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Application of Compensatory TOPSIS-based Multiple Criteria Decision-making System for Selecting Appropriate Salts in Noodle Production

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ABSTRACT

Aim of current study was to identify suitable carbonate and phosphate salts for noodle making using TOPSIS. A total of 21 groups of carbonates and 28 groups of phosphates were evaluated to determine their impact on flour and noodle quality. Addition of carbonates significantly enhanced the yellowness and hardness of noodles, whereas significantly reduced cooking loss and peak viscosity. On the other hand, addition of phosphates resulted in a significant decrease in hardness and an increase in peak viscosity. The yellowness of the noodles did not exhibit a substantial change upon addition of phosphate salts. Based on TOPSIS analysis, combinations of salts with a Na-to-K carbonate ratio of 50:50 or 40:60, at a concentration of 1.25%, were identified as suitable choices for noodle production, according to the experimental findings. Among phosphate groups, Di-sodium phosphate at concentration of 0.25% was determined to be the preferred option for noodles.

Key words: Noodles, TOPSIS technique, carbonate salts, phosphate salts

INTRODUCTION

Noodles are manufactured by mixing wheat flour, water and salt or/and alkaline reagents. Two types of noodles are more common, namely, yellow alkaline and white salted noodles. While making yellow alkaline noodles, *Kansui* (a mixture of carbonates of sodium and potassium) is used (Fan *et al.,* 2018). Quality and quantity of alkaline salts affect noodles quality (Obadi *et al.,* 2022). Texture is considered the most important characteristic of noodles followed by color, surface appearance and cooking parameters (Fan *et al.,* 2018). In addition to elastic and soft texture, alkaline reagents also provide yellowness to noodles by reacting with colourless flavones present in wheat flour (Obadi *et al.,* 2022). Sodium carbonate significantly affected colour, pH and firmness of noodles and its 0.7-1.2% concentration was recommended (Obadi and Xu, 2021). Use of 0.1-0.3% alkaline salt was sufficient to improve noodle quality but for attaining appropriate yellowness, 0.5-1.5% was needed. The need for low-sodium diets has led to the rise in popularity of potassium carbonate (Fan *et al.,* 2018). Asian noodle manufacturers utilized various food additives including polysaccharide gums, glycerol monostearate and inorganic salts. Among these additives, inorganic phosphates emerged as particularly promising (Obadi *et al.*, 2022). Phosphate salts are commonly employed as functional additives, serving as water holding agents, buffering agents, sequestrants, or dispersants (Thangavelu *et al.*, 2019).

Phosphate salts are commonly employed in cereal products to serve as leavening agents and enhance the quality of noodles. They are utilized to increase elasticity of noodles and minimize dough cracking (Liu *et al.*, 2016). By modifying the process of starch gelatinization and acting as chelating agents in dough systems, phosphates effectively enhance properties of dough during processing and prevent discolouration of fresh noodles (Niu and Hou, 2019). In recent times, there has been a growing inclination towards the application of phosphate salts in wheat-based foods, particularly noodles. Chen *et al.* (2019) revealed that phosphate salt decreased hardness and slightly increased springiness,

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cohesiveness and resilience of whole wheat noodles.

Multi-criteria decision making (MCDM) involves evaluating alternatives based on a variety of qualitative and quantitative criteria to facilitate selection or ranking. One helpful MCDM technique is the technique for order preference by similarity to ideal solution (TOPSIS), which selects the greatest alternative after identifying solution alternatives from the positive and negative ideal solutions (Hajiaghaei-Keshteli *et al.,* 2023). Recently Hedayatia *et al.* (2021) used TOPSIS for selecting appropriate hydrocolloids for eggless cakes. They concluded that TOPSIS is an effective approach for facilitating comparison and decision-making. In the present study, the objective was to examine impact of various carbonates (21 groups) and phosphates (28 groups) of sodium and potassium on the quality of flour and noodles. The aim was to select the most suitable salts using the TOPSIS methodology for noodle making.

MATERIALS AND METHODS

Refined wheat flour was purchased from the Vardhan Foods, India, having moisture, protein and ash contents of 12.5, 11.93 and 0.55%, respectively. All salts, chemicals, solvents and reagents used were of analytical grade. Sodium carbonate (Na_2CO_3), potassium carbonate (K_2CO_3) and seven types of phosphate salts (PS), namely, monosodium phosphate (MSP), disodium phosphate (DSP), sodium hexametaphosphate (SHMP), dipotassium phosphate (DKP), tripotassium phosphate (TKP), trisodium phosphate (TSP) and sodium pyrophosphate (TSPP), were supplied by Sigma-Aldrich, India.

Peak viscosity of wheat flour was measured using a Rapid Visco Analyser (RVA Techmaster, Perten Instruments Inc., Australia) as described by Chen *et al.* (2019).

Basic formulation for noodle making contained wheat flour (12.5% mb), water, NaCl and guargum in a ratio of 100:34:1.54:0.28 by weight. A control sample using basic formulation was prepared without adding any carbonate salt or phosphate salt. Selected levels of mixtures (100:0, 50:50, 40:60, 30:70, 20:80, 10:90, 0:100) of Na-to-K carbonate were 0.25, 0.75 and 1.25% on flour weight basis. Except MSP (0.015, 0.025, 0.035 and 0.045%), all other phosphate salts were added to levels of 0.15, 0.25, 0.35 and 0.45% on flour weight basis. Noodles were prepared as per the method described by Chaudhary *et al.* (2016).

Colour, yellowness value of b of instant noodle powder was measured using chromameter (CR400, Konica Minolta, Osaka, Japan) equipped with D65 illuminant. Cooking loss was measured following Niu and Hou (2019). Hardness of cooked noodles was measured using Texture Analyser (Stable Micro Systems TA-XT 2i, Godalming,U.K.) following Chen *et al.* (2019). Results were presented as mean±SD. Data analysis was done by one-way analysis of variance through the IBM SPSS Statistics 21. Tukey's test was performed for checking significance of variations among average value ($P< 0.05$).

TOPSIS approach was followed twice separately for ranking of carbonate salts (CS) and phosphate salts (PS) groups. In the current study, selection of appropriate CS group and PS group was done individually. So, salt group was selected as decision marker. Cooking loss, yellowness (b value), hardness of noodles and peak viscosity of flour were taken as selection criteria. Cooking loss was considered non-beneficial criteria, while values of b, hardness and peak viscosity were considered beneficial criteria (Hedayatia *et al.,* 2021).

RESULTS AND DISCUSSION

Effects of salts on peak viscosity of wheat flour: The pasting properties of the flour suspension during heating and cooling cycles, which lead to alterations in starch granules, were measured using a Rapid-visco-analyzer (RVA). Peak viscosity (PV) is an important parameter for estimating eating quality of alkaline noodle products (Li *et al.,* 2020). PV of the control sample was determined to be 1932 cP (Fig. 1).

When carbonate salts (CS) were initially added at a 0.25% level in flour, the peak viscosity (PV) of flours with all carbonate salts increased compared to the control sample. Subsequently, a continuous decrease in PV was observed as concentration of CS was increased from 0.25 to 1.25% in flour, with the highest PV recorded at 0.25%. The variation in the sodium-to-potassium carbonate ratio did not result in any significant differences in the PV values of the

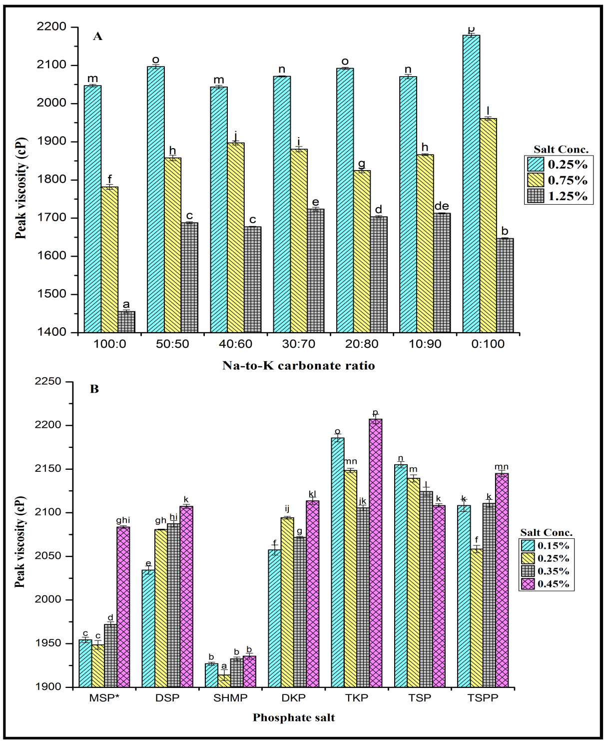

Fig. 1. Effect of carbonate salts (A) and phosphate salts (B) on peak viscosity of flour. Error bars indicate mean values±standard deviation of three replicates. Bars with different letters are significantly different ($P<0.05$). MSP –Monosodium phosphate; DSP–Disodium phosphate, SHMP–Sodium hexametaphosphate, DKP–Dipotassium phosphate, TKP–Tripotassium phosphate, TSP–Trisodium phosphate and TSPP–Sodium pyrophosphate. MSP was used at concentration of 0.015, 0.025, 0.035 and 0.045%.

flours (Fig. 1). These observations align with a previous study (Fan *et al.*, 2018). The increase in PV upon adding 0.25% CS in flour was likely caused by an increase in the swelling power of starch granules. Additionally, the alkali present in the flour suspension had elevated the concentration of anions (OH- or CO32-) to a level that significantly altered the peak viscosity by disrupting the hydrogen bonds among starch molecules (Pedcharat *et al.*, 2021). With the exception of sodium hexameta phosphate, all phosphate salts caused increase in PV of the flour, which was consistent with previous observation (Chen *et al.*, 2019).

The increase in PV may be attributed to formation of amylopectin aggregates resulting from the interaction between phosphates and starch chains (Chen *et al.*, 2019). When flours were supplemented with tri-potassium phosphate, tri-sodium phosphate and sodium pyrophosphate, higher PV values were observed. On the other hand, sodium hexametaphosphate and monosodium phosphate exhibited the lowest PV. Upon increasing salt level from 0 to 0.45%, only monosodium phosphate and disodium phosphate showed an increase in PV, while trisodium phosphate caused a decrease. The concentration of sodium hexametaphosphate from 0.15 to 0.45% did not cause a significant difference in PV values. The covalent bonding and electrostatic interaction of phosphate salts with the hydroxyl groups in starch resulted in longer starch chain lengths and increased cross-linkage among starch molecules. Sodium hexametaphosphate, having fewer hydroxyl groups compared to trisodium phosphate, sodium pyrophosphate, and disodium phosphate, led to a weaker network with starch, resulting in lower viscosity values. At lower levels of phosphate salts, the higher PV may be attributed to the cross-linking of hydroxyl groups between the phosphate salts and starch. However, at higher levels, the combination of phosphate salts with proteins showed minimal effects on viscosity (Chen *et al.*, 2019). The higher PV contributes to a smoother and more elastic mouth feel in noodles (Jia *et al.*, 2019). Therefore, it is suggested to use a blend of carbonate and phosphate salts to achieve the desired PV values.

Effects of salts on yellowness (b value) of noodles: Colour is one of the main criteria for noodles. Yellow appearance which is represented as b value is desired by the consumers (Siah and Quail, 2018). Value of b for control flour noodles was 13.29. At a concentration of 0.25% for all CS, there was seen only a slight improvement in the yellowness (b value) of noodles in comparison with that in the control sample (Fig. 2). However, when the concentration of CS was increased from 0.25 to 1.0%, a noticeable increasing trend was observed, with the highest value obtained at 1.25%. The variation in the ratio of sodium to potassium carbonate did not have any effect on the yellowness of the noodles. These results align with findings of Fan *et al.* (2018). The yellow colour of noodles was attributed to a chromophoric shift caused by the reaction of endogenous flavonoids

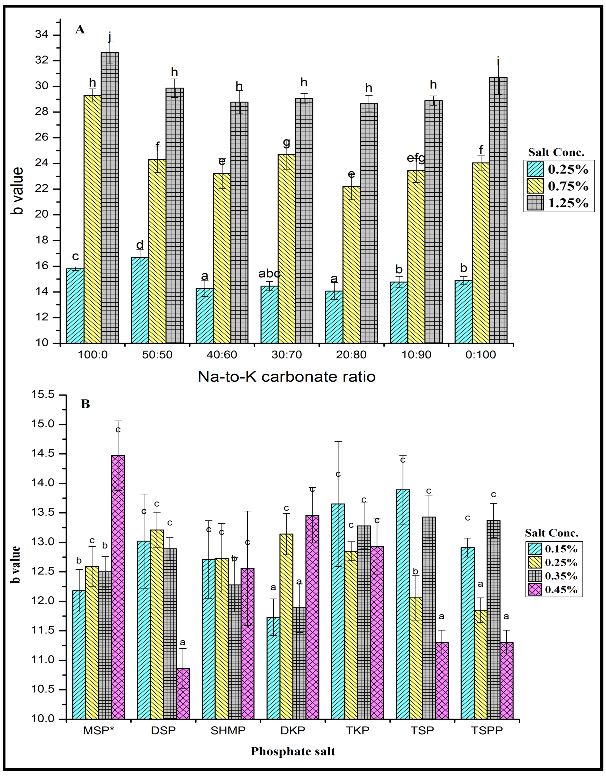

Fig. 2. Effect of carbonate salts (A) and phosphate salts (B) on b value of noodles which is yellowness/blueness. Error bars indicate mean values±standard deviation of eight replicates. Bars with different letters are significantly different (P<0.05). MSP–Monosodium phosphate, DSP–Disodium phosphate, SHMP–Sodium hexametaphosphate, DKP–Dipotassium phosphate, TKP–Tripotassium phosphate, TSP–Trisodium phosphate and TSPP–Sodium pyrophosphate. MSP was used at concentration of 0.015, 0.025, 0.035 and 0.045%.

available in wheat flour with the alkaline pH provided by carbonate salts (Obadi *et al.*, 2022). Regarding phosphate salts (PS), there were no significant differences observed among various PS groups in terms of yellowness (b value) of the noodles. Although all phosphate salts led to slightly higher b values compared to the control sample, this influence was not as pronounced as in the CS groups. The addition of monosodium phosphate, dipotassium phosphate, tripotassium phosphate and trisodium phosphate at certain concentrations resulted in slight improvement in the yellowness of noodles. On the other hand, disodium phosphate, sodium hexametaphosphate, and sodium pyrophosphate caused a slight decrease in yellowness of noodles at all concentrations. The yellowness of noodles was influenced by the alkali used. Phosphate salts had minimal effects on increasing the pH value since they were not caustic salts, which explained why they result in lower b values compared to carbonate salts (Obadi *et al.*, 2022). Carbonate salts are therefore recommended for achieving the desired yellow colour in noodles.

Effects of salts on cooking loss of noodles: Cooking loss is a crucial factor that significantly impacts overall acceptability of noodles (Obadi *et al.*, 2022). It serves as an indicator of the structural integrity of the noodle network (Tan *et al.*, 2018). The control sample exhibited a cooking loss of 9.36%. The addition of carbonate salts, ranging from 0 to 1.25%, resulted in a decrease in cooking loss

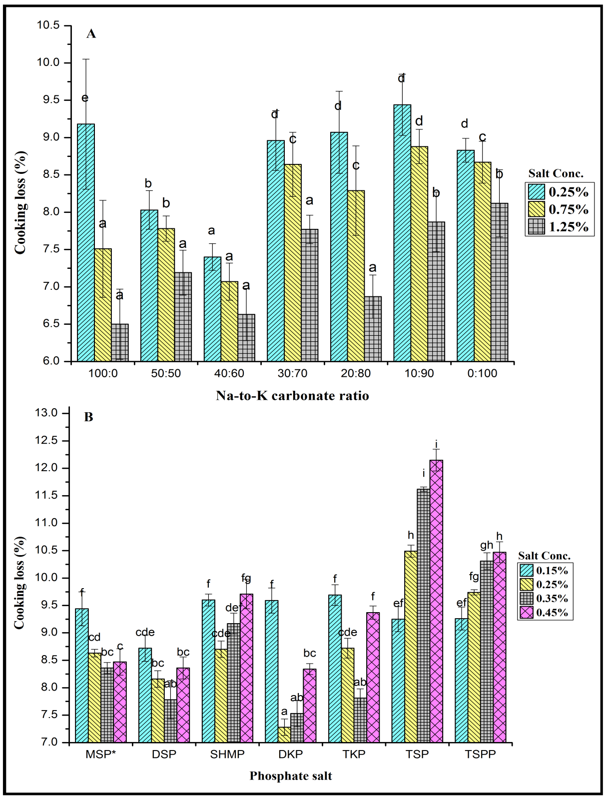

Fig. 3. Effect of carbonate salts (A) and phosphate salts (B) on cooking loss of noodles. Error bars indicate mean values±standard deviation of three replicates. Bars with different letters are significantly different (P<0.05). MSP–Monosodium phosphate, DSP–Disodium phosphate, SHMP–Sodium hexametaphosphate, DKP–Dipotassium phosphate, TKP–Tripotassium phosphate, TSP–Trisodium phosphate and TSPP–Sodium pyrophosphate. MSP was used at concentration of 0.015, 0.025, 0.035 and 0.045%.

in the noodles (Fig. 3). These findings align with the research conducted by Wang *et al.* (2021). Reduced cooking loss is associated with a higher level of gluten cross-linkage under alkaline conditions (Li *et al.*, 2018). Strengthening the bonding forces within starch granules may also contribute to the observed decrease in cooking loss (Kasunmala *et al.,* 2020). When comparing the sodium-to-potassium ratios, samples with added sodium carbonate exhibited lower cooking loss compared to those with potassium carbonate. Altering the carbonate ratios did not significantly influence the cooking loss, consistent with the findings reported by Fan *et al.* (2018).

No specific pattern was observed regarding the impact of adding phosphates on noodles' cooking loss. The addition of trisodium phosphate and sodium pyrophosphate resulted in the highest cooking loss, and the values increased as the concentration reached 0.45%. On the other hand, the lowest cooking loss values were obtained when using disodium phosphate and dipotassium phosphate at concentrations of 0.25 and 0.35%, respectively. The presence of hydroxyl groups in phosphate salts facilitates interaction with starch, potentially stabilizing the amorphous region and reducing cooking loss. Additionally, phosphate salts may promote the formation of disulfide bonds in wheat gluten, enhancing the gluten network and ultimately reducing cooking loss (Chen *et al.*, 2019). The increased cooking loss caused by trisodium phosphate and sodium pyrophosphate could be attributed to the dissolution of soluble gliadins (α and γ) under alkaline pH conditions (Chen *et al.,* 2019).

Effects of salts on hardness of cooked noodles: Among various criteria used for assessing the quality characteristics and consumer acceptance of noodles, the hardness of cooked noodles is considered crucial. Many researchers have recommended use of TPA (Textural profile analysis), which is widely recognized as one of the most commonly employed instrumental techniques to evaluate quality characteristics of cooked noodles (Ross, 2020). Hardness of control sample of noodles was measured to be 2926.51 g (Fig. 4).

The addition of 0.25% carbonate salts did not have a significant impact on the hardness of the noodles. However, a notable increasing trend in hardness was observed when the level of carbonate salts was increased from 0.25 to 1.25%. Furthermore, altering the sodium-to-potassium ratio did not result in a significant difference in the hardness of the noodles. It is possible that the competition between alkali and gluten proteins for free water contributed to the higher hardness values. Additionally, the increased formation of covalent protein cross-links may have played a role in the harder texture of the noodles when carbonate salts were added (Fan *et al.*, 2018; Li *et al.,* 2018).

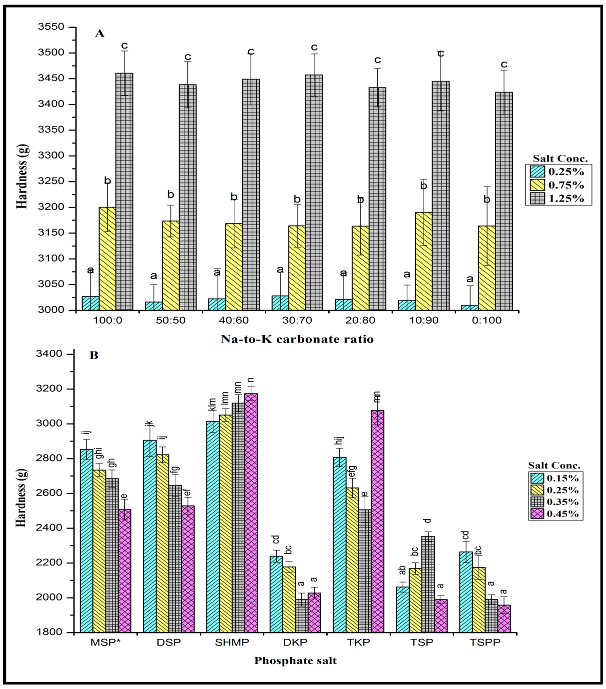

Fig. 4. Effect of carbonate salts (A) and phosphate salts (B) on hardness of noodles. Error bars indicate mean values±standard deviation of five replicates. Bars with different letters are significantly different (P<0.05). MSP–Monosodium phosphate, DSP–Disodium phosphate, SHMP–Sodium hexametaphosphate, DKP–Dipotassium phosphate, TKP–Tripotassium phosphate, TSP–Trisodium phosphate and TSPP–Sodium pyrophosphate. MSP was used at concentration of 0.015, 0.025, 0.035 and 0.045%.

On the other hand, increasing the level of sodium hexametaphosphate and trisodium phosphate from 0 to 0.45% led to an increase in the hardness of the noodles (Fig. 4). Among the samples, those with sodium hexametaphosphate exhibited the highest hardness, while dipotassium phosphate, trisodium phosphate and sodium pyrophosphate resulted in lower hardness values.

TOPSIS ranks: In this study, determination of suitable concentrations of carbonate salts (CS) and phosphate salts (PS) for noodle production was based on the rankings obtained through the TOPSIS method. CS and PS commonly utilized in noodle manufacturing due to their various benefits. However, selecting the ideal CS or PS was challenging due to the influence of multiple criteria, including peak viscosity, yellowness (b value), cooking loss and hardness, which all impact noodle quality. To address this challenge, the TOPSIS approach was employed to rank different salts. The rankings were determined by calculating the distances between each alternative and the positive and negative ideal solutions for each criterion. The panelists' collective responses were considered, and equal weight age (0.25) was assigned to each criterion, namely, cooking loss, b value, hardness and peak viscosity. The distances and closeness coefficient guided the final rankings of the CS groups (Table 1) and PS groups (Table 2).

The concentration of carbonate salts had a more significant impact on noodle quality compared to changing the Na-to-K carbonate ratios (Table 1). Carbonate salts at 1.25% concentration achieved higher rankings, followed by concentrations of 0.75 and 0.25%, respectively. At 1.25% concentration, higher values of b (yellowness) and hardness, along with lower cooking loss, contributed to the top rankings. In terms of the sodium to potassium carbonate ratio, ratios of 100:0, 50:50 and 40:60 achieved top rankings. Considering the low sodium requirement in the diet, ratios of 40:60 or 50:50 were recommended for making noodles. This study is the first attempt to use combinations of sodium and potassium carbonate salts for noodle making.

Among different concentrations of phosphate salts, 0.25 and 0.35% achieved higher rankings compared to 0.15 and 0.45%. Samples added with disodium phosphate obtained the top rank, followed by sodium hexametaphosphate tripotassium phosphate, monosodium phosphate, dipotassium phosphate, sodium pyrophosphate, and trisodium phosphate, respectively. Sodium pyrophosphate and trisodium phosphate gradually increased cooking loss and decreased hardness, leading to their lower rankings (Table 2).

Table 1. Final ranking of carbonate groups of salts as given by TOPSIS

Na-to-K carbonate ratio	Level (%)	di^+	di^-	C	Ranks
50:50	1.25	0.0163	0.0403	2.5184	1
100:0	0.75	0.0160	0.0384	2.4405	2
40:60	1.25	0.0170	0.0398	2.3736	3
20:80	1.25	0.0167	0.0389	2.3635	4
100:0	1.25	0.0210	0.0474	2.3035	5
30:70	1.25	0.0177	0.0376	2.1582	6
0:100	1.25	0.0194	0.0400	2.0998	7
10:90	1.25	0.0185	0.0370	2.0396	8
40:60	0.75	0.0238	0.0294	1.2633	9
50:50	0.75	0.0233	0.0286	1.2523	10
30:70	0.75	0.0252	0.0278	1.1309	11
0:100	0.75	0.0258	0.0277	1.1024	12
10:90	0.75	0.0283	0.0250	0.9080	13
20:80	0.75	0.0290	0.0229	0.8140	14
50:50	0.25	0.0386	0.0217	0.5847	15
40:60	0.25	0.0431	0.0219	0.5300	16
0:100	0.25	0.0441	0.0215	0.5082	17
100:0	0.25	0.0432	0.0177	0.4275	18
20:80	0.25	0.0464	0.0186	0.4202	19
30:70	0.25	0.0453	0.0182	0.4193	20
10:90	0.25	0.0460	0.0179	0.4074	21

Table 2. Final ranking of phosphate groups of salts as given by TOPSIS

Phosphate salt type	Level (%)	di^+	di^-	C	Ranks
DSP	0.25	0.0097	0.0276	2.8916	1
DSP	0.15	0.0111	0.0262	2.3816	2
SHMP	0.25	0.0120	0.0277	2.3308	3
DSP	0.35	0.0120	0.0270	2.2752	4
TKP	0.45	0.0123	0.0271	2.2393	5
TKP	0.35	0.0136	0.0264	1.9626	6
SHMP	0.35	0.0141	0.0269	1.9292	7
MSP	0.045	0.0141	0.0256	1.8434	8
MSP	0.035	0.0140	0.0244	1.7717	9
SHMP	0.45	0.0156	0.0266	1.7285	10
MSP	0.025	0.0141	0.0239	1.7240	11
TKP	0.25	0.0139	0.0234	1.7025	12
TKP	0.15	0.0144	0.0235	1.6556	13
SHMP	0.15	0.0153	0.0245	1.6336	14
DKP	0.25	0.0193	0.0269	1.4208	15
MSP	0.015	0.0162	0.0222	1.3877	16
DSP	0.45	0.0190	0.0225	1.2111	17
DKP	0.35	0.0242	0.0242	1.0244	18
DKP	0.45	0.0224	0.0223	1.0167	19
TSPP	0.15	0.0206	0.0181	0.8959	20
TSP	0.15	0.0231	0.0195	0.8634	21
DKP	0.15	0.0236	0.0148	0.6439	22
TSPP	0.35	0.0273	0.0140	0.5284	23
TSP	0.35	0.0272	0.0132	0.4993	24
TSP	0.25	0.0265	0.0116	0.4492	25
TSPP	0.45	0.0303	0.0102	0.3472	26
TSPP	0.25	0.0529	0.0139	0.2762	27
TSP	0.45	0.0353	0.0048	0.1396	28

MSP–Monosodium phosphate, DSP–Disodium phosphate, SHMP–Sodium hexametaphosphate, DKP–Dipotassium phosphate, TKP–Tripotassium phosphate, TSP–Trisodium phosphate and TSPP–Sodium pyrophosphate.

CONCLUSION

The findings of this study highlighted the positive impact of carbonates and phosphates on the overall acceptability of noodles, particularly at specific salt concentrations. The application of TOPSIS analysis revealed that a 50:50 or 40:60 ratio of sodium-to-potassium exhibited superior acceptability in noodles, with disodium phosphate ranking as the top-performing phosphate salt. The utilization of TOPSIS as a comparison tool proved beneficial in facilitating the assessment process. However, further research is required to determine the optimal combination of suitable carbonates and phosphates, enabling a comprehensive evaluation of their relative acceptability in noodles.

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