Study of conical screen milling for size reduction of roots for extraction processes

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INTRODUCTION

Plant extracts have gained increasingly greater attention and are more extensively used in the food, nutraceutical and pharmaceutical industries. Particle size reduction plays an important role in the extraction of bioactive principles from medicinal plants as appropriate particle size and particle size distribution (PSD) of the raw material are crucial for effective extraction[1,2]. Conventionally, size reduction of plant is achieved by employing cut and impact milling. The conical screen mill is used for wet and dry granulation. Its suitability for milling roots has not been reported. In this study, it is hypothesized that conical screen mill is suitable for milling roots. Other than milling mechanism, processing variables such as rotor speed, screen type and aperture size, and type of impeller, can affect the milling efficiency and subsequently the PSD and bulk properties of the milled materials[3,4]. Using multivariate statistical technique, the variables can be optimized to enable efficient milling and obtain milled product with desired properties.

OBJECTIVES

1. To evaluate and compare the effects of different milling methods on the particle and bulk properties of roots for extraction processes.
2. To study the effects of rotor speed, screen aperture size and gap setting in conical screen milling using full factorial design and response surface methodology (RSM).
3. To identify the optimum milling conditions to obtain milled product with desired particle and bulk properties for subsequent extraction processes.

METHODOLOGY

(A) Milling of licorice root and characterization studies of milled material

- Sliced licorice root (*Glycyrrhiza uralensis* Fisch, cultivated in Inner Mongolia, WHL Ginseng & Herbs Pte Ltd, Singapore) was chosen as the model plant material.

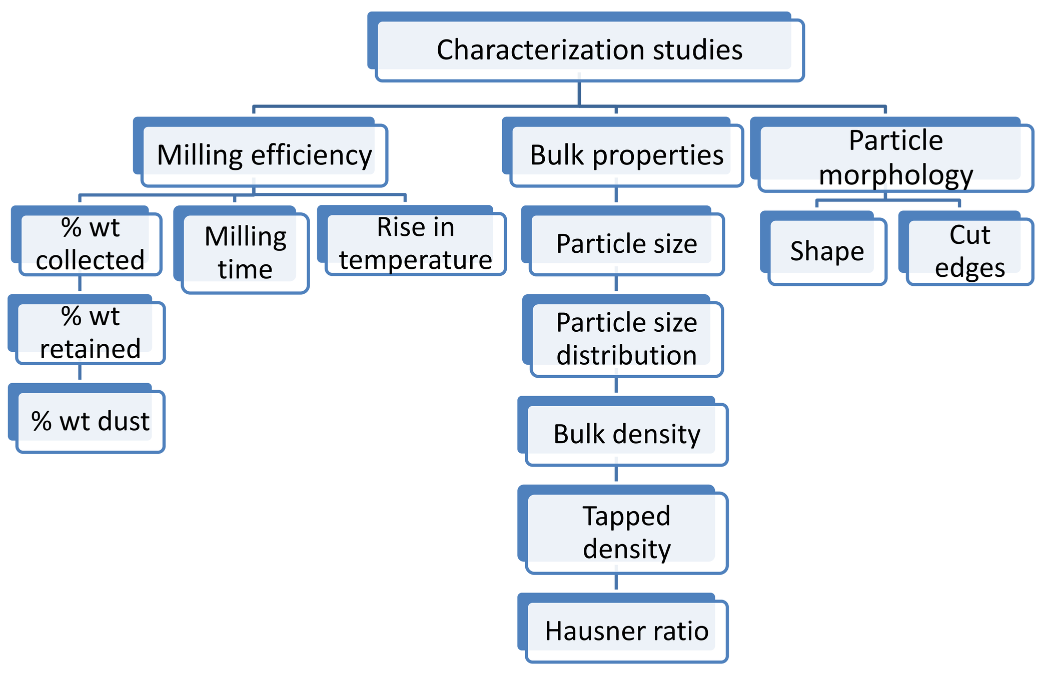
Fig. 1. Slices of Licorice root.

- 400 g batches of oven-dried licorice roots were milled by conical screen mill (Quadro Comil Model 197S, Canada), while cut and impact milling were performed using a Fitzmill (Fitzpatrick Comminutor M5A, USA).
- Milling conditions studied are summarized in Table 1.

Table 1. Milling methods studied.

Code	Mill type	Impeller type	Screen type
RR'	Conical screen	Rectangular-bar impeller	Round bore
RG	Conical screen	Rectangular-bar impeller	Grater bore
TR'	Conical screen	Round-bar impeller with teeth	Round bore
TG	Conical screen	Round-bar impeller with teeth	Grater bore
CR'	Cut	Sharp-edge impeller	Round bore
IR'	Impact	Blunt-edge impeller	Round bore

- Milling was performed in triplicates for each set of conditions studied.
- Milling efficiency and characterization studies of the milled material were carried out as follows:



(B) Optimization of milling variables

- 3^3 full factorial design and response surface methodology (RSM) were employed.
- Process variables studied are listed in Table 2.

Table 2. Process variables and levels for full factorial design.

Rotor speed (rpm)	Screen aperture size (µm)	Gap setting (inches)
2000	3175	0.250
3000	4750	0.275
4000	6350	0.300

- This study was carried out for conical screen milling using round-bar impeller with teeth and grater-bore screen.
- Feed weight was fixed at 400 g.
- Response variables determined were as above (except for milling time and rise in temperature).

RESULTS & DISCUSSION

Conical screen mill

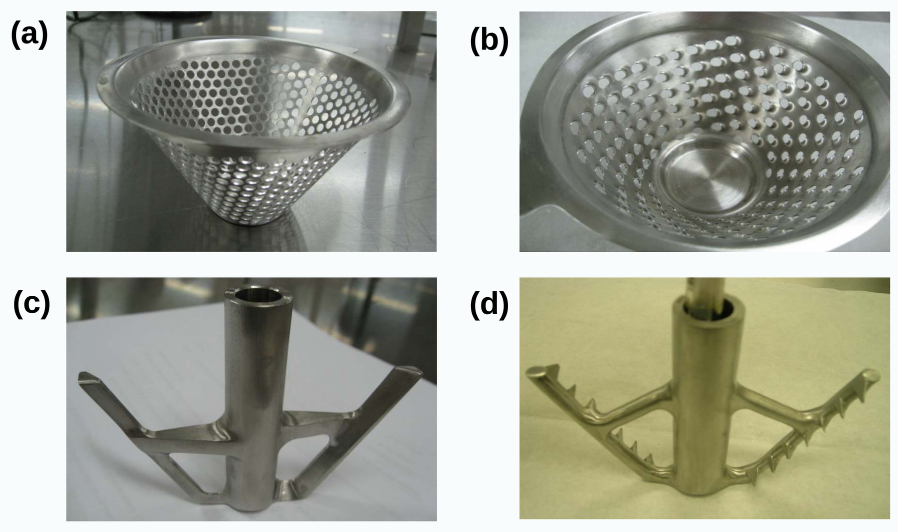


*Fig. 2. **(a)** Round-bore screen, **(b)** grater-bore screen, **(c)** rectangular-bar impeller and **(d)** round-bar impeller with teeth.*

Fitzmill mill

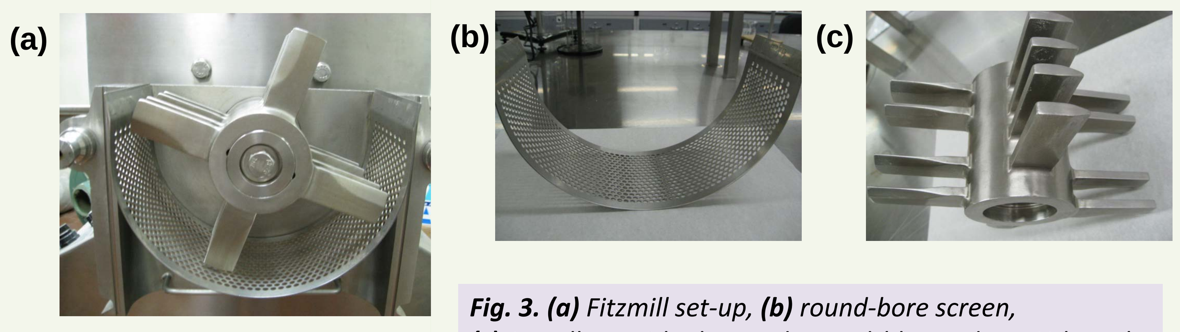


*Fig. 3. **(a)** Fitzmill set-up, **(b)** round-bore screen, **(c)** Impeller with sharp edge and blunt edge. When the impeller is rotated in a sharp-edge forward configuration, impact milling is performed. When the impeller is rotated in a sharp-edge forward configuration, cut milling is performed.*

(A) Milling of licorice root and characterization studies of milled material

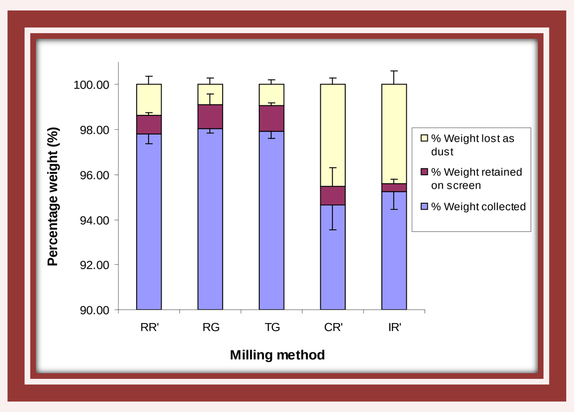


Fig. 4. Percentage weight of material collected, retained on screen and dust for each milling method. Error bars indicate standard deviation (n = 3).

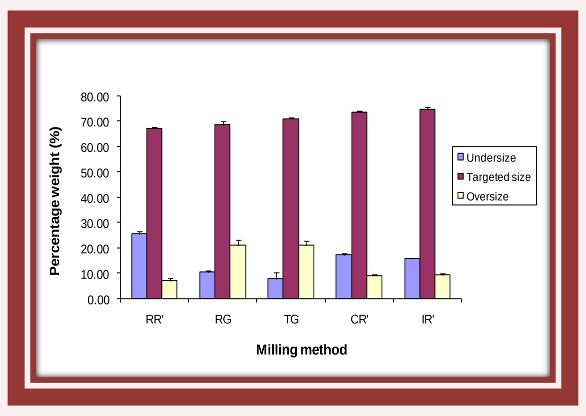


Fig. 5. Percentage weight of undersize, targeted size and oversize particle for milled licorice roots obtained by different milling methods. Error bars indicate standard deviation (n = 3).

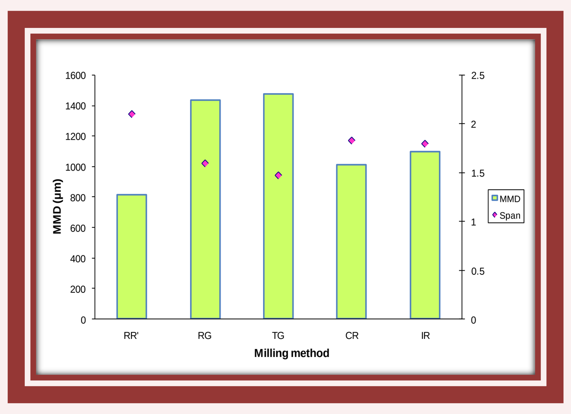


Fig. 6. MMD and span for milled licorice roots obtained by different milling method.

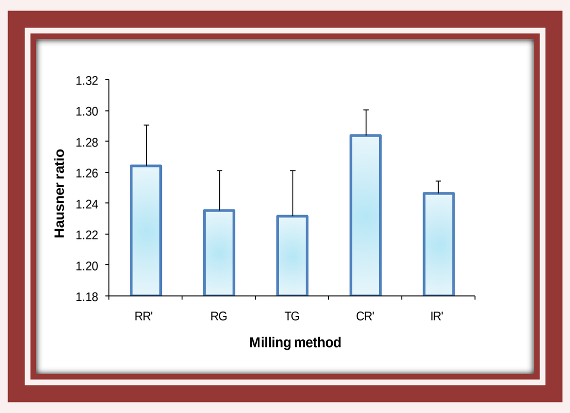


Fig. 7. Hausner ratio for milled licorice roots obtained by different milling methods. Error bars indicate standard deviation (n = 3).

- Conical screen mill employing round-bar impeller with teeth and round-bore screen combination was not suitable for milling fibrous root material, hence, it was not considered for further investigation.
- **Conical screen mill** gave higher yield of milled product with less dust formation.
- **Grater-bore screen** was more suitable in milling roots, as evident from the reduced milling time and rise in temperature, less fines formation and tighter size distribution as indicated by the lower span value.
- **Round-bar impeller with teeth** provides greater shearing force than rectangular-bar impeller resulting in slightly shorter milling time.
- All milling conditions produced particles of comparable flowability as indicated by similar Hausner ratio.
- **Round-bar impeller with teeth** coupled with **grater bore screen** was considered to be the most appropriate combination for milling of model root material and was chosen for the full factorial study.

Table 3. Milling time and rise in temperature of milled licorice roots obtained by different milling method

	Conical screen milling			Cut milling	Impact milling
	RR'	RG	TG	CR'	IR'
Approximate milling time (min)	4.30	2.00	1.10	2.50	2.00
Approximate rise in temperature of milled material	5.5	2.0	2.0	2.0	3.0

- Conical screen milling with **grater-bore screen** (RG or TG) and **cut milling:** needle-like in shape and fibrous at the edges.
- Conical screen milling with **round-bore screen** (RR') and **impact milling**: mainly cuboidal and less fibrous.

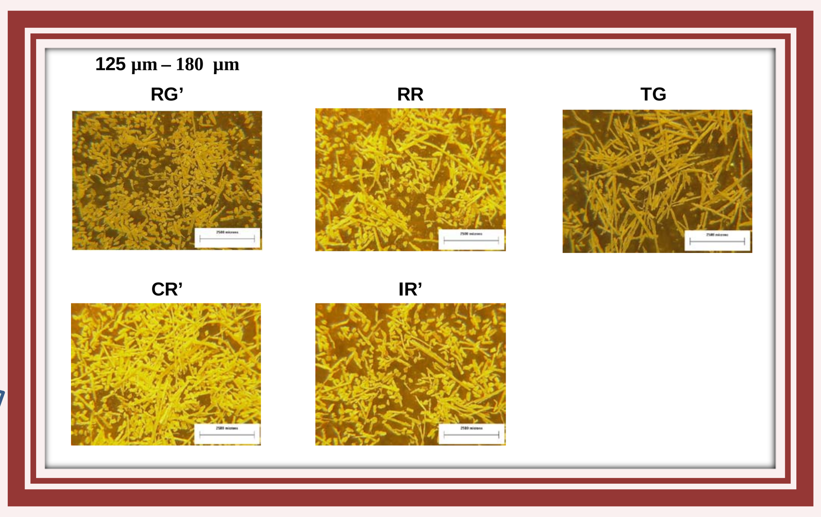


Fig. 8. Microscopic images illustrating particle shape of milled particles obtained by different milling methods.

(B) Optimization of milling variables

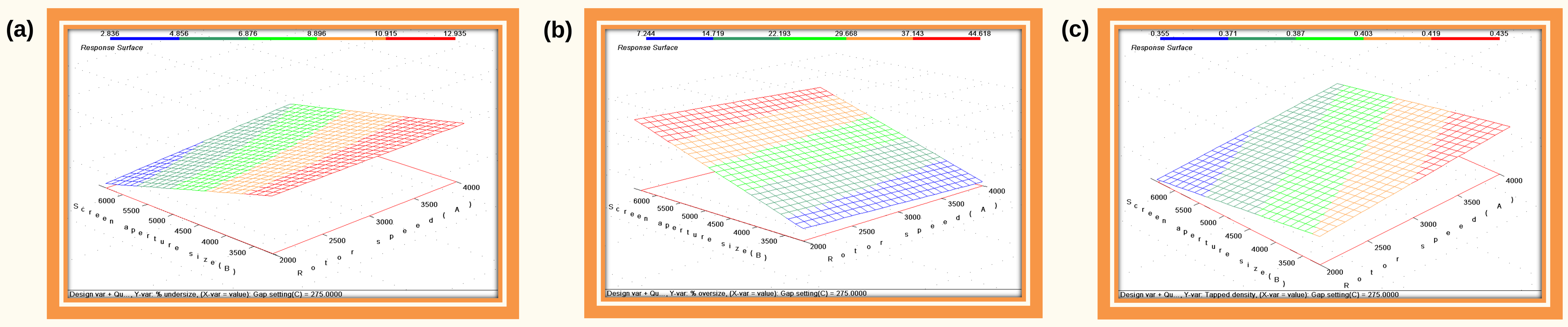


*Fig. 9. RSM plots for **(a)** percentage weight of undersize material, **(b)** percentage weight of oversize material and **(c)** tapped density. For each plot, the third variable was held at level 0.*

- Screen aperture size was most significant in affecting the percentage weight of undersize, percentage weight of oversize, percentage weight of targeted-size material and tapped density.
- Effect of interaction between impeller speed and screen aperture size was significant on percent weight of undersized and percent weight of targeted-sized material.

CONCLUSION

- Conical screen milling was more efficient than cut milling and impact milling in reducing the size of fibrous root material.
- Shear force was the dominant force in reducing size of fibrous root and a grater screen was essential to impart a slicing action on the roots.
- The round-bar impeller with teeth coupled with grater- bore screen formed the most efficient combination, producing the least fines and a high percentage weight of targeted-size material in the shortest milling time. The milled material also had the smallest size distribution.
- The properties of the milled materials were affected by the rotor speed, screen aperture size and gap setting to different extent.
- The screen aperture size was the most significant factor in affecting the bulk properties of milled material.

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