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Investigating the impact of milk protein, inulin, and honey on quality attributes of goat milk *yoghurt*

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Abstract In this present study, a three-factor Box–Behnken, response surface methodology (RSM) design was employed to optimize the skimmed milk powder (SMP)/whey protein concentrate (WPC) ratio (0.25–0.75%w/v) as a source of milk protein, inulin (1–2%w/v), and honey (4–6%w/v) for production of high-quality goat milk *yoghurt* (GMY). The resulting ANOVA and response surface equations revealed the significant effect ($p < 0.05$) of these variables on the various attributes such as total solid (%), pH, titratable acidity [(LA) % by weight], syneresis (%), DPPH (% inhibition), viscosity (m.Pa·s), whiteness index (WI), and overall acceptability (OA). The coefficient of determination (R^2) for all response variables ranged from 0.88 to 0.99. Lack-of-fit tests resulted in non-significant F-values. The optimal conditions were determined as SMP/WPC at 0.36%w/v, inulin at 1.00%w/v, and honey at 6.00%w/v. The optimum values for total solid, pH, titratable acidity, syneresis, DPPH, viscosity, WI, and OA were 22.03, 4.46, 0.77, 6.34, 25.20, 182.30, 76.29 and 8.37, respectively with desirability value of 0.95.

Abbreviations

GMY	Goat milk *yoghurt*
SMP	Skimmed milk powder
WPC	Whey protein concentrate
BBD	Box Behnken design
RSM	Response surface methodology
TA	Titratable acidity
LA	Lactic acid
OA	Overall acceptability
WI	Whiteness index
$L*$	Lightness
$a*$	Redness
$b*$	Yellowness
ANOVA	Analysis of variance
CV	Coefficient of variation
R^2	Coefficient of determination
AOAC	Association of Official Analytical Chemists

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Introduction

Consumers' interest in goat milk has gradually gained momentum in recent years due to nutritional and health benefits such as higher digestibility, lipid metabolism, low allergenicity, alkalinity, higher buffering capacity, and specific therapeutic effects compared to cow milk (Haenlein 2004; Park 2009). Due to goat milk distinct characteristics, its use in

dairy products offers a chance to diversify the dairy industry. Globally, goat milk is consumed directly or as dairy products. However, fermented products from goat milk are more popular since they lack *goaty* flavour due to fermentation by different microbes (Pulina et al. 2018). Processing of dairy products, particularly *yoghurt*, has increased recently due to the rising trend of healthy eating. *Yoghurt* has been a popular fermented dairy product worldwide since ancient times because of its nutritional value and health benefits. However, low amount of α_{S1} casein, smaller casein micelles, low levels of proteins, as well as lower total solids, might negatively affect the texture of goat milk *yoghurt* (GMY) (Park et al. 2007; Nguyen et al. 2018) as well as customer liking and acceptance (Guichard 2002). Further, different factors, including the *yoghurt* milk base's composition and processing parameters, impact the quality characteristics. In order to increase the overall solid content and prevent undesired textural defects including weak gel structure and syneresis, skim milk powder (SMP) and other milk protein preparations are frequently added to the milk base (Tamime and Robinson 2007). Several authors have investigated the effect of various forms of protein addition on the quality improvement of *yoghurt i.e.,* GMY with milk protein–based products (Gursel et al. 2016), and GMY with WPC (Zoidou et al. 2019). The addition of prebiotics, which further enhances the overall solid content, texture/rheological, nutritional value, and sensory perception of *yoghurt*, is one method that manufacturers are attempting to include health-promoting components into the product (Allgeyer et al. 2010). By promoting and preserving the survival of probiotic bacteria, inulin may also be used to alter *yoghurt's* texture (Mituniewicz-Malek et al. 2014). Honey has grown in popularity as an antioxidant, antimicrobial agent and substitute sweetener in a range of foods in recent years due to its perceived health benefits and ability to boost consumer acceptance of acidic meals like *yoghurt* (Chick et al. 2001; Varga 2006; Mercan and Akin 2017). According to our knowledge, there is no literature on response surface methodology (RSM)-based optimization of SMP/WPC, inulin, and honey-incorporated goat milk *yoghurt*. RSM has demonstrated value in experiment design, factor optimization to forecast desired responses, and evaluation of the effects of several factors (Singh et al. 2018). Considering the information mentioned above, the current study was designed to use the RSM statistical tool to optimize the concentration of different ingredients for manufacturing high-quality goat milk *yoghurt*.

Material and methods

Materials

The fresh goat milk was obtained from the Jamunapari goat farm of ICAR-Central Institute for Research on Goats (CIRG), Makhdoom (India). The lyophilized starter culture containing *Streptococcus thermophilus* and *Lactobacillus bulgaricus* was procured from Chr Hansen (India) Pvt Ltd., Mumbai. Skim milk powder (0.56% w/w fat, 34% w/w protein; Govind milk and milk products®, Maharashtra, India), and honey (Dabur) were procured from local market. Whey protein concentrate was procured from M/s Modern Dairies Ltd., Karnal. The precious gift of Inulin (Orafti®GR) sample was obtained from BENEO India Private Limited, Gurugram, India. All the chemicals (AR grade) were supplied by standard firms like Sigma chemicals (India) Pvt Ltd., Central Drug House and Hi-media.

Preparation of goat milk yoghurt

For the manufacturing of set-type goat milk *yoghurt*, selected concentrations of SMP/WPC ratio (0.25, 0.5 and 0.75%w/v) were added to the fresh goat milk and mixed thoroughly. The milk was heated in a stainless-steel vat at 90 ± 1 °C for 5 min with occasional stirring. Further, the milk was supplemented with different levels of inulin (0.5, 1.0 and 1.5%w/v) and honey (2.0, 4.0 and 6.0%w/v) followed by cooling to 43 ± 1 °C. The milk was inoculated at a rate of 2% with *yoghurt* culture followed by incubation at a temperature of 43 ± 1 °C in an incubator until the pH reduced to 4.5–4.7. After fermentation, the *yoghurt* cups were transferred to a refrigerator and stored at 4 ± 1 °C. The developed product was then analysed for total solid (%), pH, titratable acidity [(LA) % by weight], syneresis (%), DPPH (% inhibition), viscosity (m.Pa.s), whiteness index (WI) and overall acceptability (OA) of developed product. Using response surface technique, the impact of SMP/WPC, inulin, and honey levels on goat milk *yoghurt* was assessed.

Experimental Design

The Box Behnken Design (BBD) of response surface methodology was used to study the possible combinations of factor levels containing the central point (five replicates) used for the optimization. Using Design -Expert statistical

software (Trial version 13, Stat-Ease, Inc., Minneapolis, USA), 17 experiments were designed and the ranges of the independent variables in the design were prescribed into three levels, which were 0.25, 0.5 and 0.75% w/v for SMP/WPC (X_1); 0.5, 1.0 and 1.5% w/v for inulin level (X_2); and 2.0, 4.0 and 6.0% w/v for honey level (X_3). The ranges of independent variables were selected after conducting a series of preliminary trials. The following response variables were measured: total solid (%), pH, titratable acidity [(LA) % by weight], syneresis (%) DPPH (% inhibition), viscosity (m.Pa.s), WI and OA. The experiment results were fitted with quadratic polynomial model for each response according to Eq. 1.

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 \tag{1}$$

where Y is the response variable, the β_0, β_i β_{ik} and β_{ii} are the regression coefficients for intercept, linear, interaction and quadratic effects, respectively. X_i and X_j are the coded independent variables influencing the responses Y. With a 5% significance level, the P value (probability) was used to determine model terms and the fit polynomial model was evaluated by coefficient of determination (R^2). The response surface plots were also generated to assess the effect of independent variables on responses of GMY.

Analytical procedure

The total solid (%) of *yoghurt* samples was evaluated by using a moisture analyser. The pH of *yoghurt* samples was measured with the help of a digital pH meter (Mettler Toledo®, Ohio, USA). Titratable acidity was evaluated by titration with 0.1N sodium hydroxide solution by following the method of AOAC (2005) and results were expressed as lactic acid (% by weight). Syneresis (%) in the *yoghurt* samples was carried out using the centrifugal method according to the procedure of Nguyen et al. (2017). Antioxidant activity was estimated by DPPH method according to the procedure described by Brand-Williams et al. (1995). The viscosity of the samples were evaluated using a dynamic rheometer (MCR72, Anton Paar Ltd., Austria) following the method of Nguyen et al. (2017). The colour values of the *yoghurt* samples were measured by evaluating Hunter lightness (*L**), redness (*a**) and yellowness (*b**) values using Color Tec PCM + (Color Tec Associates, Inc., Clinton, NJ). The whiteness index (WI) was calculated through Eq. 2.

$$WI = 100 - [(100 - L^*)^2 + a^{*2} + b^{*2}]^{1/2} \tag{2}$$

Sensory analysis

Sensory analysis of *yoghurt* samples was carried out by a panel of 20 semi-trained panellists comprised of scientists and scholars. The panellists were not specifically trained, they were previously acclimatised with the sufficient knowledge of sensory evaluation methods and product attributes. The panellists were briefed about the experiment and were requested to rate the coded samples on the sensory evaluation sheet using 9-point hedonic scale (1 = extremely dislike and 9 = extremely like) for overall acceptability. The overall acceptability of product took into account the average scores for colour and appearance, body and texture, flavour and mouth feel. The panellists provided overall acceptability scores for the *yoghurt* samples based on their collective perception of the samples.

Results and discussion

Model fitting

The findings of the experiment investigating the impact of independent variables on goat milk *yoghurt* production, along with the recorded responses for the 17 treatments, are detailed in Table 1. A statistically adequate models was obtained using the response surface method that effectively elucidates the influence of independent variables on the studied responses. There were linear, quadratic, and interactive effects recorded for each model. The response surface graphs generated from experiment data are shown in Figs. 1, 2 and 3. Experimental data were used to obtain models, which were then analysed for level of significance. An analysis of variance (ANOVA) was conducted to determine the statistical significance of each model term. The results of the regression analysis and ANOVA for each response are shown in Table 2. In all the cases, we observed an insignificant lack of fit (F-values), which confirmed the validity of the models. The coefficient of determination (R^2) values for all responses were higher than 0.85. According to Lima et al. (2010), the (R^2) should be approximately 80% to indicate that the model fits well.

Total solid

This study investigated the influence of SMP/WPC, inulin, and honey levels on total solid content of GMY using the application of RSM. The R^2 value of 0.9164 indicates a strong fit of the model to the data (Table 2). The quadratic

Table 1 Observed responses for three level-three factors Box–Behnken response surface experimental design process un-coded variables of goat milk *yoghurt*

Runs	SMP: WPC (% w/v)	Inulin (% w/v)	Honey (% w/v)							Responses	
	Un-coded levels			Total Solid (%)	pH	TA [(LA) % by weight]	Syneresis (%)	DPPH (% inhibition)	Viscosity (m.Pa.s)	WI	OA
1	0.50	1.50	4.00	19.58	4.39	0.76	9.04	22.63	141.21	77.25	8.30
2	0.75	1.00	4.00	20	4.38	0.75	9.14	22.67	146.41	78.69	8.08
3	0.50	1.50	4.00	20.75	4.41	0.74	9.32	22.39	152.45	77.29	8.30
4	0.50	1.50	4.00	20.71	4.40	0.75	9.75	22.99	138.16	77.14	8.30
5	0.25	1.00	4.00	21.01	4.36	0.74	8.93	22.92	155.67	77.70	8.33
6	0.75	1.50	2.00	18.04	4.36	0.72	11.67	21.43	125.33	80.46	7.80
7	0.50	1.00	2.00	19.96	4.34	0.70	11.51	21.82	121.88	80.93	7.90
8	0.50	1.50	4.00	20.77	4.42	0.74	9.54	22.78	157.65	77.97	8.48
9	0.50	2.00	2.00	20.34	4.33	0.72	11.55	21.89	130.16	79.95	7.88
10	0.50	1.50	4.00	20.09	4.41	0.75	9.97	22.12	148.41	77.24	8.35
11	0.25	1.50	2.00	19.14	4.31	0.71	11.32	20.68	128.41	79.63	7.78
12	0.25	1.50	6.00	21.19	4.45	0.79	6.09	24.71	181.47	75.45	8.20
13	0.50	1.00	6.00	21.79	4.47	0.77	6.49	25.09	176.78	76.75	8.33
14	0.75	2.00	4.00	20.77	4.38	0.75	8.82	23.04	151.43	79.14	8.05
15	0.50	2.00	6.00	22.33	4.48	0.78	6.32	25.03	179.21	76.59	8.25
16	0.75	1.50	6.00	20.77	4.49	0.77	6.65	25.17	171.45	76.48	8.15
17	0.25	2.00	4.00	20.71	4.35	0.73	8.51	22.95	148.09	77.56	8.00

[#] LA-lactic acid, WI-Whiteness index, OA-Overall acceptability

equation representing the model that elucidates the correlation between the total solid content of GMY and its independent variables is as follows: Total solid $= +25.50 + 2.82X_1 - 10.26X_2 + 0.42X_3 + 2.14X_{12} + 0.34X_{13} + 0.04X_{23} - 8.62X_{11} + 3.13X_{22} - 0.01X_{33}$. In this case, honey level (linear), SMP/WPC, and inulin levels (quadratic) were significant model terms and affected the GMY. Notably, honey level displayed the most pronounced linear effect, suggesting its dominant influence on total solid (Table 2). Factors SMP/WPC and inulin level have statistically significant quadratic effects, implying a non-linear relationship with total solid. The model is statistically significant and provides a good fit to the data. Quadratic effects indicate the curvature in the response due to squared values of factors (Fig. 1a–c). Similarly, an increase in total solid value on honey addition has been reported for set type *yoghurt* by Mercan and Akin (2017); Sert et al. (2011). Differences in the total solid of GMY may be due to higher solid-non-fat and protein levels on SMP/WPC additions in different formulations. The above results followed Gursel et al. (2016) and Costa et al. (2016), who also found changes in the composition of GMY with the incorporation of protein ingredients.

pH

The pH of the GMY varied from 4.31 to 4.49 (average pH of 4.40) (Table 1). The R^2 value was 0.9836, this value indicates that approximately 98.36% of the variability in the pH can be explained by the model (Table 2). This suggests a strong relationship between the factors and the pH response. The pH value can be determined using the following equation: $pH = +4.10 + 0.39X_1 + 0.18X_2 - 0.00X_3 + 0.02X_{12} - 0.01X_{13} + 0.01X_{23} - 0.33X_{11} - 0.07X_{22} + 0.00X_{33}$. In Table 2, the linear effects represent the changes in pH due to variations in each factor. Factors SMP: WPC and honey levels have significant linear effects on pH. Quadratic effects indicate curvature in the response due to squared values of the factors. All three factors have significant quadratic effects on pH. Response surface plot of pH values are presented in Fig. 1d–f. The coefficient of variation (CV) = 0.23%, indicates the relative variability of the data (Table 2). A low CV suggests that the data points are closely clustered around the mean. There is a possibility that different pH values can be attributed to the metabolic activities of lactic acid bacteria in the presence of additives in milk. Further, pH variation in *yoghurt* was reported due to buffering action of whey proteins (Akalin et al. 2007). Sert et al. (2011) reported a similar change in pH in set-type *yoghurt* added with honey.
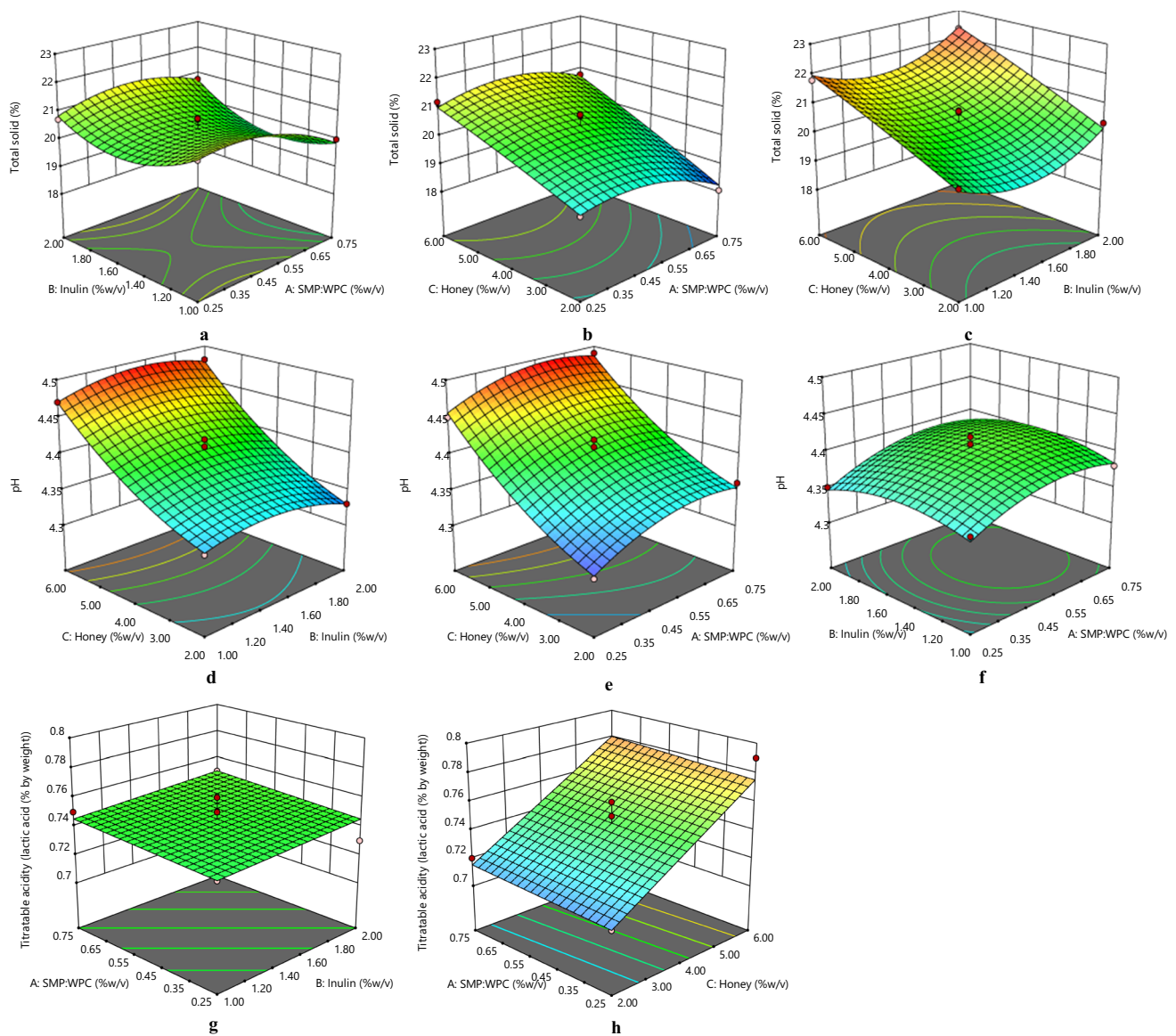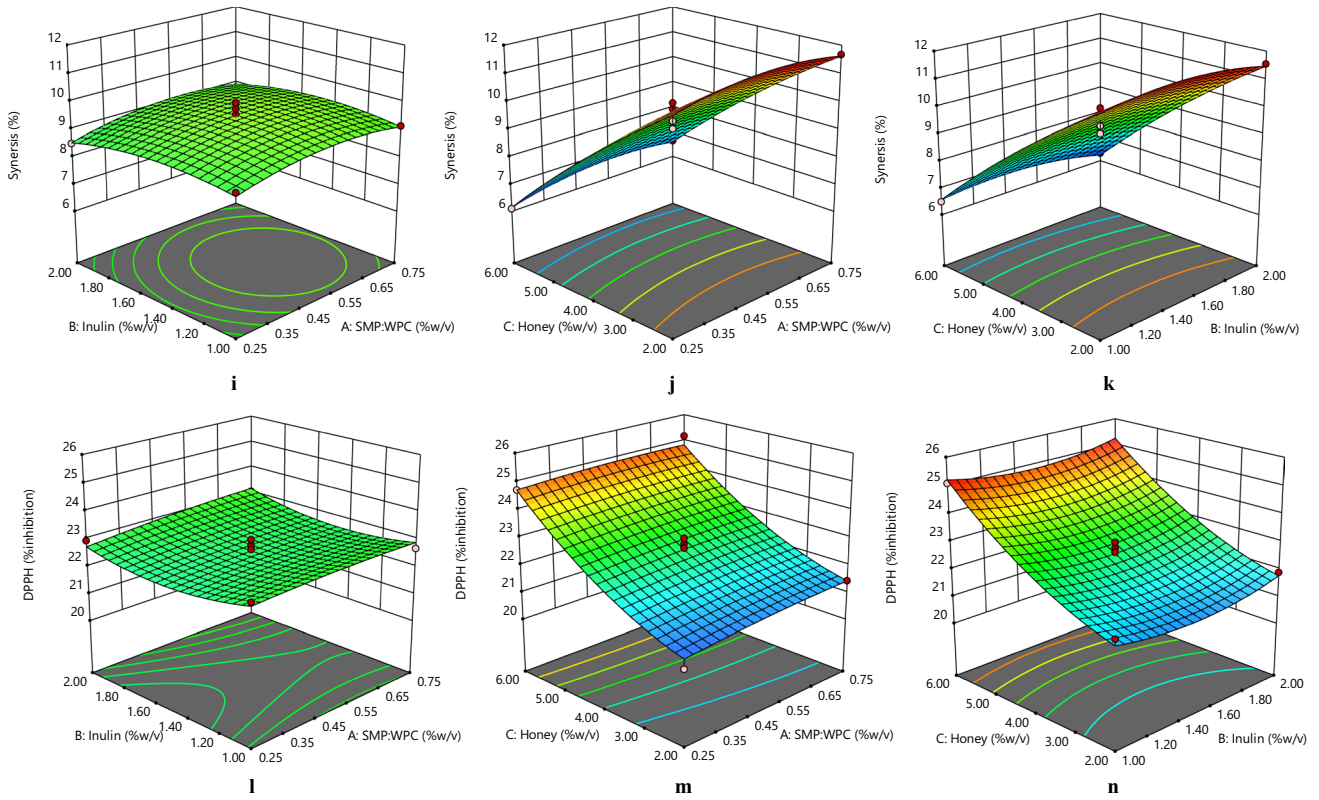
Fig. 1 Response surface plots related to total solid **a-c**, pH **d-f**, TA **g-h**, syneresis **i-k** and DPPH **l-n** as influenced by independent variabls

According to Passeephol and Sherkat (2009) inulin powder additions did not affect *yoghurt* milk pH and TA.

Titratable acidity (TA)

A *yoghurt's* titratable acidity is essential when analysing its consumer acceptability. The linear model for acidity can be obtained by the following equation: $TA = +0.67 + 0.01\beta_1 + 0.01\beta_2 + 0.02\beta_3$. The linear effects represent the changes in TA due to variations in each individual factor. The analysis of variance showed that honey has a significant ($p < 0.05$) linear effect on titratable acidity. The TA of GMY in the present study varied from 0.70 to 0.79 with independent variables (Table 1). The CV indicates the relative variability

of the data. A moderate $CV = 1.22\%$ suggests a moderate dispersion of data points around the mean (Table 2). The pattern of variation of TA as an effect of honey level can be observed from Fig. 1g, h. As we increase the honey level, there might be an upward trend in TA. This is because the significant positive coefficient indicates that increasing the honey level leads to higher TA. The trend might be relatively steep due to the high coefficient (102.33*). This suggests that even small changes in honey level could result in noticeable changes in titratable acidity. The International Dairy Federation has recommended *yoghurt* should have a minimum acidity of 0.70%, and most of the formulations assessed has achieved this level in the present study (Obi et al. 2010). Further, a study by Akalin et al. (2007) found

Fig. 1 (continued)
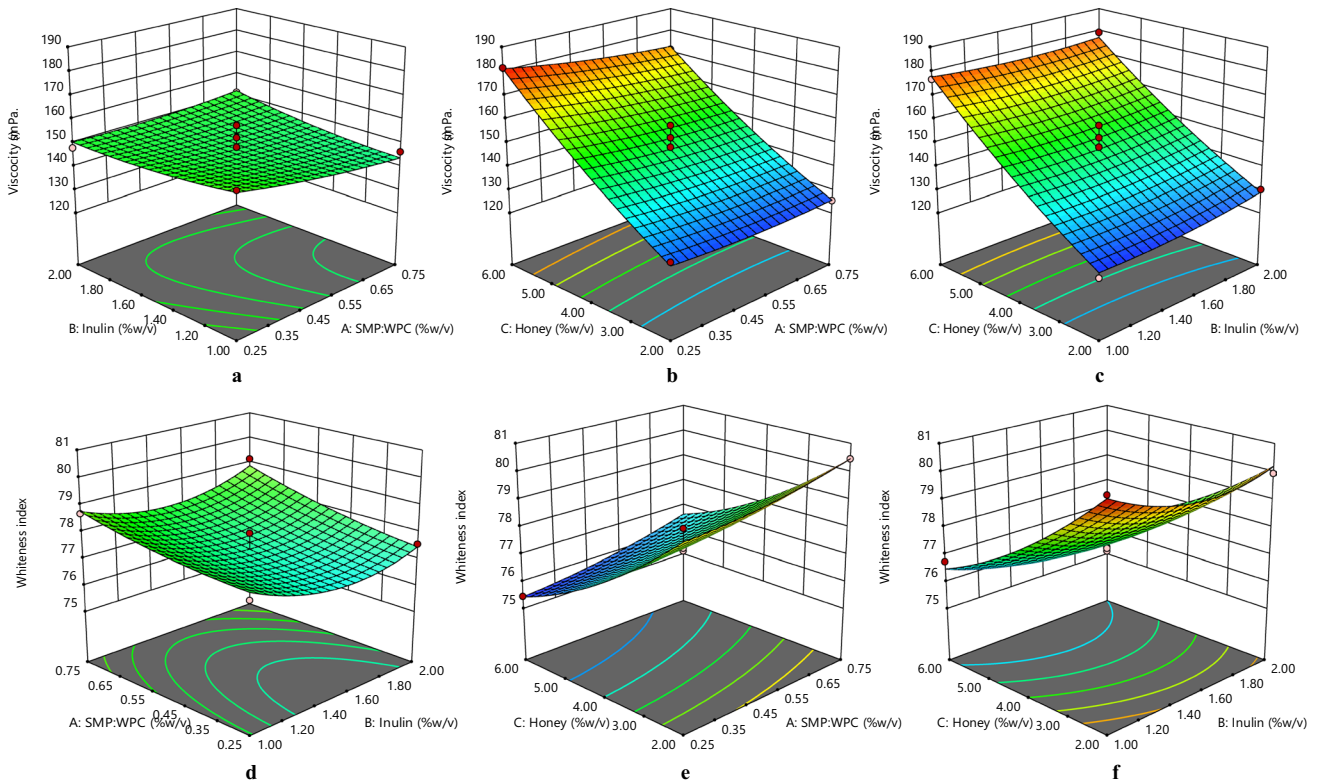
Fig. 2 Response surface plots related to viscosity **a-c** and whiteness index **d-f** as influenced by independent variabls
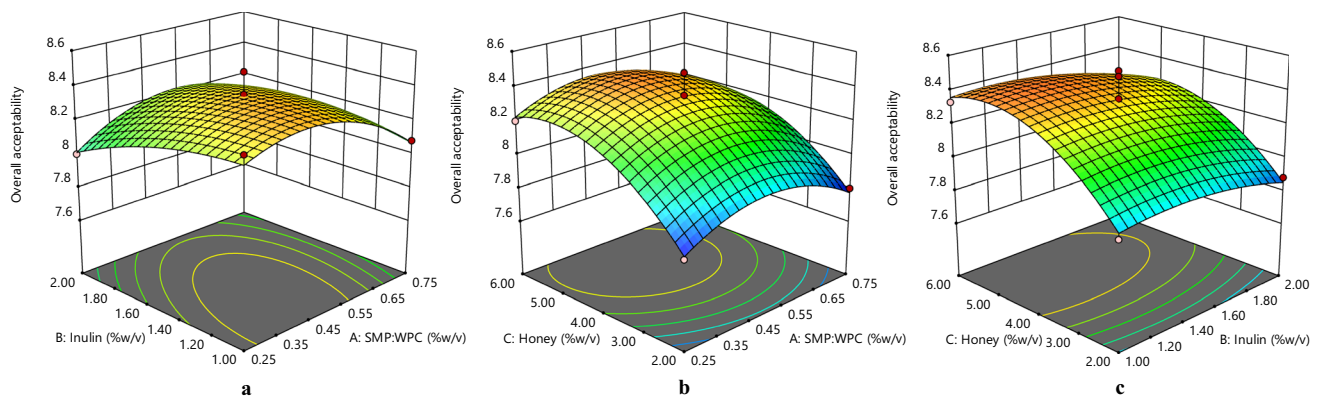
Fig. 3 Response surface plots related to overall acceptability **a-c** as influenced by independent variabls

Table 2 Significance of the regression models (F-values) and the effects of variables on the goat milk *yoghurt*

Source of variance	Total Solid $R^2=0.9164$	pH $R^2=0.9836$	TA $R^2=0.8884$	Syneresis $R^2=0.9892$	DPPH $R^2=0.9663$	Viscosity $R^2=0.9492$	WI $R^2=0.9784$	OA $R^2=0.9497$
	F values							
Linear								
β_1	4.10	23.02*	0.61	3.02	1.02	1.08	20.86*	1.27
β_2	1.30	0.11	0.61	1.12	0.16	0.20	0.75	5.07
β_3	49.66*	355.29*	102.33*	621.52*	186.55*	126.67*	263.32*	59.10*
Cross Product								
β_{12}	1.54	0.23	–	0.03	0.21	0.97	0.76	4.32
β_{13}	0.62	0.23	–	0.13	0.16	0.32	0.10	0.24
β_{23}	0.03	0.93	–	0.13	0.03	0.21	1.46	0.17
Quadratic								
β_{11}	6.56*	16.63*	–	6.26*	0.17	0.15	1.07	23.13*
β_{22}	13.80*	12.82*	–	5.09	4.67	0.27	18.73*	3.08
β_{33}	0.07	11.43*	–	2.80	7.47*	0.82	7.39*	30.47*
Lack of fit	0.22	0.58	1.26	0.17	1.41	0.16	1.12	0.67
C.V	2.11	0.23	1.22	3.20	1.60	4.25	0.43	0.89
Mean	20.47	4.40	0.74	9.10	22.96	150.23	78.01	8.15
Std. Dev	0.43	0.01	0.01	0.29	0.37	6.39	0.34	0.07
Model	8.52*	46.63*	34.51*	71.30*	22.33*	14.53*	35.19*	14.69*

*$p<0.05$; R^2– Coefficient of determination, C.V. – Coefficient of variation, # TA-Titratable acidity, WI-Whiteness index, OA-Overall acceptability

that, the fructooligosaccharides present in honey stimulate *bifidobacteria*, whereas the honey level increased the titratable acidity of the product. The results in this study contradict those reported by Varga (2006), who found that honey did not significantly affect acidity.

Syneresis

A syneresis occurs when the gel network becomes unstable and impairs its ability to trap all the serum phase (Costa et al. 2016). The following equation

can obtain the quadratic model for syneresis: Syneresis = $+9.42+5.67\beta_1+3.73\beta_2$-$0.78\beta_3+0.20\beta_{12}+0.11\beta_{13}$-$0.05\beta_{23}$-$5.67\beta_{11}$-$1.28\beta_{22}$-$0.06\beta_{33}$. Syneresis (%) varied from 6.09 to 11.67 among a range of formulations studied (Table 1). The syneresis in the GMY was demonstrated by the high R^2 value (0.9892) as shown in Table 2. The linear effects represent the changes in syneresis due to variations in each factor. Honey has a significant ($p<0.05$) linear effect on syneresis, whereas the effect of SMP/WPC level on syneresis was significant ($p<0.05$) in quadratic terms. This suggests that the SMP/WPC level and syneresis

relationship follow a curved pattern, possibly with an optimal point where syneresis is minimized or maximized (Table 2, Fig. 1i, j, k). In fermented milk gels, syneresis can be reduced by increasing total solid and protein contents, apparently due to higher water-holding sites (Costa et al. 2016; Hussain et al. 2016). Previous studies have also reported that the water holding capacity of *yoghurt* is significantly improved by adding caseins or whey proteins in the form of caseinates to milk (Akalin et al. 2012). The reduced syneresis may also come from honey, which is high in water-binding capacity due to its fructose content (Sert et al. 2011). A study by Srisuvor et al. (2013) found no significant differences in syneresis between samples of *yoghurt* made from reconstituted milk and that supplemented with 1, 2 or 3% inulin.

DPPH

The DPPH scavenging activity of the GMY formulations ranged from 20.68% to 25.17% (Table 1). The R^2 indicates that the model can explain approximately 96.63% of the variability in DPPH (Table 2). This suggests a strong relationship between the factors and the DPPH response. DPPH can be obtained by following equation: $DPPH = + 23.79 + 1.26\beta_1 - 4.75\beta_2 + 0.03\beta_3 + 0.68\beta_{12} - 0.15\beta_{13} - 0.03\beta_{23} - 1.18\beta_{11} + 1.55\beta_{22} + 0.12\beta_{33}$. The linear terms of honey level were observed to have a significant effect ($p < 0.05$) on DPPH scavenging activity of GMY. Quadratic effects indicate curvature in the response due to squared values of the factors. Independent variables such as inulin and honey have significant ($p < 0.05$) quadratic effects, suggesting non-linear relationships with DPPH activity. A lack of fit value of 1.41 suggests that there might be some unexplained variability between the model and the observed data (Table 2). Response surface plots (Fig. 1l–n) show the effect of independent variables on DPPH of the GMY. As the honey level increases or decreases, a distinct change in DPPH activity would be observed. The coefficient value will likely govern the steepness of this change. Similar reports of higher DPPH with increase in honey level were also reported by Mercan and Akin (2017) during the preparation of set-type *yoghurt*. It is generally believed that *yoghurt's* antioxidant capacity is primarily attributed to small bioactive peptides (protein hydrolysates) released during fermentation.

Viscosity

The viscosity of *yoghurt* is one of the most important parameters that describe its texture. *Yoghurt* can be described as a non-Newtonian fluid with shear-thinning characteristics (Afonso and Maia 1999). The following equation can express the viscosity of GMY: $Viscosity = + 131.95 - 52.20\beta_1 - 24.07\beta_2 + 11.06\beta_3 + 25.20\beta_{12} - $ $3.59\beta_{13} - 1.46\beta_{23} + 19.37\beta_{11} + 6.45\beta_{22} + 0.70\beta_{33}$. The F-value of quadratic model for viscosity was significant ($p < 0.05$). Viscosity of GMY varied from 121.88 to 181.47 m.Pa.s depending on the varying levels of SMP/WPC, inulin and honey (Table 1). The R^2 indicates that the model can explain approximately 94.92% of the viscosity variability (Table 2). This suggests a strong relationship between the factors and the viscosity response. As shown in Table 2, the individual effect of honey level significantly affected the viscosity of GMY ($p < 0.05$). As the honey level changes along the axis, a corresponding viscosity value change was observed. The steepness of the change will likely be determined by the coefficient value of 126.67 wherein increasing the honey level leads to higher viscosity (Table 2). This suggests that even slight changes in honey level could lead to notable variations in viscosity. A trend line shows how viscosity changes as the honey level varies (Fig. 2a-c). By adding honey, the *yoghurt's* solids content increased and its consistency improved, leading to a direct connection between the amount of honey added and its viscosity (Machado et al. 2017). The previous study also showed that adding pine honey to *yoghurt* enhanced viscosity (Mercan and Akin 2017). However, SMP/WPC and inulin level showed a little increase in the viscosity of GMY at the studied range. Akin to the present study, Costa et al. (2016) reported a similar increase in the viscosity of *yoghurt* after the addition of inulin and whey protein. This behaviour can also be explained by the milk base composition which plays a role in casein aggregation and gel structure formation (Damin et al. 2009).

Whiteness Index (WI)

The coefficient of determination (R^2) indicates that the model can explain approximately 97.84% of the variability in WI (Table 2). This suggests a strong relationship between the factors and the WI response. The linear effects represent the changes in WI due to variations in each factor. Since the linear effects of factors SMP: WPC and honey are significant ($p < 0.05$) with coefficients of 20.86*, and 263.32*, respectively, a clear and noticeable pattern for each factor can be observed (Table 2). The quadratic equation of the model that explained the relationship between the WI of GMY and the independent variable is shown in the equation: $WI = + 91.86 - 2.76\beta_1 - 10.29\beta_2 - 2.25\beta_3 + 1.19\beta_{12} + 0.11\beta_{13} + 0.20\beta_{23} + 2.76\beta_{11} + 2.89\beta_{22} + 0.11\beta_{33}$. It is evident from Table 2, inulin and honey level had a significant ($p < 0.05$) effect in quadratic terms. Quadratic effects indicate curvature in the response due to squared values of the factors. In the 3D plot, this might translate to a more pronounced curvature along the axis (Fig. 2d, e, f). The curvature might be more pronounced since the coefficient is relatively large viz., 18.73 and *7.39* for inulin and honey, respectively. A similar result was reported by Sert et al. (2011)

for set type *yoghurt* added with honey where lightness (*L**) value decreased, redness (*a**) and yellowness (*b**) values increased. The increase of milk protein content in dairy foods elevates the total protein acidic groups, resulting in better protein coagulation which further affects the ratio reflected: absorbed light, leading to a reduced perception of lightness (da Silva Teba et al. 2017).

Overall acceptability (OA)

The sensory acceptability of *yoghurt* is considered one of the most important characteristics that determine its ultimate use. The OA varied from 7.78 to 8.48 for all the formulations (Table 1). The following quadratic equation of the model that explains the relationship between the OA of GMY and the independent variable: OA = + 6.46 + 1.83β_1 + 0.39β_2 + 0.53β_3 + 0.60β_{12} - 0.04β_{13} - 0.02β_{23} - 2.71β_{11} - 0.25β_{22} + 0.05β_{33}. The linear effects represent the changes in OA due to variations in each factor. The honey level had a significant ($p < 0.05$) positive effect on OA of GMY at the linear level with a coefficient of 59.10* (Table 2). Increasing honey levels substantially increases OA values, whereas factors SMP/WPC and honey level have significant quadratic effects ($p < 0.05$) on OA. The high coefficient value of 23.13* indicates a substantial quadratic effect of factor SMP/WPC. This could lead to a pronounced curve along the axis on the OA response surface. A large positive coefficient of 30.47* indicates a significant quadratic effect of honey. As honey increases or decreases, it significantly influences the non-linear variation in OA (Fig. 3a, b, c). The coefficient of variation CV = 0.89% indicates the relative variability of the data (Table 2). A relatively low CV suggests that the data points are not widely dispersed around the mean. *Yoghurt* acceptability is closely related

to its composition which enhances flavour, texture, and appearance. Improved score ratings were also reported by Mercan and Akin (2017) in set-type *yoghurt* incorporated with honey. It is evident from the finding of Mazzaglia et al. (2020) that the addition of inulin does not affect the sensory qualities of goat milk *yoghurt*.

Optimization

In order to optimize the level of independent variables for the development of novel goat milk *yoghurt*, various constraints were identified. Table 3 shows the optimization experiment related to the independent variables (factors) and dependent variables (responses). The aim is to find the optimal conditions for the independent variables (SMP/WPC, inulin level, honey level) to achieve the desired outcomes for the dependent variables. The analyses show that the goat milk *yoghurts* have total solid ranged from 18.04 to 22.33, pH from 4.31 to 4.49, TA from 0.70 to 0.79, syneresis from 6.09 to 11.67, DPPH from 20.68 to 25.17, viscosity from 121.88 to 181.47, WI from 75.45 to 80.93 and overall acceptability varied from 7.78 to 8.48. During optimization, the responses i.e. total solid (%), pH, titratable acidity [(LA) % by weight], and whiteness index, were kept in range while the other responses like syneresis (%), DPPH (% inhibition), viscosity (m.Pa.s.), and overall acceptability were maximized. However, all factors have been assigned equal importance. To confirm the obtained optimum formulation, two replications of *yoghurt* samples with the optimized formulation were prepared and the validation test was performed. The changes in predicted and observed value were not significant. It was found that optimal conditions for goat milk *yoghurt* production were achieved at a 0.36%w/v

Table 3 Goals identified and predicted and the observed value for the optmized goat milk *yoghurt*

Name	Goal	Lower limit	Upper Limit	Predicted value	
Independent variables					
SMP: WPC ratio (% w/v)	is in range	0.25	0.75	0.36	
Inulin level (% w/v)	is in range	1.0	2.0	1.00	
Honey level (% w/v)	is in range	2.0	6.0	6.00	
Dependent variables				Predicted value	Observed value
Total solid (%)	is in range	18.04	22.33	22.03	22.51 [ns]
pH	is in range	4.31	4.49	4.46	4.41 [ns]
TA [(LA)% by weight]	is in range	0.70	0.79	0.77	0.74 [ns]
Syneresis (%)	minimize	6.09	11.67	6.34	6.37 [ns]
DPPH (% inhibition)	maximize	20.68	25.17	25.20	25.32 [ns]
Viscosity (m.Pa.s)	maximize	121.88	181.47	182.30	180.47 [ns]
WI	is in range	75.45	80.93	76.29	76.82 [ns]
OA	maximize	7.78	8.48	8.37	8.41 [ns]
Desirability			0.95		

[#] LA-lactic acid, WI-Whiteness index, OA-Overall acceptability

of SMP/WPC, 1.00%w/v of inulin level, and 6.00%w/v of honey content with a desirability of 0.95.

Conclusion

This study successfully utilized a three-factor Box-Behnken design coupled with response surface methodology to optimize the formulation of high-quality goat milk *yoghurt* by considering the concentrations of SMP/WPC, inulin, and honey. The outcomes of the study showcased the substantial influence of these variables on several key attributes of GMY, including total solid, pH, titratable acidity, syneresis, DPPH, viscosity, whiteness index, and overall acceptability. Honey played a significant role in improving the overall quality of *yoghurt* and both SMP/WPC and honey have improved the overall acceptability of *yoghurt*. However, no significant effect of inulin was observed at linear and interaction level. The desirability value of 0.95 highlighted the attainment of the optimization process in achieving the desired product characteristics. Therefore, the present study provides valuable insights into the formulation optimization of goat milk *yoghurt* using a systematic approach. The results contribute to the enrichment of GMY production processes, ultimately producing a novel product with well-balanced rheological attributes and high overall acceptability.

Author contributions TPS: conceptualization, methodology, investigation, writing-original Draft. AKV: data analysis, reviewing and editing. VR: Supervision. MKC: Supervision. SA: data analysis, reviewing and editing. BR: Supervision.

Data availability The Data and material that support the findings of this study are available from the corresponding author (TPS), upon reasonable request.

Code availability 'Not applicable'.

Declarations

Conflict of interest All authors declare that they have no competing interests to report.

Ethics approval 'Not applicable'.

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