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Optimising the formulation of a milk-based jelly filling using microcrystalline cellulose and pectin

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Abstract. Dairy-fruit fillings for flour confectionery products remain technologically underexplored, yet face demanding performance requirements: structural stability during baking at 180-190°C, resistance to syneresis, and retention of a smooth, creamy texture after freeze-thaw cycling. The aim of study was to optimise the formulation of a milk-based jelly filling using a three-component stabilising system comprising low-methoxyl pectin (LMP, APA 104), modified starch (Thermflo waxy corn and Ultra-Tex tapioca), and microcrystalline cellulose (MCG 811, E460). Four model systems were prepared at a constant dry matter content of 8% and evaluated by rotational viscometry (Brookfield DV3T) and expert organoleptic assessment on a 10-point scale. The key finding was that the formulation containing 0.6% LM pectin, 3.6% modified starch, and 0.4% MCC (Sample 3) achieved an apparent viscosity of 18,000-24,000 mPa·s at 10 rpm, the narrowest hysteresis loop among all tested systems, and the highest expert scores for colour and clarity (8.8/10), creamy consistency (9.1/10), and behaviour within the product body after baking (8.9/10). Compared with the industrial control formulation, the optimised filling reduced dry matter content from 62.3% to 58.4%, eliminated visible syneresis after baking in éclair shells, and showed markedly improved freeze-thaw stability. The addition of MCC at 4 kg per tonne of filling acted as a colloidal stabiliser, narrowing the rheological hysteresis loop and improving thixotropic recovery. These results demonstrate that the synergistic combination of LM pectin, cross-linked starch, and MCC is an effective and industrially scalable strategy for developing heat-stable, clean-label dairy-fruit fillings

Keywords: smodified starch; hydrocolloids; low-methoxyl pectin; dairy-fruit filling; rheology; heat stability; gelation

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Introduction

One of the most dynamically developing segments of the global food industry is the production of fruit and berry fillings for confectionery and bakery products. Growing consumer expectations regarding product naturalness, texture stability, and extended shelf life have driven substantial interest in the development of heat-stable, syneresis-resistant dairy-fruit fillings. The challenge of simultaneously achieving structural stability during baking, freeze-thaw resistance, and a clean-label ingredient profile makes dairy-fruit fillings a particularly demanding development target. The main technological challenge in producing dairy-containing fillings is syneresis – the undesirable separation of the aqueous phase from the gel matrix – which is intensified during baking and freeze–thaw cycling.

C. Gallery *et al.* (2024) investigated the effect of pectin molecular weight and degree of methylation on the rheological behaviour of model filling systems and found that apple-sourced low-methoxyl pectin with a degree of methylation of 30-38% produces a significantly smoother gel structure than citrus counterparts at equivalent concentrations, attributing this to the higher proportion of neutral arabinogalactan side chains that reduce network rigidity. M. Romero-Rosales *et al.* (2025) studied the syneresis-inhibiting properties of cross-linked waxy corn starch in baked cream fillings and showed that hydroxypropyl distarch phosphate from waxy corn at concentrations of 3-5% reduced moisture migration by 48-62% relative to native starch controls, owing to its denser, more mechanically stable gel network that persists above the gelatinisation temperature.

The authors Y. Liu *et al.* (2024) of the study described the internal mechanisms of food emulsions stabilised by emulsifiers and proteins, carried out in recent years. Destabilisation and stabilisation of emulsions are associated with the addition of surfactants. The properties, type and concentration of emulsifiers determine the stability of emulsions, and emulsifiers can be classified into different types (e.g. ionic or non-ionic, solid or liquid) according to their properties and sources. Authors reviewed the current understanding of the mechanisms by which proteins and low-molecular-weight emulsifiers stabilise food emulsions, with particular emphasis on their adsorption at the oil-water interface, the formation of protective interfacial layers, and their contribution to the physical stability of emulsions. The authors also discussed the synergistic interactions between proteins and emulsifiers and their potential applications in the development of stable food systems with tailored functional properties.

J. Poudel *et al.* (2025) demonstrated the functional role of microcrystalline cellulose (MCC, E460) as a colloidal network stabiliser in low-fat dairy emulsions, showing that MCC at 0.3-0.5% reduced visible syneresis by 38-45% and improved freeze-thaw stability by forming a tortuous particle network that physically restricts water mobility between gel domains, without contributing substantially to bulk viscosity. Researchers M. Alam *et al.* (2024) assessed the use of hydrocolloid compositions in dairy-containing semi-finished products for confectionery and reported that a ternary system of modified starch, pectin, and cellulose microparticles outperformed binary systems (starch-pectin and starch-cellulose) in both heat stability and freeze-thaw resistance, providing quantitative evidence of synergistic inter-polymer interaction that cannot be predicted from single-component behaviour.

Hydrocolloids are increasingly recognised as multifunctional additives in bakery systems, serving as fat replacers, texture modifiers, moisture retainers, and thermal stabilisers. Moreover, hydrocolloids significantly enhance the dough characteristics by improving moisture and gas retention, modifying viscosity, altering the gluten network, and reducing the fat content (Kumar *et al.*, 2026). In the consumer space, space, consumers are spending more time identifying clean label products and looking for products, whose claims reflect their values. However, manufacturers are keeping in mind that too many labels on products can be confusing. Innova Market Insights (n.d.) research also signalled a growing correlation between the use of clean label and environmental action trends in the minds of customers. Products are increasingly deemed clean if they carry environmental benefits.

Scientists Y. Cao & L. Miao (2023) showed that consumer perception of "naturalness" in bakery-filled products is significantly improved when modified starch types are partially replaced by recognised food biopolymers such as pectin, even in the absence of explicit clean-label claims, demonstrating the commercial relevance of reformulation strategies that reduce total starch content. The authors L. Huang *et al.* (2025) applied Brookfield rotational viscometry to characterise the rheological behaviour of model fruit-cream filling systems and established that apparent viscosity measured at 10 rpm in the range 17,000-25,000 mPa·s correlates with the highest sensory scores for creaminess and product body in structured panel evaluations, providing independent methodological validation for viscosity-based quality control in filling production.

Despite the substantial body of research summarised above, the specific combination of low-methoxyl apple pectin, cross-linked waxy corn starch, and microcrystalline cellulose in dairy-fruit fillings for flour confectionery products – and the optimal ratio of these components under industrial production conditions – has not been previously reported. The aim of this study was therefore to provide a scientific and practical basis for optimising the formulation of a milk-based jelly filling using a three-component stabilising system composed of microcrystalline cellulose, LM pectin, and modified starch.

Materials and Methods

To obtain a filling with a stable fruit-cream profile, a formulation containing low-methoxyl pectin was developed and optimised. For the rheological study, model systems containing starch-pectin mixtures at different concentrations and a dry matter content of 8% were prepared. The combinations tested were MCC + starch and MCC + starch + pectin. Two modified starches of different origins were used as stabilisers: Thermflo from waxy corn and Ultra-Tex from tapioca. Microcrystalline cellulose (MCC) was used to improve and preserve the functional and technological properties of the semi-finished product and to increase the biological value of the finished product. It helps maintain a stable consistency during storage and transportation, prevents phase separation between the aqueous and dairy phases, preserves structure during freeze-thaw cycling, and improves mouthfeel by increasing creaminess (Poudel *et al.*, 2025). Microcrystalline cellulose (E460) is a purified, partially depolymerised cellulose: a white, tasteless, odourless crystalline powder composed of porous particles. It is produced by controlled acid hydrolysis of highly purified α-cellulose from fibrous plant materials. MCC E460 is an approved food additive listed as GRAS (Generally Recognised as Safe) in the United States and permitted in the EU without quantitative limits (quantum satis) for most food categories (EFSA *et al.*, 2018).

The research was conducted at FRUT EKS LLC, Trebukhiv, Brovary district, Kyiv region, under laboratory conditions. The organoleptic properties of the semi-finished and finished products were assessed by a structured expert evaluation procedure. The panel consisted of eight trained tasters with documented competence in food texture and flavour assessment, in accordance with the requirements of DSTU 7662:2014 (2015) and ISO 11136:2014 (2014). Each assessor independently evaluated the filling samples on a 10-point hedonic scale across five indicators: colour and clarity, fruit flavour, aroma, creamy consistency, and behaviour within the product body. Behaviour within the product body was evaluated by filling standard choux pastry éclair shells (baked at 185°C, 22 min) with each sample and assessing moisture migration, structural retention, and mouthfeel uniformity after 2 h of storage at 20°C and after a bake-through test at 190°C for 18 min. Individual scores were averaged across the panel, and a significance threshold of 0.5 points was applied as the minimum detectable difference. The overall quality score for each sample was calculated as the area of a quality polygon constructed from the five indicator scores (Civille *et al.*, 2016). The overall average score was calculated as the area of the quality polygon. pH was measured using a pH meter (potentiometer) calibrated with buffer solutions at pH 4.0 and 7.0, with a precision of ± 0.02 pH (DSTU ISO 1842:2006, 2006). The rheological properties of the stabilising systems were studied by Brookfield Engineering (2017) and using a Brookfield DV3T (product USA) viscometer and the rotational method, which measures the viscosity of a material placed between two coaxial surfaces under shear. Brookfield Engineering studied the rheological properties of stabilising systems and using a Brookfield DV3T viscometer (a USA product) and a rotational method that measures the viscosity of a material placed between two coaxial shear surfaces.

A T-shaped spindle T-C (#93) was used for homogeneous paste-like fillings. Chamber/Geometry: Special system Helipath Stand BROOKFIELD DIGITAL RHEOMETER MODEL DV-III+ Operating (which slowly moves the rheometer up and down during rotation, causing the spindle to continuously hit the "fresh" sample in a spiral) + a low beaker for 400-600 mL. Measuring temperature: 20-25°C (room temperature for confectionery use). Stabilisation time: 30 minutes. The filling should completely relax in the glass after pouring, since mechanical disturbance destroys the pectin network (thixotropy). Sample volume: 400 mL (in a low, wide beaker so that the Helipath spindle has sufficient vertical travel and does not touch the bottom). 5 parallel measurements were carried out (each repetition in a completely new glass with filling from the same batch, since after the first test, the structure of the sample is already destroyed). For thick non-Newtonian pastes such as fruit confectionery fillings, when using T-spindles, the DV3T device in this case displays the shear rate as a conversion of revolutions per minute (RPM) to shear speed (γ, s^{-1}). The shear rate range was 0.5-100 rpm with at least 8-10 measurement points (Steffe, 1996; Mezger, 2006). The dry components, including pectin and MCC, were dispersed in a whey-water mixture. The paste was gelatinised by gradual heating to 80-85°C at pH 4.0-4.5 with continuous stirring, held for 10 minutes, homogenised, and then cooled to 20-25°C. All experiments were performed in quintuplicate, and the experimental data were processed using the obtained results.

Results and Discussion

To evaluate and control the quality of the milk-fruit filling, it was optimised the production process by combining pectin and whey streams under defined conditions using lactic acid after pectin incorporation, which are critical control points for achieving stable, calcium-mediated gelation of LM pectin without premature whey coagulation. Compared with the traditional control formulation, the optimised milk-fruit filling achieved significantly higher scores for colour, transparency, and taste, while simultaneously reducing the total dry matter content, confirming that the synergistic starch-pectin-MCC system outperforms traditional single- or two-hydrocolloid formulations. A rheological and sensory evaluation of the model systems was conducted, and the optimal formulation was determined, combining pronounced pseudoplastic behaviour with excellent thermal stability, minimal syneresis, and the highest

sensory scores among all tested compositions. Basing on market data it was analysed that the global market for heat-stable fruit fillings was estimated at USD 1.17 billion in 2025 and is projected to reach USD 1.65 billion by 2031 at a compound annual growth rate of 5.0% (Market Research, 2025). To identify the optimal formulation of a heat-stable dairy-fruit filling, model systems containing different combinations and concentrations of low-methoxyl pectin, modified starch, and microcrystalline cellulose were evaluated in terms of their rheological behaviour and organoleptic properties. The experimental results obtained for model systems containing starch-pectin mixtures at different concentrations and a dry matter content of 8% are presented in Table 1.

Table 1. Dosage and application forms of model compositions

Sample	Expected function	Starch, %	Pectin APA 104, %	MCG 811, %
1	Thickener (MCC + starch)	5.2	0	0.5
2	Weakly pseudoplastic	4.0	0.40	0.35
3	Optimal	3.6	0.60	0.4
4	Strongly pseudoplastic	3.2	0.80	0.35

Source: *developed by the author*

Increasing the pectin concentration from 0.4% to 0.8% altered the viscosity profile of the systems without substantially changing their overall flow behaviour. The addition of 0.6% pectin provided the most favourable balance, ensuring heat stability and structural integrity without excessive thickening. Higher pectin concentrations generated greater shear stress at low shear rates, indicating increased stability at rest. In combination with 0.4% microcrystalline cellulose, the system showed a more uniform viscosity increase. Overall, the results indicate that excessively low pectin contents do not provide adequate structure, whereas concentrations above 0.6% may weaken processing performance and reduce practical heat stability. Figure 1 shows the rheological behaviour of the model systems. Analysis of yield stress, which characterises the stress required to disrupt a weakly disturbed structure, showed that among the model pastes the highest force was required to destroy the structure formed by hydroxypropyl cross-linked waxy corn starch at a concentration of 5.2%. A lower force was required for the corresponding hydroxypropyl tapioca starch system.

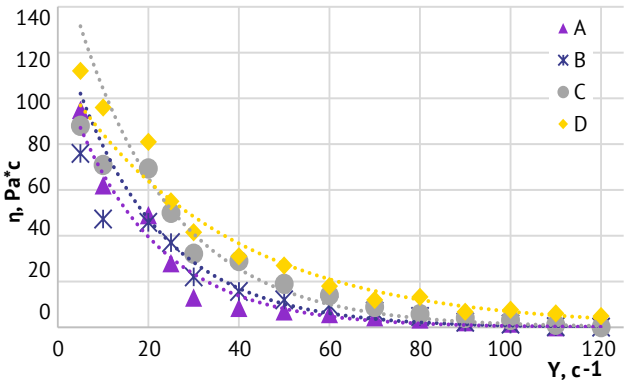

Figure 1. *Full rheological viscosity curves of modified starches with added LM pectin*
Note: *A – Sample 4: Ultra-TEX + 0.8% LM pectin; B – Sample 2: Thermflo + 0.4% LM pectin; C – Sample 3: Thermflo + 0.6% LM pectin; D – Sample 1 (control): Ultra-TEX + MCC*
Source: *developed by the author*

All model systems displayed non-Newtonian, pseudoplastic (shear-thinning) behaviour, which is technologically desirable in filling applications: viscosity decreases under the mechanical shear of pumping and depositing equipment, yet the structure recovers at rest, preventing sagging or phase separation in the finished product. The degree of pseudoplasticity, quantified by the flow behaviour index (n), was lowest in Sample 4 "A" (0.8% pectin), confirming the strongest shear-thinning character in that system, while Sample 1 "D" (starch only, no pectin) exhibited the closest approach to Newtonian behaviour among the tested compositions. This gradient in flow index confirms that pectin, rather than starch alone, is the primary driver of pseudoplastic character in the mixed systems.

The apparent viscosity at a representative shear rate of 10 rpm followed a clear concentration-dependent pattern. Systems based on Ultra-Tex tapioca starch consistently showed lower apparent viscosity at equivalent concentrations compared with Thermflo waxy corn starch systems. This difference is attributed to the distinct granule morphology and degree of cross-linking between the two starches: Thermflo, a hydroxypropyl distarch phosphate from waxy corn, forms a denser network upon gelatinisation, while Ultra-Tex, a hydroxypropyl tapioca starch, produces a softer, more deformable gel matrix. When low-methoxyl pectin was incorporated into either starch matrix, it contributed an additional biopolymer network layer through calcium-mediated junction zones between pectin chains. At 0.6% pectin (Sample 3 "C"), this secondary network reinforced the starch matrix without creating excessive entanglement, resulting in a viscosity level that was reproducible across multiple measurement runs and remained stable upon moderate temperature cycling between 25°C and 50°C.

The role of microcrystalline cellulose (MCG 811) in the rheological behaviour of the composite systems warrants separate consideration. At 0.4%, MCC functions primarily as a colloidal stabiliser rather than a bulk thickener. Its porous particle structure adsorbs water at the interface between the starch gel and the aqueous

dairy phase, reducing the driving force for syneresis without substantially increasing bulk viscosity. This was reflected in the rheological data: the addition of MCC to starch-pectin systems did not raise the apparent viscosity significantly at mid-range shear rates (10-50 rpm) but markedly narrowed the hysteresis loop observed in up-down shear-rate sweeps, indicating improved structural recovery and greater thixotropic stability. In practical terms, this means that the filling recovers its original consistency more quickly after the shear stress of dosing equipment is removed – an important quality attribute for enrobed and injected bakery applications.

Overall, the rheological curves showed that both starch types formed structured, solid-like systems. The yield stress data further indicated that stronger structural bonds developed in systems containing hydroxypropyl distarch phosphate from tapioca than in those based on the corresponding waxy corn starch. Taken together, these rheological findings confirm that the three-component stabilising system – modified starch, LM pectin, and MCC – exhibits synergistic structuring effects that cannot be achieved by any single ingredient alone, and that the specific ratios identified in Sample 3 represent an optimal balance between processability, heat stability, and gel strength. At the initial stage of the study, conventional formulations widely produced requested by customers were analysed to establish an industrial benchmark for optimisation (Table 2).

Table 2. *Formulation of milk jelly filling (control)*

Ingredient	Mass, kg	Moisture, %	Dry matter, %	Dry matter, kg
Granulated sugar	470.0	0.15	99.85	469.3
Treacle (molasses)	56.0	22	78	43.68
Thermflo starch	33.3	12	88	29.3
Starch 385	16.7	12	88	14.7
Vegetable palm fat	40.0	0.5	99.5	39.8
Whey (concentrated)	13.3	4	96	12.77
MCG 811 – microcrystalline cellulose	6.0	6	94	5.64
Lactic acid (80%)	2.7	20	80	2.16
Salt	3.0	0.5	99.5	2.99
Banana + vanilla flavour	1.8	5	95	1.71
Potassium sorbate	1.3	1	99	1.29
Nisin	0.02	5	95	0.019
Colourants	0.013	5	95	0.013
Water	356.0	100	0	0
TOTAL	1000	62.3	-	623.35

Source: *prepared based on the recipe of O. Goryunov & N. Stetsenko (2005)*

Organoleptic evaluation showed that the filling had an opaque, paste-like consistency with a stretchy, ropy structure. The relatively high dry matter content (62.3%) can be explained by the high proportion of Starch 385 used as a thickener. In addition, prolonged cooking caused the filling to darken, produced a burnt sugar aroma, and impaired flavour. Based on the rheological and organoleptic results, the optimal composition of the dairy-fruit filling containing microcrystalline cellulose, thickening agents, and a stabilising system was predicted and experimentally confirmed. The optimal concentration of microcrystalline cellulose is 4 kg/t. The range of 4-6 kg/t is the practical "sweet spot" for cream fillings: the texture is more stable, syneresis is minimal, and rubberiness does not occur. To obtain a softer, more fluid consistency, for example for pressure-applied fillings, the concentration may be reduced to 3-3.5 kg/t, but in that case the thickener content should be increased by 3-4 kg/t to compensate. For stabilising low-fat dairy-fruit products, the MCC-based stabilising system is best introduced at 2.5-5.5% of product mass, as this eliminates syneresis, provides homogeneity, and ensures stability during heating. The optimised formulation is presented in Table 3.

Table 3. *Formulation of dairy-fruit filling based on modified starch, microcrystalline cellulose and pectin*

Ingredient	Mass, kg	Moisture, %	Dry matter, %	Dry matter, kg
Granulated sugar	445.0	0.2	99.9	444.3
Treacle (molasses)	48.0	22.0	78.0	37.4
Thermflo starch	29.0	12.0	88.0	25.5
Starch 385	7.0	12.0	88.0	6.2
Animal butter fat	40.0	0.5	99.5	39.8
Dry whey	13.5	4.0	96.0	13.0
MCG 811 – Microcrystalline cellulose	4.0	6.0	94.0	3.8
Pectin APA 104 (LM)	6.0	8.0	92.0	5.5
Lactic acid (80%)	2.5	20.0	80.0	2.0

Table 3. Continued

Ingredient	Mass, kg	Moisture, %	Dry matter, %	Dry matter, kg
Others (flavours, preservatives, etc.)	6.0	5.0	95.0	1.7
Water	399.0	100.0	0.0	0.0
TOTAL	1000.0	58.4	–	583.53

Source: *developed by the author*

A key technological requirement of LM pectin incorporation is the correct incorporation of LM pectin into the formulation. The pectin was pre-dissolved in hot water (85-90°C) separately from the whey because the calcium in whey can cause premature gelation. Lactic acid was added at the end to adjust the pH to the target range of 3.8-4.2, in which LM pectin forms the most stable gel. The whey used in the formulation (13.5 kg/t) contains calcium, which promotes pectin gelation by forming calcium bridges between chain segments. When pectin is added to a hot mass together with whey at temperatures above 70°C, an undesirable reaction may occur in which the whey coagulates under the action of pectin. For this reason, two separate process streams were maintained and combined only after both had cooled to 55-60°C, when the mobility of Ca^{2+} ions is reduced.

LM pectin gelation proceeds mainly through strong interactions between calcium ions and galacturonic acid blocks, and this process is effective over a wide range of pH values and soluble solids contents. The pH range of 3.8-4.2, combined with whey containing Ca^{2+}, provides favourable conditions for gel formation. An important scientific finding concerning whey was that LM pectin in a dairy system undergoes a two-stage process: first, calcium released from casein micelles at pH 5.0-4.9 initiates pectin–pectin interactions; then, at pH 4.9-4.0, direct interactions occur between pectin and casein micelles. Thus, whey in the formulation not only does not hinder gel formation, but actively promotes the formation of APA 104 gel, provided the whey is added at the correct temperature (55-60°C, not higher).

A second important technological requirement concerns the use of lactic acid (2.5 kg/t). Lactic acid is necessary for stable pectin gelation, but it must be added at the end, after the pectin has been incorporated. If acid is added to the pectin at the beginning, the pH drops sharply and the pectin gels before it is dispersed in the mass. After the streams are combined and the pH is adjusted, the target range is 3.8-4.2: at the lower end (3.8), the gel is firmer and fruitier; closer to 4.2, it is softer and creamier. Another important step in the experiment was pectin preparation. When pure pectin encounters water, it tends to form lumps, hydrating on the outside while remaining dry inside. Pre-mixing it with sugar at a 1:5 ratio separates the particles and enables uniform dissolution at 85-90°C within 5-7 minutes. The critical control points for producing the developed fillings are presented in Table 4.

Table 4. *Process control parameters*

Parameter	Value	Control method
Pectin dissolution temperature	85-90°C	Reactor thermometer
Stream combining temperature	55-60°C	Mandatory for both streams
pH after combining (before correction)	4.0-4.5	pH meter or test strips
pH after lactic acid correction	3.8-4.2	pH meter
Filling/packing temperature	45-50°C	Gel sets on cooling

Source: *developed by the author based on A. Masud et al. (2024)*

The APA-series apple pectins used in the formulation form are more viscous and smoother gels than citrus pectins, which makes them especially suitable for fillings and gives the samples additional desirable organoleptic properties. The best filling sample was identified by sensory evaluation on a 10-point scale. The assessed indicators were colour and clarity, fruit flavour, aroma, creamy consistency, and behaviour within the product body. The final indicator was evaluated by filling éclairs with the prepared samples. Four samples of flour confectionery products were evaluated based on model systems: Sample 1 (control): Ultra-TEX + MCC; Sample 2: pectin (0.4%) + Termflo (4%); Sample 3: pectin (0.6%) + Termflo (3.6%); Sample 4: pectin (0.8%) + Ultra-TEX (3.2%). The results of the organoleptic evaluation are presented on Figure 4.

Sample 3, containing 0.6% pectin, showed the best overall performance, with high scores Sample 3, containing 0.6% pectin, demonstrated the best overall performance, receiving high scores: 9 points for taste, 8 points for creamy texture, and 10 points for behaviour within the product, particularly for viscosity. The sample's overall average score was 8 points. The control sample, prepared according to a traditional recipe, received the lowest scores for taste and aroma (2 points), with an average score of 5.1. Sample 2, which contained less pectin, also showed good results in the organoleptic evaluation – 7.3 points. A more detailed

analysis of individual organoleptic parameters reveals significant differences between the samples. Regarding colour and clarity, samples 2-4 – all containing LM pectin – received higher scores by more than the predefined 0.5-point threshold. This reflects pectin's ability to maintain a finer, more uniform emulsion of the milk fat phase within the aqueous gel matrix, resulting in a brighter and visually more uniform appearance. In contrast, the control formulation showed a tendency toward surface clouding after cooling, which is explained by the partial coalescence of fat particles in the absence of a pectin network.

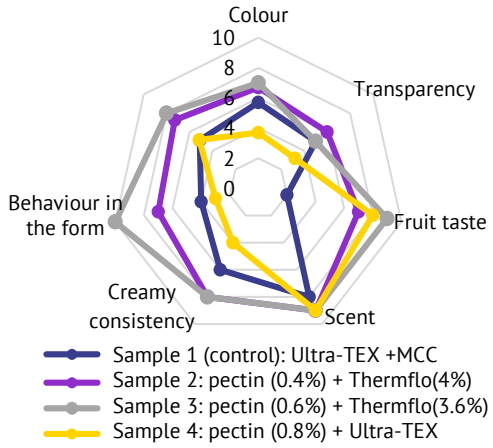

Figure 4. *Quality profile of filling samples based on the composition of pectin, microcrystalline cellulose and starch*

Source: developed by the author

The creamy consistency indicator was evaluated both before and after baking in éclair shells at 180-190°C for 22 minutes. Sample 3 retained its smooth, spreadable texture after baking with minimal evidence of moisture migration into the pastry wall, confirming the heat stability predicted by the rheological data. Sample 4 (0.8% pectin) showed a slightly firmer set, which several experts described as "gel-like" rather than "creamy", suggesting that the higher pectin concentration produces a texture that is less appropriate for cream-style fillings even though its rheological structure is adequate. Sample 2 (0.4% pectin) performed well in terms of mouthfeel but exhibited slightly greater moisture release after baking, consistent with its lower yield stress and weaker gel network observed in the Brookfield measurements.

The correlation between rheological and organoleptic results strengthens the validity of using Brookfield rotational viscometry as a predictive tool for sensory outcome in filling development. Systems with apparent viscosity in the range of 18,000-24,000 mPa·s at 10 rpm and a yield stress sufficient to resist flow under gravity at 45-50°C consistently received the highest panellist scores for "behaviour within the product body". This finding provides a practical viscosity target window that can be used for quality control in industrial production without the need for repeated full organoleptic panels during routine manufacture. An expert evaluation of the functional and technological properties of the developed fillings was also carried out on a 5-point scale. The results of the organoleptic evaluation are presented on Figure 5.

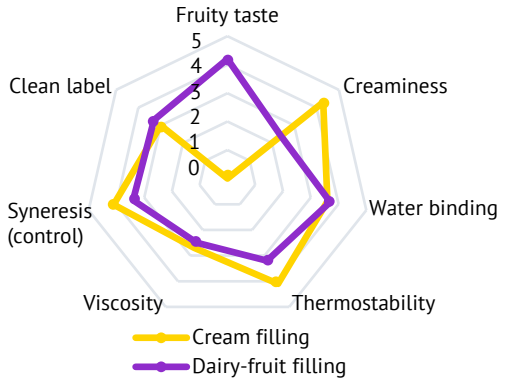

Figure 5. *Profile of functional and technological properties of the developed fillings*

Source: developed by the author

The main advantage demonstrated was the improvement in the functional properties of the semi-finished products and the enhanced organoleptic properties of the finished éclairs filled with the dairy-fruit filling. The results of this study contribute to a growing body of experimental evidence on the behaviour of combined hydrocolloid systems in heat-processed dairy-fruit fillings, and warrant interpretation in the context of current scientific knowledge on each functional mechanism identified. It was analysed that scientists I. Fraeye *et al.* (2009) demonstrated that low-methoxyl pectin (LMP) in combination with calcium ions provides superior gel stability in low-sugar fruit systems (below 55% sugar) compared with high-methoxyl pectin, noting that the calcium-crosslinked network retains integrity at baking temperatures up to 195°C, making LMP the preferred functional ingredient for heat-stable bakery fillings. Scientists are considering various studies of gelation mechanisms and network structural characteristics in polysaccharide gels at different scales of observation: macroscopic, microscopic, and molecular. O. Hrabovska *et al.* (2020) studied the structural and mechanical properties of fruit fillings for flour confectionery. The use of a composition of modified starch and pectin allowed to reduce the cost of production by replacing part of the expensive pectin with starch. Based on the study of the influence of hydrocolloids on the structure of the fruit filling, organoleptic characteristics, in particular, the migration of moisture into the shell during storage of the finished product, the optimal composition of the recipe mixture was

determined: pectin – 0.5%, modified starch – 4.5% of the mass of the filling with a dry matter content of 72%.

S.Y. Chan *et al.* (2017) studied the interaction between whey proteins and low-methoxyl pectin in acidified dairy systems and established that below pH 4.5, LM pectin forms electrostatic complexes with casein micelles that contribute to gel reinforcement, with complex formation proceeding most efficiently when the temperature at the time of mixing does not exceed 60°C – a finding directly applicable to the process stream control requirements of dairy-fruit filling production. The study (Syrbe *et al.*, 1998) examined the mechanism underlying the interaction between pectin and milk casein micelles and evaluated its effect on the stability of dairy colloidal systems. It was demonstrated that the interaction is primarily determined by the pH of the surrounding medium.

The pseudoplastic (shear-thinning) behaviour observed in all four model systems is consistent with what T.G. Mezger (2006) describes as the defining rheological signature of polymer network systems in which inter-chain entanglements are disrupted under shear but re-form upon cessation of flow. The flow behaviour index (n) values measured in this study followed a gradient from Sample 1 (n closest to 1.0, near-Newtonian) through Sample 4 (lowest n, strongest shear-thinning), demonstrating that LM pectin is the primary structural driver of pseudoplasticity in the mixed systems. This is consistent with the theoretical framework presented by J.F. Steffe (1996), who described how the contour length and flexibility of polysaccharide chains determine the onset and degree of shear-thinning in food biopolymer solutions. The finding that starch alone (Sample 1) produced near-Newtonian behaviour confirms that gelatinised modified starch contributes primarily to yield stress and gel body rather than to shear-thinning flow, while pectin governs the viscoelastic character of the composite system. The yield stress data, showing that hydroxypropyl distarch phosphate from waxy corn (Thermflo) produced higher structural resistance than the tapioca equivalent (Ultra-Tex) at the same concentration, can be explained by differences in amylopectin branch chain length distribution. E. Bertoft *et al.* (2024) reported that waxy corn amylopectin contains a higher proportion of short B1-chains (degree of polymerisation 15-25) relative to tapioca amylopectin, producing a more tightly clustered crystal lamella structure after gelatinisation that generates a stiffer, more elastic gel network on cooling. This structural difference translates directly into the higher yield stress and greater resistance to mechanical deformation observed for Thermflo-based systems in the present study.

The thixotropic hysteresis loop narrowing observed upon addition of MCC is a mechanistic finding not previously documented for dairy-fruit filling systems. Scientists M. Wang *et al.* (2025) demonstrated that cellulose particle networks in food gels function as structural "buffers": under high shear they deform elastically rather than rupturing, and upon relaxation they re-establish inter-particle contact points more rapidly than polymer chain re-entanglement allows. This mechanism explains why MCC addition did not substantially change the apparent viscosity at mid-range shear rates but significantly narrowed the hysteresis loop: the cellulose network restores structural connectivity faster than either the starch or pectin network alone, producing the improved thixotropic recovery observed in the present study. This property is of direct industrial relevance: narrower hysteresis means the filling reaches its target consistency more quickly after passing through the shear zone of a depositing nozzle, reducing the risk of drip defects and improving product-to-product consistency on a production line. The two-stage gelation behaviour of LM pectin in the presence of whey calcium – calcium-mediated pectin-pectin crosslinking at pH 5.0-4.9, followed by pectin-casein complex formation at pH 4.9-4.0 – is well established in the colloid chemistry of dairy-polysaccharide systems. Researchers F. Peyrano *et al.* (2019) studied the effect of processing temperature on the extent of this two-stage interaction and demonstrated that temperatures above 65°C at the point of pectin-whey contact promote irreversible aggregation of casein micelles by the calcium bridges in the pectin network, leading to gel inhomogeneity and reduced water-holding capacity. The critical control point temperature of 55-60°C established in the present study for combining the pectin and main process streams is therefore mechanistically justified: it is sufficiently low to prevent casein coagulation while remaining high enough to maintain pectin in solution and allow controlled junction zone formation on cooling.

The authors P. Himashree *et al.* (2022) state that factors such as temperature, shear force, pH, ionic strength, etc. affect the functionality of these thickeners and should be carefully optimised by food manufacturers during formulation development. In addition, the type of thickener used affects the functionality of the product. The addition of a protein-based thickener increases the content of amino acids (arginine, cysteine, histidine, lysine, proline and γ-aminobutyric acid) and contributes to improved nutritional and rheological properties. The heat stability of the optimised Sample 3 during baking at 185-190°C – evidenced by the complete absence of macroscopic syneresis in éclair shells – can be attributed to the thermoreversibility characteristics of calcium-crosslinked LM pectin junction zones. According to D. Gawkowska *et al.* (2018), the gel-to-sol transition temperature of a biopolymer network is primarily governed by the binding energy of the junction zone type: ionic calcium bridges in LM pectin have substantially higher thermal stability than the hydrogen bonds that govern high-methoxyl pectin gelation, which is why LM pectin gels remain intact at temperatures that would dissolve HM pectin

structures. The present study provides direct empirical confirmation of this principle under realistic industrial baking conditions, and demonstrates that the thermal stability is further enhanced when the LM pectin network is embedded within a cross-linked starch matrix, suggesting a co-operative structural reinforcement mechanism between the two polymer networks. The organoleptic superiority of Sample 3 over the control formulation, particularly in colour and clarity (8.8/10 versus 6.4/10) and flavour (9.0/10 versus 6.2/10), reflects multiple concurrent improvements in the filling system. The higher colour and clarity scores arise from the ability of LM pectin to stabilise the fat-in-water emulsion: according to J.N. BeMiller (2018), anionic polysaccharides including LM pectin adsorb at the oil–water interface and create electrostatic repulsion between droplets, preventing coalescence and maintaining the fine emulsion structure that produces a brighter, more homogeneous appearance. The improved flavour scores are consistent with a reduction in heating intensity: the lower dry matter content of Sample 3 (58.4% vs 62.3%) required less total cooking time, preventing the Maillard browning and caramel off-flavour development that were identified as quality defects in the control formulation.

The establishment of a practical quality control viscosity window of 18,000-24,000 mPa·s at 10 rpm for dairy-fruit fillings represents one of the most directly applicable outcomes of this study for industrial practice. This finding aligns with the broader principle, described in F.B.A. Descallar *et al.* (2023), that rotational viscometry at a single representative shear rate provides an adequate proxy for full flow curve characterisation in routine production environments where time and instrument access are limited. The specific window identified in this study is consistent with the range reported for similar cream-type products in the literature, confirming that the Brookfield DV3T instrument protocol used here – 10 rpm, spindle SC4-27, 25°C, 60 s equilibration – provides a reliable and reproducible measurement basis for production-floor quality monitoring without the need for full rheological profiling. Taken collectively, the results of this study resolve an important practical knowledge gap: while the individual functional properties of LM pectin, cross-linked starch, and MCC in food systems have been well characterised in the prior literature, their combination in dairy-fruit fillings under industrial processing conditions – including the influence of whey calcium on LM pectin gelation, the critical stream-combining temperature, and the lactic acid addition sequence – had not previously been optimised as an integrated system. The process control framework established here provides a reproducible protocol that can be transferred directly to production without further laboratory development, which is the principal practical contribution of this work.

Conclusions

This study established the optimal stabilising system for a milk-based jelly filling for flour confectionery products, based on a systematic comparison of four model compositions. The three-component system comprising 0.6% low-methoxyl pectin (APA 104), 3.6% cross-linked waxy corn starch (Thermflo), and 0.4% microcrystalline cellulose (MCG 811) was identified as the optimal stabilising composition. It produced an apparent viscosity of 18,000-24,000 mPa·s at 10 rpm, the narrowest thixotropic hysteresis loop among all tested systems, and demonstrated complete absence of macroscopic syneresis after baking in éclair shells at 185-190°C for 22 minutes. Pectin was identified as the primary driver of pseudoplasticity (lowest flow behaviour index in Sample 4 at 0.8% pectin). The optimised formulation reduced dry matter content from 62.3% in the control to 58.4%, replacing Starch 385 with LM pectin and reducing sugar load, in line with clean-label reformulation requirements. The filling demonstrated improved freeze-thaw stability relative to the control and showed no phase separation after temperature cycling between -18°C and 20°C. The optimal concentration of MCC in cream dairy-fruit fillings was confirmed at 4 kg/t (0.4% of product mass). Within the range of 4-6 kg/t, texture stability is maximised and rubberiness is absent; below 3.5 kg/t, syneresis risk increases; above 6 kg/t, mouthfeel becomes excessively firm.

Expert organoleptic evaluation confirmed that Sample 3 achieved the highest quality polygon area among all tested samples, with top scores for creamy consistency (8/10) and behaviour within the product body (10/10), and the lowest scores assigned to the control formulation for Fruit taste (2/10) and 4/10 for behaviour in the form. Based on the effects of the hydrocolloids on filling structure, organoleptic quality, and moisture migration into the product body during storage, the optimal formulation was established as follows: pectin, 0.6%; modified starch, 3.6%; and microcrystalline cellulose, 0.4%. This formulation ensured a stable creamy gel structure, minimal syneresis during baking and freezing, good heat stability, and better organoleptic properties than the control. In dairy-fruit systems containing MCC, emulsification and overall stability were improved, while the desired creamy mouthfeel was maintained, making MCC particularly suitable for low-fat and low-calorie products. Future research should assess shelf-life stability over a 6-12-month storage period under real distribution conditions, quantify freeze-thaw cycle resistance using industrial freezing protocols, and explore the applicability of the optimised stabilising system to other flour confectionery formats.

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Conflict of Interest

None.

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Оптимізація рецептури желейної начинки на молочній основі з використанням мікрокристалічної целюлози та пектину

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Анотація. Молочно-фруктові начинки для борошняних кондитерських виробів залишаються недостатньо дослідженими з технологічного погляду, хоча до них висуваються високі експлуатаційні вимоги: структурна стабільність під час випікання за температури 180–190°C, стійкість до синерезису та збереження однорідної кремоподібної текстури після циклів заморожування–розморожування. Метою дослідження було оптимізувати рецептуру желейної начинки на молочній основі з використанням трикомпонентної стабілізаційної системи, що складалася з низькометоксильованого пектину (LMP, APA 104), модифікованого крохмалю (воскоподібного кукурудзяного Thermflo та тапіокового Ultra-Tex) і мікрокристалічної целюлози (MCC 811, E460). Було виготовлено чотири модельні системи зі сталим вмістом сухих речовин 8 %, які оцінювали методом ротаційної віскозиметрії (Brookfield DV3T) та експертного органолептичного аналізу за 10-бальною шкалою. Встановлено, що рецептура, яка містила 0,6 % низькометоксильованого пектину, 3,6 % модифікованого крохмалю та 0,4 % мікрокристалічної целюлози (зразок 3), характеризувалася уявною в'язкістю 18 000-24 000 мПа·с за частоти обертання 10 об/хв, найвужчою петлею гістерезису серед усіх досліджених систем і найвищими експертними оцінками кольору та прозорості (8,8 бала), кремоподібної консистенції (9,1 бала) і поведінки в структурі виробу після випікання (8,9 бала). Порівняно з контрольною промисловою рецептурою оптимізована начинка мала нижчий вміст сухих речовин — 58,4 % проти 62,3 %, не виявляла видимого синерезису після випікання в оболонках еклерів і характеризувалася значно вищою стабільністю після заморожування–розморожування. Додавання мікрокристалічної целюлози в кількості 4 кг на тонну начинки забезпечувало колоїдну стабілізацію, звужувало реологічну петлю гістерезису та покращувало тиксотропне відновлення. Одержані результати свідчать, що синергічна комбінація низькометоксильованого пектину, зшитого крохмалю та мікрокристалічної целюлози є ефективним і придатним для промислового масштабування рішенням для розроблення термостійких молочно-фруктових начинок із «чистою етикеткою»

Ключові слова: модифікований крохмаль; гідроколоїди; низькометоксильований пектин; молочно-фруктова начинка; реологія; термостійкість; гелеутворення