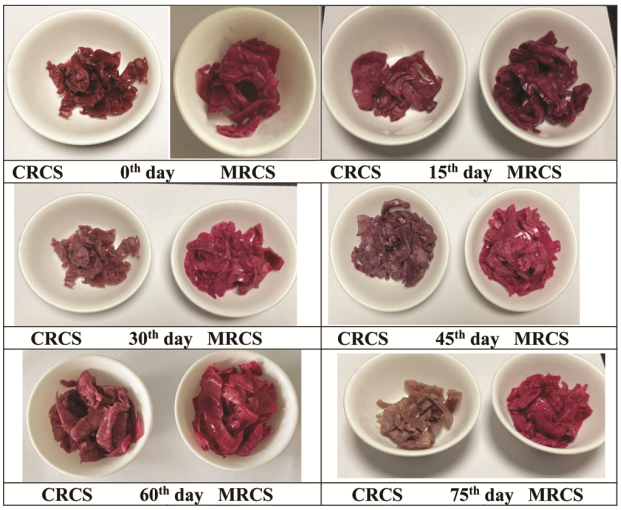

Fig. 1 — Appearance of red cabbage sauerkraut prepared with carom (CRCS) and mustard seeds (MRCS) during refrigerated storage

Effect of refrigerated storage on quality of sauerkraut

Sensory evaluation

Sensory quality of red cabbage sauerkraut with mustard seeds was better in terms of taste, colour, texture, odour, and overall acceptability as compared to CRCS on storage (Fig. 2 a & b). Taste of red sauerkraut was extremely liked (9.7 ± 0.46) for MRCS as compared to CRCS which was moderately liked (7. 2± 0.42). With storage, the acceptability of sauerkraut declined steadily. Both formulations were well liked upto 45th day, following which score for texture of CRCS declined below 5. MRCS texture however was ranked 6.8 ± 0.4 and 6.4 ± 0.52 on 60th and 75th day. In terms of appearance too, the ratings for appearance of fresh MRCS were extremely liked (9.6 ± 0.50) compared to CRCS which was neither liked nor disliked (5.7 ± 0.48). On 75th day of storage, colour of MRCS was still bright red and was moderately liked (Fig. 2b) while for CRCS colour deteriorated and was neither liked nor disliked (5.3 ± 0.48). On 75th day of storage, texture of MRCS was slightly liked (6.4 ± 0.52) while CRCS was slightly disliked (4.2 ± 0.42). The odour of red cabbage on conversion to sauerkraut with mustard seeds was extremely liked (9.4 ± 0.50) compared to CRCS which was liked very much (8.5 ± 0.53). On 75th day however, the odour was rated as neither liked nor disliked for MRCS (5.2 ± 0.42) while odour

Table 2 — Total phenolic content, ascorbic acid, and titratable acidity of carom seed and mustard seed red cabbage sauerkraut

Day of storage	Total phenolic (mgGAE/100 g)		Ascorbic acid (mg/100 g)		Titratable acidity (%)	
	CRCS	MRCS	CRCS	MRCS	CRCS	MRCS
Fresh	167.05 ± 0.11^{a}	167.05 ± 4.11^{a}	3.26 ± 0.01^{a}	3.26 ± 0.01^{a}	0.18 ± 0.01^{a}	0.18 ± 0.01^{a}
0	150.70 ± 0.89^{b}	151.27 ± 0.77^{a}	2.17 ± 0.02^{b}	3.25 ± 0.01^{b}	1.06 ± 0.01^{b}	1.49 ± 0.01^{a}
15th	144.77 ± 0.45^{b}	147.72 ± 0.66^{a}	2.17 ± 0.001^{b}	3.24 ± 0.01^{a}	1.32 ± 0.02^{a}	1.68 ± 0.01^{b}
30th	121.13 ± 0.67^{b}	130.24 ± 0.26^{a}	1.89 ± 0.001^{b}	2.87 ± 0.03^{a}	1.47 ± 0.03^{b}	1.86 ± 0.01^{a}
45th	89.81 ± 0.49^{b}	112.75 ± 0.28^{a}	1.80 ± 0.14^{a}	1.91 ± 0.03^{b}	1.48 ± 0.01^{b}	1.86 ± 0.01^{a}
60th	75.11 ± 0.11^{b}	109.58 ± 0.56^{a}	1.41 ± 0.04^{a}	1.87 ± 0.40^{b}	1.49 ± 0.01^{b}	2.04 ± 0.05^{a}
75th	72.09 ± 0.56^{b}	106.06 ± 0.34^{a}	0.54 ± 0.001^{a}	1.07 ± 0.02^{b}	1.49 ± 0.01^{b}	2.24 ± 0.02^{a}

*different letter of superscript indicates significant level of difference in means

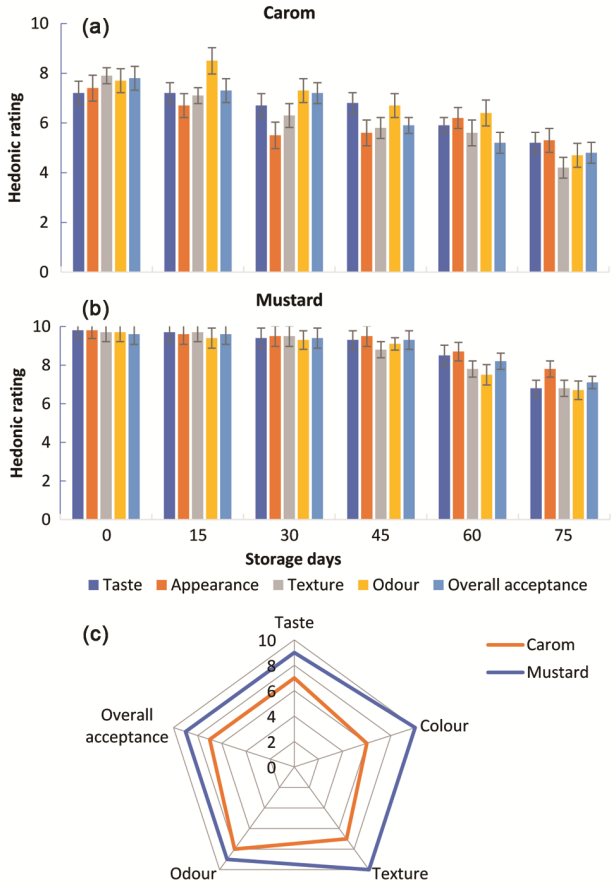

Fig. 2 — Change in sensory quality of (a) carom seed, and (b) mustard seed red cabbage sauerkraut with storage

of CRCS was slightly disliked (4.3 ± 0.48). Overall acceptability of red cabbage conversion to sauerkraut was extremely liked (9.6 ± 0.5) whereas CRCS was moderately liked (7.3 ± 0.48). On 75th day of storage, overall acceptability of MRCS was slightly liked compared to CRCS which was slightly disliked (4.6 ± 0.52). It can thus be stated that the MRCS was acceptable upto 60 days while CRCS remained acceptable upto 45 days only. The CRCS preparation was not liked on and beyond 60th day as apparent with hedonic ratings below 5 for most parameters (Fig. 2c).

Regarding sensory characteristics of sauerkraut, the appearance and texture was strongly associated with amount of salt introduced into brine.[23] Higher salinity decreased crunchiness and softness of tissues which was associated with an increase in osmotic pressure.[24] Sauerkraut storage quality of 6 to 12 weeks with acceptable taste has been reported.[25]

Appearance

The appearance of the two developed sauerkraut variants showed stark comparisons during refrigerated storage of sauerkraut. Uptill 30th day, the appearance of both sauerkrauts was bright red and acceptable. The CRCS however rapidly lost its appearance on further storage (Fig. 1). MRCS on the other hand retained its bright colouration till 75th day of storage.

Hunter Scale Colour

Table 1 shows colour values of carom seed and mustard seed red cabbage sauerkraut in terms of L* (Lightness); a*(redness) and b* (yellowness). L* of fresh cabbage was 40.13 which decreased to 31.75–33.12 on conversion to sauerkraut. Upon storage the L* is indicative of brightness decreased. The decrease was however lower for MRCS compared to CRCS. The saturation of colour observed can be seen from Fig. 1 and appearance scores during sensory evaluation (Fig. 2). The most important indicator of colour for red hued products is a*. The a* values for CRCS showed a sharp decline of 0.51 times during storage for 75 days. On the other hand, the MRCS formulation retained 0.7 times higher redness. Similar findings have been reported.[26]

Texture

On conversion of red cabbage to sauerkraut, the hardness of shreds decreased by 10 to 29%. This is on expected lines since the fermenting bacteria act on

pectin fibres and breakdown the structural matrix of cabbage shreds. Since glucose is readily available and is used by most microorganisms during the initial stages of fermentation, once it is depleted, bacteria efficiently shift to the galacturonate metabolism pathway, as this compound is present in the pectin-component of the plant cell wall.[27] In the early stage of kohlrabi fermentation, due to the rapid loss of water, cells shrank and the interstitial space reduced, initially resulting in increase in firmness.[28] Subsequently, due to the action of pectin methyl esterase, ester bonds were broken, and more branched structure of chelate-soluble pectin was formed. As the pickling continued, under the combined action of polygalactouronase and pectin methyl esterase, the molecular weight of pectin decreased and the rigidity of tissues decreased, causing kohlrabi texture also to decline.

Hardness of sauerkraut mixed with culture and control was decreased (7600 to 3400 g/cm^2) as fermentation time was increased.[29] Higher hardness was recorded for MRCS (5917.36 ± 1.12N) and gradually decreased to 1244.55 ± 1.04 N after 75 days of storage. On 75th day of storage, the MRCS was 16.5% more firm than the CRCS shreds (Table 1).

Anthocyanins

Anthocyanin content (ACN) was found to decrease from 16.83 ± 0.59 mg/L to 16.81 ± 0.13 mg/L on conversion to sauerkraut with mustard seeds, whereas CRCS showed 45.77% decrease (Fig. 3a). Though anthocyanins retention was high till 15th day, a sharp decline was recorded on the 30th day storage interval MRCS retained 9.62 ± 0.27 mg/L ACN on 75th day while CRCS retained (4.52 ± 0.13 mg/L) of the pigment. These findings correlate with the values for Hunter a* and appearance scores in Table 1 and Fig. 2.

ACN retains well in acidic conditions, since MRCS was more acidic, the ACN retention was higher. Similar finds showed, reduction in total anthocyanins following fermentation of red cabbage.[30] Total anthocyanins in fermented red cabbage were determined as 4.78 ± 0.09 mg of cyanidin/100g dry matter of red cabbage.[31] Oxidation during fermentation is known to decrease the observed monomeric anthocyanin content from raw to alcoholic fermentation stages.[32] The main anthocyanin in red cabbage is cyanidin-3-glucoside, the mutual transformation between cyanidin-3-O-glucoside and cyanidin glycosyl during fermentation as well as emergence of microbial metabolites besides complex changes in the metabolism of anthocyanins occur due to various environmental factors.[33]

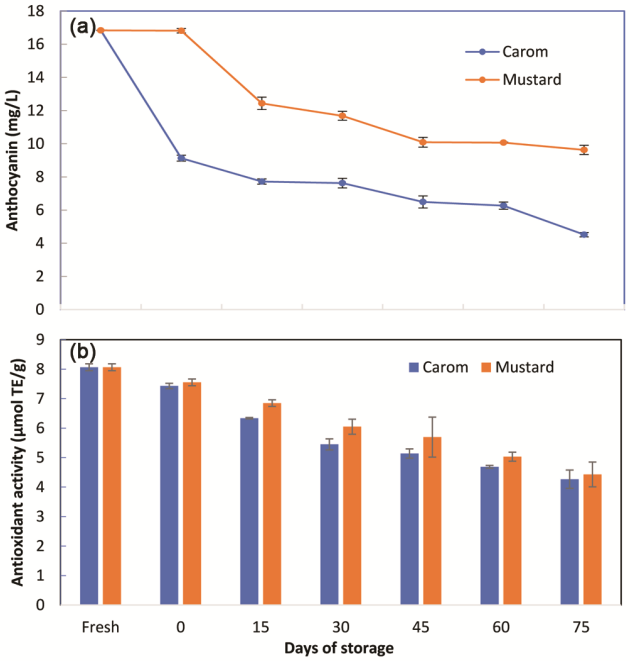

Fig. 3 — Changes in (a) total anthocyanin content, and (b) antioxidant activity in carom seed and mustard seed red cabbage sauerkraut with storage

Ascorbic acid

Ascorbic acid slightly decreased from 3.26 ± 0.01 mg/100g to 3.25 ± 0.001 mg/100g on conversion to sauerkraut with mustard seeds, while CRCS showed 33.34% decrease. Ascorbic acid retention was high till 15th day, a sharp decline was observed on the 30th day of storage interval. 1.07 ± 0.002 mg/100 g ascorbic acid was observed for MRCS on 75th day of storage while CRCS retained 0.54 ± 0.001mg/100 g (Table 2).

Ascorbic acid contents of the samples are lower than the reported values, which may be attributed to the variations in the temperature prevailing in North India during the growth period of red cabbage. The decrease in the levels of ascorbic acid may also be due to cabbage fermentation because of ascorbic acid forming ascorbigen[34] while glucosinolates break down to simpler structures. Losses in vitamin C occur due to severe cutting or shredding in case of cabbage.

Titratable Acidity

Titratable acidity increased from 0.18 ± 0.01% to 1.06 ± 0.01% upon conversion to sauerkraut with mustard seeds. CRCS showed sharp increase of 0.3 times during 75 days of refrigerated storage. Acidity increased due to natural fermentation process. Value of 2.24 ± 0.02% acidity was observed for MRCS on 75th day of storage while CRCS attained 1.49 ± 0.01%

acidity (Table 2). As per FDA norms, the acidity of sauerkraut should be not less than 1% (section 52.2963 of USFDA standard for sauerkraut, 2017).[35]

Total Phenolic Content

Total phenolic content of 134.7 to 257.0 mg/100g has been reported across literature for fresh cabbage. The fresh red cabbage used for the current study recorded 167.1 ± 4.1 mg GAE/100g of total phenolics. In general, the content of total polyphenols increases after fermentation. Such an increase may be attributed to the activity of bacterial enzymes on cell walls of red cabbage; as a result, phenolic compounds get released from the glycosidic linkages and ester bonds. Natural fermentation of red cabbage inoculated with *Lactobacillus plantarum* and *Lactobacillus acidophilus* resulted in initial increase in total phenolic content but gradual decrease with increase in fermentation time.[30] This was attributed to the presence of lactic acid bacteria involved in sauerkraut fermentation metabolizing phenolics and converting into aromatic and/or other compounds.[32]

In the current study, the total phenolic content decreased to 72–151 mg GAE/100 g on conversion to sauerkraut. Total phenolic content of 4019 mg GAE/100g has been reported for red sauerkraut on dry matter basis.[36] Considering 11% dry mass in fresh sauerkraut, this value comes to be 554–645 mg GAE/100g. The lower value in the samples (150 mg/100g) could be due to variation in variety and climate of production. Total phenolic content retention was high till 15th day of storage but a sharp decline was observed from 30th day of storage interval. Total phenolic content of 106.06 ± 0.3 mg GAE/100 g was observed for MRCS on 75th day of storage while CRCS retained 72.09 ± 0.56 mg GAE/100g (Table 2).

Antioxidant Activity

Antioxidant activity (AOX) of red cabbage has been reported as 5–40 µmol TE/g using ABTS assay. The fermentation initially enhanced the antioxidant activity of cabbage, which stabilized following 10-days of fermentation.[37] This was attributed to the combination of two effects: tissue disruption which released the bound phytochemicals and hence increased total polyphenol content and the result of chemical progressions under the influence of lactic acid bacteria.

AOX was high in fresh red cabbage but declined by 6–8% after conversion to sauerkraut. Further, during storage, the AOX of MRCS decreased from 7.55 ± 0.12µmol TE/g to 4.43 ± 0.42µmol TE/g on refrigerated storage (Fig. 3b). In case of CRCS, the recorded decrease was from 7.43 ± 0.09 to 4.26 ± 0.31µmol TE/g antioxidant activity on 75th day of storage (Fig. 3b). Significant changes ($p \leq 0.05$) in the antioxidant activity of sauerkraut following 2, 3, and 4 months of chilled storage in the PE-LD bags, which was lower in comparison to fresh vegetable.[36]

Conclusions

This study demonstrated the effect of variation in starter spice (mustard seeds or carom seeds) on the nutritional and functional profile of sauerkraut prepared from red cabbage. It was inferred that red cabbage can also be converted to sauerkraut and used for extended period of time even without preservatives and provide variety to diet. Findings of this study clearly indicate the superior attributes of mustard seeds fermented red cabbage which showed better nutrients retention and higher acceptability upto 60 days of refrigerated storage. Further studies can be done to check for prebiotic potential of sauerkraut and the suitability of red cabbage to aseptic packed salad formulations too. Comparison with conventional green cabbage sauerkraut can also be done.

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Conflict of Interest:

Authors state no conflict of interest in the findings of this study.

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