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Influence of Starch as a Glidant on the Flow Behavior of Calcium Carbonate and Potassium Dichromate: An Angle of Repose Analysis

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Abstract: Powder flowability plays a crucial role in pharmaceutical manufacturing, affecting both processing efficiency and product quality. This study aimed to specifically examine its differential effects on powders with contrasting morphologies (porous versus non-porous) and varying concentrations. Flowability was assessed using the angle of repose, measured by the fixed funnel method, at varying starch concentrations (0%, 1%, 3%, and 5% w/w). For calcium carbonate, the angle of repose increased from 30.54°±0.6 at 0% starch to 42.0°±0.9 at 5%, indicating that higher starch levels led to particle agglomeration and reduced flowability. In contrast, potassium dichromate exhibited minimal variation, with the angle of repose ranging from 12.6°±0.5 to 19.7°±0.9, suggesting its naturally good flow was largely unaffected by starch. SPSS goodness-of-fit analysis showed that all flowability data followed a normal distribution ($P > 0.94$), supporting the reliability of parametric comparisons across powders. The results demonstrate that starch alters flow mainly through surface interactions, strongly affecting porous powders prone to adhesion and agglomeration, while having little impact on non-porous materials. These findings emphasize the importance of considering powder morphology when selecting glidants for optimizing pharmaceutical processes.

Keywords: Powder flowability; angle of repose; glidant effect; pharmaceutical excipients; interparticle friction; flow-enhancing agents.

1. Introduction

The flow properties of powders play a crucial role in processes such as tablet compression, capsule filling, and granulation. The AOR is one of the most commonly used criteria for evaluating powder flowability [1,2]. While traditional glidants such as talc and colloidal silicon dioxide are frequently used to improve flowability, starch has gained attention as a potential alternative due to its availability and multifunctional properties [3,4]. Calcium carbonate is widely used in pharmaceuticals as an excipient and active ingredient. However, its poor flowability presents challenges in manufacturing processes such as tablet compression and capsule filling. To improve its flow properties, glidants like starch can be added [5-7].

The AOR is a crucial parameter used to evaluate the flowability of powders, which is essential in material handling, pharmaceutical formulation, and industrial applications.

Potassium dichromate, a crystalline powder, can exhibit poor flow properties due to interparticle cohesion and irregular particle shape [8,9]. The properties of both powders were described in Table 1, as reported [3,4].

Potassium dichromate ($K_2Cr_2O_7$) is non-porous due to its crystalline nature, forming well-defined, dense crystals that lack significant internal voids or pores. It is highly soluble in water, meaning it dissolves rather than retaining liquid through porosity [3]. Its surface properties are relatively smooth and compact, further reducing the likelihood of significant porosity. Due to its non-porous nature, potassium dichromate has a higher bulk density and limited moisture-absorption capacity [8]. However, despite being non-porous, its particle shape and size distribution contribute to poor flowability, necessitating the use of glidants such as starch or colloidal silicon dioxide to improve handling. In contrast, calcium carbonate ($CaCO_3$) can be either porous or non-porous, depending on its source, processing method, and particle structure [9,10]. Natural calcium carbonate, such as limestone, chalk, or marble, is generally non-porous due to its dense crystalline structure, which has minimal surface porosity. On the other hand, precipitated calcium carbonate (PCC) can exhibit porosity depending on its synthesis conditions, making it suitable for applications in pharmaceuticals, plastics, and coatings due to its high surface area and controlled porosity.

Table 1. Comparison of potassium dichromate and calcium carbonate powders.

Property	**Potassium Dichromate ($K_2Cr_2O_7$)**	**Calcium Carbonate ($CaCO_3$)**
Appearance	Orange-red crystalline powder	White fine powder
Density (g/cm^3)	~2.68	~2.71
Solubility	Water soluble, insoluble in alcohol	Slightly soluble in water, reacts with acids
Toxicity	Highly toxic, carcinogenic	Non-toxic
Industrial Uses	Oxidizer, analytical reagent, glass coloring	Pharmaceutical excipient, filler, construction material
Flowability	Poor (AOR ≈ 44°)	Poor to fair (AOR ≈ 42°-45°)
Need for Glidants	Yes (talc, starch, colloidal silicon dioxide)	Yes (talc, starch, silica)

Starch, when used as a glidant, enhances powder flow by reducing interparticle friction and cohesion, thereby improving the flowability of pharmaceutical powders. Glidants are substances added to powder formulations to enhance their flow characteristics by minimizing friction and cohesion, which are primary factors that hinder smooth flow. As a common excipient, starch can serve as a glidant in tablet formulations, improving powder flow and ensuring uniformity during manufacturing [11,12].

The mechanism of action of starch involves multiple factors that contribute to enhanced powder flow. First, starch particles act as "spacers" between larger powder particles, reducing direct contact and friction, thereby helping prevent particle aggregation and enhancing movement [13]. Additionally, starch can fill in surface gaps and irregularities on powder particles, creating a smoother surface that further minimizes interparticle friction. Furthermore, due to its hydrophilic nature, starch can reduce the formation of liquid bridges, which may otherwise lead to greater cohesiveness and poor flowability among solid particles [14]. By addressing these factors, starch plays a crucial role in improving the overall flow characteristics of powders, ensuring uniformity and efficiency in pharmaceutical production.

The impact of glidants on the Angle of Repose, a key indicator of powder flowability, is described in Table 2 [15-18]. A lower AOR signifies improved flow, which is crucial for ensuring uniform powder movement during pharmaceutical manufacturing. Enhanced flow properties contribute to consistent tablet weight and uniform distribution of active ingredients, reducing variability and improving the quality of the final product [7].

In addition to starch, other commonly used glidants include talc, magnesium stearate, and colloidal silicon dioxide, each offering distinct advantages depending on the formulation. While the flow-enhancing effects of these commonly used glidants have been extensively studied, limited research has evaluated starch's efficacy as a glidant specifically in combination with calcium carbonate and potassium dichromate powders. However, the effectiveness of starch as a glidant depends on several factors, including its type (e.g., pregelatinized starch), concentration, and interactions with other excipients. While starch can enhance powder flow, excessive amounts may negatively impact flow properties or alter other tablet characteristics, such as disintegration and dissolution rates. Therefore, careful optimization and control of starch concentration are necessary to balance its benefits while maintaining the desired properties of the final dosage form [10, 19-21].

Table 2. Impact of starch as a glidant on powder flow properties.

Aspect	Description
Reduction in AOR	Glidants, including starch, lower the AOR, indicating improved powder flowability.
Enhanced Flow Properties	Better powder movement ensures consistent tablet weight and uniform distribution of active ingredients, reducing variability.
Importance in Manufacturing	Improved flow contributes to efficient tablet compression, reducing production issues such as weight variation and segregation.
Other Common Glidants	Besides starch, talc, magnesium stearate, and colloidal silicon dioxide are commonly used, each offering different flow-enhancing properties.
Factors Affecting Effectiveness	Starch’s impact as a glidant depends on its type (e.g., pregelatinized starch), concentration, and interaction with other excipients in the formulation.
Potential Negative Effects	Excessive starch may negatively affect flow properties, disintegration, and dissolution rates, requiring careful concentration control.
Optimization Considerations	Balancing starch concentration is crucial to maximizing flow enhancement while maintaining the desired tablet properties.

This study aims to specifically investigate its differential effects on powders with contrasting morphologies (porous versus non-porous) and varying concentrations. Therefore, it highlights the practical insights into material-dependent flow behavior. By analyzing these changes, the research seeks to provide a comprehensive understanding of how starch affects powder flow properties and its potential role as a flow-enhancing agent in pharmaceutical formulations. It is hypothesized that starch will have a more pronounced effect on porous powders, increasing the Angle of Repose through enhanced adhesion and agglomeration, while exerting minimal impact on non-porous materials. This will provide practical insights into excipient selection for optimized pharmaceutical manufacturing, tailored to each API.

Despite existing studies on traditional glidants, there remains a lack of comprehensive analysis of starch's performance in modifying the flow behavior of powders with distinct morphologies and surface properties, such as calcium carbonate (highly porous and irregular) and potassium dichromate (non-porous and crystalline). This contrast in porosity and morphology provides a robust basis for assessment, thereby allowing a more mechanistic understanding of glidant performance across material types. This study addresses this gap by systematically evaluating the AOR as a function of starch concentration. Hence, the hypothesis provides a mechanistic foundation for understanding material-dependent glidant performance.

2. Materials and Methods

The study utilized calcium carbonate ($CaCO_3$) procured by QUALIKEMS LIFESCIENCES PVT. LTD, VADODAEA-391340, Gujarat (India). Potassium dichromate ($K_2Cr_2O_7$), known for its crystalline and non-porous nature, was purchased from NICE

CHEMICALS PVT. LTD., KOCHI-682024, Kerala (India). Starch Soluble (EX POTATO) was incorporated as a glidant at varying concentrations of 1.0%, 3.0%, and 5.0% (w/w) to assess its impact on flow properties, which was acquired from LOBA CHEME PVT. LTD., Mumbai 400005, India. All laboratory reagents were used in this work. The AOR was measured using a standard fixed-funnel method, following the guidelines of the United States Pharmacopeia (U.S.P.) and the Indian Pharmacopeia (I.P.) to ensure accurate, standardized flowability assessment.

2.1. Methodology of experimental process.

2.1.1. Preparation of powder mixtures.

Starch was added to calcium carbonate and potassium dichromate in predetermined concentrations (0-5% w/w). The mixtures were blended using a tumbling mixer for uniform distribution. Before proceeding with the measurement, pass the powder sample through sieve no. 22 [2]. The different amounts of starch in grams were mentioned in Table 3.

Table 3. Different concentrations of starch (glidant).

Sieve no 22	**Concentration of starch (glidant) w/w**			
	0%	1%	3%	5%
Weight of sample 1 (gm)	20	20.2	20.6	21
Weight of sample 2 (gm)	40	40.4	41.2	42

2.1.2. Angle of repose measurement.

The powder was allowed to flow through a funnel with an internal diameter of 30 mm and an orifice size of 10 mm, which was mounted at a fixed height of 5.0 ± 0.1 cm above a flat, smooth surface to form a conical pile. The height (h) and base diameter (d) were measured at 25°C temperature [2], and the AOR (θ) was calculated using equation (1). The experimental framework was illustrated in Figure 1. Triplicate measurements were conducted for each concentration, and the mean AOR ± standard deviation was reported.

$$\theta = \tan^{-1}\frac{(h)}{\left(\frac{d}{2}\right)} \qquad (1)$$

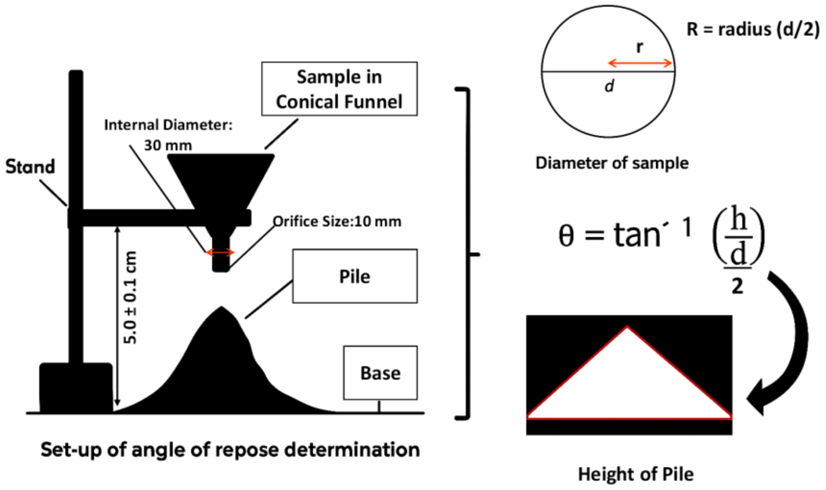

Figure 1. Experimental Layout for angle of repose (AOR) measurement using the fixed-funnel method at a funnel height of 5.0 ± 0.1 cm (n = 3).

2.2. Comparison of flowability.

The angle of repose values were compared for both powders with and without starch to determine the effectiveness of starch as a glidant, as depicted in Figure 2. This angle represents the maximum angle between the surface of a pile of powder and the horizontal plane, and smaller angles generally indicate better flowability. Starch modifies the surface morphology of cohesive powders, promoting rolling rather than sliding among particles, thereby enhancing flow behavior [22-25]. Similarly, native starches improved the flow properties of excipients in pharmaceutical blends by decreasing both the AOR and the compressibility index [26].

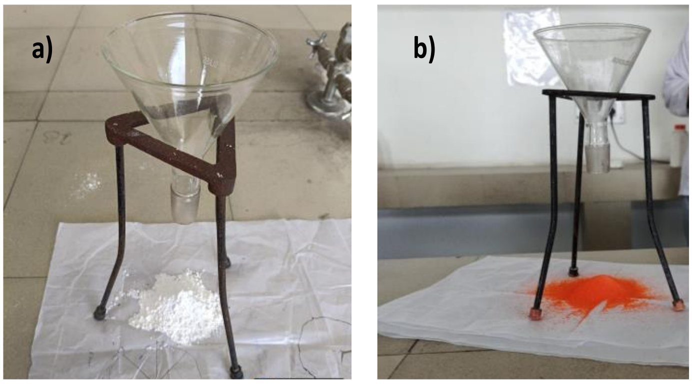

Figure 2. Evaluation of the **(a)** AOR for calcium carbonate; **(b)** potassium dichromate using the fixed funnel method. Measurements were performed in triplicate (n = 3).

2.3. Mechanistic insight into the flow behavior of starch.

To investigate the mechanistic impact of starch on powder flowability, the Angle of AOR was used as the primary analytical method due to its sensitivity to interparticle cohesion and surface interactions. This method allowed for the indirect assessment of starch-induced changes in interparticle forces. An increase in AOR is indicative of higher interparticle cohesion or bridging, often attributed to phenomena such as liquid bridge formation, capillary condensation, or surface energy interactions, particularly in porous powders like calcium carbonate, which offer higher adsorption sites and surface area for starch interaction [27,28]. Samples were conditioned at 25°C and relative humidity below 40% to minimize ambient moisture effects, which could otherwise exacerbate cohesion through capillary forces. The use of AOR as a metric is well-established for evaluating powder flowability and detecting cohesive mechanisms, making it suitable for studying starch-induced alterations in flow behavior [29-31].

2.4. Data analysis.

Statistical evaluation was conducted using IBM SPSS Statistics Version 20. The descriptive statistics (mean ± standard deviation) provide confidence in comparing the effects of starch across different powders. The normality of the data distribution corresponding to varying starch concentrations, specifically 0%, 1%, 3%, and 5% (VAR00002–VAR00005), was assessed using the One-Sample Kolmogorov–Smirnov (K–S) test, which serves as a supplementary assessment to support the reliability of parametric comparisons across powders. Each concentration group comprised a total sample size of N = 3. To complement the statistical tests, frequency histograms with superimposed normal distribution curves were generated for each starch concentration group to provide a visual assessment of data distribution. Mean and standard deviation values were calculated and displayed alongside each histogram to support the interpretation of normality and distribution characteristics.

3. Results and Discussion

The influence of starch as a glidant on the flow properties of calcium carbonate ($CaCO_3$) and potassium dichromate ($K_2Cr_2O_7$) was studied by estimating the AOR at varying starch concentrations (0%, 1%, 3%, and 5% w/w). The AOR provides insight into the flowability of powders, with lower angles indicating better flowability of powders.

3.1. Effect of starch on calcium carbonate flowability.

Calcium carbonate, a porous powder, showed notable changes in the AOR with the addition of starch. At 0% starch, the AOR was 30.54°±0.6, indicating moderate flowability. With 1% starch, the angle increased to 38.4°± 0.8, suggesting slight cohesion between particles. As starch concentration increased to 3% and 5%, the angles rose significantly to 40.9°±1.0 and 42.0°±0.9, respectively, indicating a marked reduction in flowability. The porous nature of calcium carbonate, which has a larger surface area, allows starch to reduce friction and improve powder flow at lower concentrations. However, at higher concentrations, excessive starch may lead to particle interactions that reduce flowability.

3.2. Effect of starch on potassium dichromate flowability.

Potassium dichromate, a non-porous crystalline powder, showed modest changes in flowability upon addition of starch. At 0% starch, the AOR was 12.6°±0.5, indicating excellent flow. The angle increased slightly to 16.09°±0.7 at 1% starch, 19.7°±0.9 at 3%, and decreased to 13.1°±0.6 at 5%. This suggests that small amounts of starch initially reduced flowability by increasing particle cohesion, but excess starch at 5% might have reduced cohesion, slightly improving flow. Since potassium dichromate already has low interparticle friction and good flow properties, the impact of starch was minimal.

3.3. Comparison of powder flow properties.

These results suggest that starch is more effective as a glidant for porous powders than non-porous crystalline powders. Table 4 summarizes the AOR values before and after the addition of starch.

Table 4. The angle of repose (AOR) values before and after the addition of starch.

Type of powder	**Concentration of starch (glidant) w/w**											
	0%			1%			3%			5%		
	H	r	θ	H	r	θ	H	r	θ	H	r	θ
(gm)	(cm)		°	(cm)		°	(cm)		°	(cm)		°
Calcium carbonate (Sample 1)	2.6± 0.1	4.4± 0.1	30.54± 0.6	3.0± 0.3	3.8± 0.1	38.4± 0.8	3.5± 0.1	4.1± 0.5	40.9± 1.0	3.3± 0.3	3.8± 0.1	42.0 ± 0.9
Potassium dichromate (Sample 2)	1.4± 0.1	6.25± 0.2	12.6± 0.5	1.5± 0.1	5.2± 0.3	16.09± 0.7	1.9± 0.1	5.3± 0.3	19.7± 0.9	1.3± 0.1	5.6± 0.2	13.1 ± 0.6

h= height of heap (cm); r= radius of heap (cm); gm= weight of Sample 1 and 2.

The flow properties of powders are critical in many industrial processes, especially in pharmaceutical and chemical manufacturing. For calcium carbonate, a porous powder, the AOR showed significant changes upon the addition of starch. At 0% starch (control), the AOR was 30.54°±0.6. At 1% starch, the angle increased to 38.4°±0.8, indicating a moderate reduction in flowability, likely due to the initial increase in interparticle cohesion. At 3% and 5% starch concentrations, the AOR rose dramatically to 40.9°±1.0 and 42.0°±0.9, respectively, suggesting that higher concentrations of starch cause excessive cohesion between particles, leading to agglomeration and reduced flowability. This observation is consistent with findings from Zafar *et al*. [9], who noted that higher concentrations of glidants can cause particle agglomeration, impairing flow. The porous structure and large surface area of calcium carbonate likely allowed the starch to adsorb effectively at lower concentrations, improving flow. However, excess starch appears to cause particle bridging, worsening the flow properties. A trend also highlighted by Schwedes [8] emphasized that porous powders respond well to glidants within an optimal concentration range.

In contrast, for potassium dichromate, a non-porous crystalline powder, the AOR showed more modest changes in flowability with starch addition. At 0% starch (control), the AOR was 12.6°±0.5, indicating excellent flow. With the introduction of starch, the AOR increased slightly to 16.09°±0.7 at 1%, and further to 19.7°±0.9 at 3%. However, at 5% starch, the angle decreased slightly to 13.1°±0.6. Potassium dichromate, being a non-porous crystalline powder, has low inter-particle friction, allowing better flow than porous powders. The limited effect of starch on its flowability is consistent with findings by Verbeek (2025), who observed that crystalline powders exhibit better flow properties and are less responsive to glidants [11]. Additionally, Shah *et al.*[13] noted that glidants have a more pronounced effect on powders with irregular shapes and larger surface areas, explaining why starch has minimal impact on potassium dichromate.

The AOR was used to assess the flowability of calcium carbonate (Sample 1) and potassium dichromate (Sample 2) at varying glidant concentrations (Figure 3). For calcium carbonate, flowability worsened with increasing glidant concentration, as indicated by a sharp rise in the AOR. In contrast, potassium dichromate showed consistently low angles, with slight improvement at higher glidant levels. These results emphasize the role of powder properties and glidant compatibility in flow optimization. Moreover, the performance of different glidants was highlighted, showing that starch-based glidants performed comparably or even better than synthetic glidants, such as colloidal silicon dioxide, in certain formulations, especially in terms of flow-reproducibility enhancement [32-35]. The positive effect of starch as a glidant observed in this study aligns well with these earlier findings. Therefore, the addition of starch not only enhances the manufacturability of powder formulations but also supports the development of more consistent and uniform dosage forms.

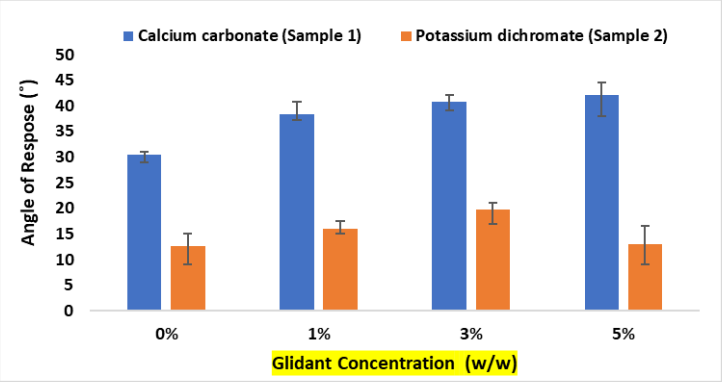

Figure 3. Bar graph illustration of angle of repose (AOR) for both powder samples at starch concentrations of 0%, 1%, 3%, and 5% w/w (n = 3).

3.4. Mechanistic insight into starch on powder flowability.

The addition of starch significantly affected the flow behavior of calcium carbonate, with the AOR increasing notably at 3% and 5% concentrations, indicating poor flowability due to agglomeration. This is attributed to mechanisms such as liquid bridge formation and capillary condensation within the porous structure (with its high specific surface area, which allows starch to adhere strongly to its surface), where starch's hygroscopic nature enhances moisture-induced cohesion [27,36,37]. Therefore, starch might initially improve flow through surface lubrication, but once the particle surface becomes saturated, excess starch could promote cohesive clustering, thereby reversing the glidant effect. Additionally, the mechanistic interpretation revealed that strong surface energy interactions between starch and calcium carbonate via hydrogen bonding could lead to overcoating, particle bridging (localized cohesion and capillary bridge formation between particles), and clumping (reduced surface smoothness), thereby reducing flowability [28]. Hence, in this case, excess starch indicated as a binder-like film former under certain humidity conditions (40±5%), thereby increasing cohesion rather than reducing it. This was because of the inclusion of particle coating, which might enhance interparticle adhesion, and moisture adsorption, leading to localized cohesion. In contrast, potassium dichromate, a non-porous crystalline powder, showed minor AOR changes, reflecting better flow stability and reduced glidant responsiveness due to its smooth surface and low surface energy [38]. These results emphasize the need to align glidant concentration with powder properties. At low levels, starch performed comparably to synthetic glidants, suggesting its potential as a cost-effective and biodegradable alternative when used within optimal limits [29].

The observed improvement in powder flow upon starch addition was consistent with commonly reported glidant mechanisms, including reduced surface friction and weakened cohesive forces. However, due to the absence of surface characterization methods such as scanning electron microscopy (SEM), atomic force microscopy (AFM), or contact-angle measurements, the proposed mechanism should be considered a plausible explanation rather than conclusive evidence. This limitation has been clarified, and future work incorporating these techniques is recommended to confirm the proposed interactions.

3.5. One-sample Kolmogorov–Smirnov (K-S) test.

A one-sample Kolmogorov–Smirnov test was conducted to evaluate the distributional characteristics of the four variables corresponding to 0%, 1%, 3%, and 5% starch concentrations (VAR00002–VAR00005), among the three theoretical models tested, i.e., Normal, Uniform, and Exponential. The Normal distribution consistently produced the highest p-values (0.941–1.000), indicating no significant deviation from normality and suggesting it as the best-fitting distribution for all variables. The uniform distribution showed comparatively lower p-values (0.583–0.893), reflecting poor fit, while the Exponential model demonstrated acceptable fit for some variables but lacked theoretical justification due to the absence of strong right skew in the data. Although the sample size was extremely small ($n = 3$), descriptive statistics revealed high variability across all variables, with standard deviations approaching or exceeding the means, yet the overall pattern remained roughly symmetric. Taken together, the results support the Normal distribution as the most appropriate model for describing the data. This distributional suitability strengthens the reliability of using normal-based descriptive summaries (mean and standard deviation) for interpreting the dataset, while Exponential distributions generally require strictly right-skewed behavior, which was not strongly evident, and Uniform models appear less appropriate for subsequent analyses due to their distribution being unsuitable because data points are clustered, not evenly spread, as illustrated in Figure 5.

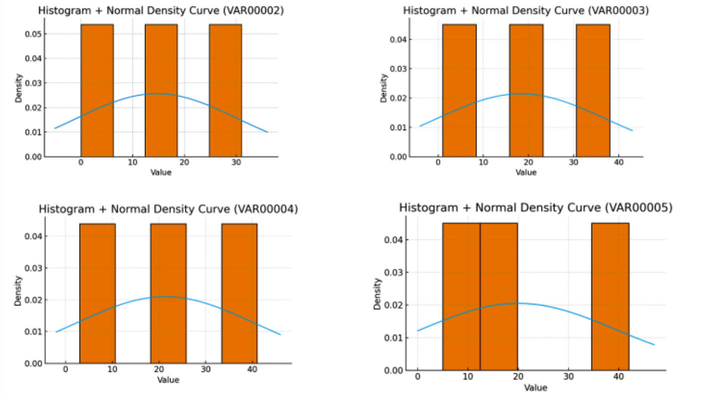

Figure 5. Combined histograms with overlaid normal density curves for variables VAR00002, VAR00003, VAR00004, and VAR00005. Each panel displays the empirical distribution of the observed values along with the fitted normal density function. The four variables show broadly symmetric patterns, with the normal curve providing a reasonable visual approximation despite the small sample size (n = 3 per variable). These plots facilitate comparison of distributional shapes across VAR00002–VAR00005 variables corresponding to 0%, 1%, 3%, and 5% starch concentrations (w/w).

Table 5 summarizes the goodness-of-fit statistics for Normal, Uniform, and Exponential distributions. All four variables (corresponding to 0%, 1%, 3%, and 5% starch concentrations) showed very high p-values (Asymp. Sig. > 0.94) under the normal distribution model, indicating no evidence against normality. Uniform and exponential fits exhibited comparatively lower p-values, suggesting that the normal distribution provides the best overall fit for VAR00002–VAR00005.

Table 5. Normality assessment of starch concentration data (VAR00002–VAR00005) using the One-Sample Kolmogorov–Smirnov test (SPSS Version 20).

Starch concentrations (% w/w)	Variable	Distribution type	Mean	Std. Deviation	p-value (Asymp. Sig.)
0	VAR00002	Normal	14.38	15.348	0.999
		Uniform	–	–	0.893
		Exponential	21.57	–	0.220
1	VAR00003	Normal	18.50	18.816	0.999
		Uniform	–	–	0.893
		Exponential	18.50	–	0.972
3	VAR00004	Normal	21.20	18.994	1.000
		Uniform	–	–	0.893
		Exponential	21.20	–	0.980
5	VAR00005	Normal	20.06	19.501	0.941
		Uniform	–	–	0.583
		Exponential	20.06	–	0.999

Overall, this study suggests that starch is a more effective glidant for porous powders, such as calcium carbonate, than for non-porous crystalline powders, such as potassium dichromate. The higher surface area and porosity of powders like calcium carbonate allow for better interaction with the glidant, enhancing flow at optimal concentrations. In contrast, non-porous powders such as potassium dichromate naturally exhibit better flow properties, showing little improvement from glidant addition. These results underline the importance of considering the mechanistic perspective of powders when selecting appropriate glidants, as porous powders benefit more from glidant addition, while crystalline powders require less modification. These findings highlight the material-dependent behavior of starch as a glidant. However, it should be noted that AOR measurements were inherently subject to variability arising from powder packing and minor fluctuations in funnel discharge. This methodological limitation may affect reproducibility despite performing all measurements in triplicate under controlled conditions.

Future research could explore alternative glidants, such as magnesium stearate, talc, or silica, especially for non-porous powders. Investigating the mechanistic interactions of starch at the particle level, including adsorption and agglomerate formation, could optimize glidant use by incorporating advanced surface characterization techniques. Additionally, studying environmental factors like humidity and temperature will provide insights into starch's stability and effectiveness. Future studies could also examine the impact of starch on compressibility, tabletability, and other mechanical properties, particularly in pharmaceutical formulations. Expanding research to include various powder morphologies and glidant combinations would enable broader applications across industries such as pharmaceuticals, cosmetics, and food processing. In conclusion, further research on glidants will enhance powder flow behavior and improve manufacturing processes across various industries.

4. Conclusions

This study has demonstrated that starch as a glidant significantly affects the flow properties of calcium carbonate (a porous powder) but has a limited impact on potassium dichromate (a non-porous crystalline powder). Flowability assessment using the AOR further revealed material-specific responses to starch addition. For calcium carbonate, the AOR increased markedly from 30.54°±0.6 at 0% starch to 42.0°±0.9 at 5%, indicating progressive particle agglomeration and reduced flow. Conversely, potassium dichromate displayed minimal variation (12.6°±0.5 to 19.7°±0.9), suggesting that its inherently good flow properties remain largely unaffected by starch levels.

The goodness-of-fit analysis demonstrated that all four variables associated with increasing starch concentrations (0%, 1%, 3%, and 5%) were best characterized by a normal distribution, as reflected by consistently high p-values (Asymp. Sig. > 0.94). In comparison, uniform and exponential models showed weaker fits, confirming that the experimental data exhibited a stable, symmetric distribution pattern suitable for parametric statistical evaluation.

Hence, these findings demonstrate that starch’s effect as a glidant is material dependent, cohesive powders like calcium carbonate, but offers little benefit for already free-flowing materials like potassium dichromate. Practical implications for pharmaceutical formulation include using lower starch concentrations (≈1–2% w/w) for cohesive powders to improve handling without impairing flow, while starch may be omitted or used minimally for non-porous powders. These findings guide the appropriate glidant levels during formulation and pre-compression optimization.

Limitations include small sample size, limited powder types, and absence of surface characterization techniques (SEM, AFM, contact angle). Future research should expand powder varieties and explore broader glidant ranges.

Author Contributions

Conceptualization, U.H.; methodology, U.H.; software, U.H.; formal analysis, S.G.; investigation, Y.C.; resources, K.G.; data curation, K.N. and T.C.; supervision, P.K. and U.H.; writing—original draft preparation, U.H.; writing—review and editing, U.H., S.G., Y.C., K.G.,

K.N., T.C., and P.K. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

Data supporting the findings of this study are available upon reasonable request from the corresponding author.

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Conflicts of Interest

All authors must declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

Abbreviations	**Definition**
AFM	Atomic Force Microscopy
API	Active Pharmaceutical Ingredients
AOR	Angle of Repose
PCC	Precipitated Calcium Carbonate
SEM	Scanning Electron Microscopy
SPSS	Statistical Package for the Social Sciences

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Supplementary Material

Table S1. Details of Materials and Chemicals Used in this Study,

Material / Chemical	**Brand**	**Manufacturer**	**Location (City, State, Country)**	**Description**
Calcium carbonate ($CaCO_3$)	QUALIKEMS	Qualikems Lifesciences Pvt. Ltd.	Vadodara, Gujarat, India	Analytical Grade
Potassium dichromate ($K_2Cr_2O_7$)	NICE	Nice Chemicals Pvt. Ltd.	Kochi, Kerala, India	Analytical Reagent (AR) Grade; crystalline, non-porous
Soluble starch (Potato-based)	LOBA CHEME	Loba Chemie Pvt. Ltd.	Mumbai, Maharashtra, India	Laboratory Grade; used as glidant (1%, 3%, 5% w/w)