EFFECT OF CONTROLLED CONDITIONS DURING DEEP BED FERMENTATION AND DRYING ON ROOIBOS TEA (*ASPALATHUS LINEARIS*) QUALITY

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ABSTRACT

Small-scale processing of rooibos tea was achieved under controlled conditions of bruising, fermentation and drying. The effects of aeration, fermentation time, fermentation temperature and drying method on rooibos quality were investigated, using plant material that was stored at -30C after harvesting and comminution. Adequate aeration significantly improved rooibos quality. Overall quality improved significantly with increasing fermentation time, mainly due to an improvement in taste. Fermentation temperature did not affect quality significantly. Freezing of the plant material before processing was detrimental to quality, resulting in some instances in a Standard grade infusion with a grassy aroma and an astringent taste that is indicative of under-fermented rooibos. Choice grade rooibos with a flat, "thin" taste and a poorly developed sweet aroma was obtained in a few cases. The drying method (deep bed versus thin layer) did not affect overall quality significantly.

INTRODUCTION

Rooibos tea produced from the needle-like leaves and small stems of *Aspalathus linearis*, is marketed in South Africa, Europe and the Far East, with Japan the biggest export market. It accounts for approximately 12% of all tea consumed locally. During 1992 the demand for high quality rooibos tea exceeded production. The traditional processing method, which has been important in establishing a viable rooibos tea industry does not meet the demands of current consumers i.e. a standardized product of consistently high quality and greater product differentiation. Furthermore, shortages cannot be supplemented by importation of stocks, since rooibos tea is only produced in

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South Africa. It is therefore essential that rooibos tea is processed under optimum conditions to increase production of the best quality product, as demanded by the market.

The traditional processing method of rooibos tea entails cutting the fresh plant material into small pieces, addition of water, bruising with a tractor, floor fermentation in heaps and drying on a cement yard by spreading it open in thin layers in the sun (Cheney and Scholtz 1963). No control over fermentation and drying conditions is possible, resulting in a product of inconsistent quality. In cases of poor weather conditions quality is impaired, especially if drying is slow and over-fermentation takes place. Under-fermentation could be a problem during low night temperatures. The objectives of this study were therefore to quantify the effects of aeration on quality of rooibos during fermentation, fermentation time and fermentation temperature under deep bed conditions. The effect of deep bed drying on rooibos quality as opposed to thin layer drying was also investigated.

MATERIALS AND METHODS

Plant Material

During the 1992 season, towards the end of January, bulk harvesting of rooibos tea took place in the Clanwilliam district in the Western Cape region of South Africa. Approximately 120 kg tea (0.46 moisture ratio, wet basis) was harvested from a six-year-old plantation by cutting the branches *ca.* 30 cm from the ground, whereafter it was transported without delay to the research facilities for processing.

Small-scale Processing

Upon arrival of the plant material at the research facilities the rooibos branches were cut into *ca.* 3 mm lengths. Batches (5 kg) were frozen in air-tight plastic containers without delay and stored at -30C until used for experimentation.

Bruising. An apparatus was constructed for controlled bruising of rooibos tea. It consisted of fixed twin rollers and a stainless steel sliding table which slid under the rollers upon rotation of the rollers. The rollers, covered with a 3 mm layer of neoprene, rotated in the same direction. Their rotation speed was controlled with a variable speed drive to give a table sliding speed of 0.012 to 0.014 m/s. The cut leaves and stems were spread in a 25 mm layer on the table and bruised once by exerting pressure via the rollers onto this layer. In this process the rooibos layer was compressed to *ca.* 11 mm.

Fermentation. A fermentation and drying test unit (FDU) was used for deep bed fermentation of approximately 5 kg wet rooibos tea, except when otherwise stated. The inlet air, forced through the layer of rooibos from underneath, was humidified to saturation to prevent it from drying out during fermentation. The rooibos temperature was controlled by controlling the dry bulb (d.b.) temperature of the inlet air and aeration took place at *ca.* 0.06 m^3/s.

Drying. Thin layer drying was used to simulate the floor drying practice of commercial scale processing of rooibos tea. A tray-drier was operated at 40C (d.b.) and a fixed air velocity of 4 m/s. Rooibos tea, sampled at intervals during fermentation, was spread open (3-4 mm depth; *ca.* 250 g/tray) on trays (300 mm × 350 mm) constructed of a stainless steel frame and a 30 mesh screen and dried for 4 h to ca. 0.10 moisture ratio (wet basis). For deep bed drying the FDU was loaded with *ca.* 4 kg wet fermented rooibos tea to give a 60 to 70 mm layer. Drying took place at 40C with an air velocity of 1 m/s for 3 h to *ca.* 0.08 to 0.10 moisture ratio (wet basis).

Effect of Aeration During Fermentation on Rooibos Quality (Experiment I)

A batch of comminuted rooibos tea was removed from freeze-storage and defrosted in the air-tight container for 12 h at room temperature before bruising, using the small-scale bruising apparatus. Water was added to the bruised leaves and stems to increase the moisture ratio to 0.65 (wet basis). Six kg of rooibos tea was fermented in the FDU at 36 ± 0.5C while continuous aeration took place as described above. The method of Julkunnen-Tiitto *et al.* (1988) was used to simulate fermentation under almost anaerobic conditions. Five 1000 mL sealed glass containers were each filled to capacity with *ca.* 500 g rooibos tea and placed in a laboratory oven at 36 ± 0.15C. No aeration took place during fermentation. A 250 g sample of fermenting rooibos tea from the FDU and a sample consisting of the content from one container were collected after 8, 10, 12, 14 and 16 h, respectively, and dried in the tray-drier. The experiment was replicated three times. The samples were stored for 6 months at room temperature before sensory evaluation.

Effect of Fermentation Time and Temperature on Rooibos Quality (Experiment II)

The plant material was prepared for fermentation as described above. Fermentation took place in the FDU at 34, 36, 38 and 40C. Five kg rooibos tea was used for each temperature treatment. Samples (250 g) were collected after 8, 10, 12 and 14 h, respectively, to determine the fermentation period responsible for optimum quality. The samples were dried in the tray-drier and stored at room temperature for 2 months until sensory evaluation. The

experiment was replicated in six blocks with the temperature treatment randomized within a block.

Effect of Drying Method on Rooibos Quality (Experiment III)

After sampling and completion of fermentation (Experiment II) the remainder of the rooibos tea (*ca.* 4 kg) was dried in the FDU to simulate deep bed drying conditions as described above. The quality of the rooibos tea was compared to the quality of the corresponding sample dried under thin layer conditions by sensory evaluation.

Sieving

The prepared rooibos samples were sieved (10 mesh; U.S. Standard; Endecotts) to obtain the finer fraction for objective color measurement and sensory evaluation.

Objective Color Measurement

The change in extract color with fermentation time and temperature was determined on two of the six batches of tea prepared for each temperature treatment as described under Experiment II. Samples were collected at the beginning of fermentation and then after 6, 8, 10, 12 and 14 h. Transmission measurements were made with a Colorgard 2000/05 system with the TM-M attachment, using a 5 mm cell (Joubert 1995). Color was expressed in terms of CIELAB values (L*, a* and b*) and the hue ($H°_{ab}$) was calculated using the equation: $H°_{ab} = \tan^{-1} (b^*/a^*)$ (Hunt 1977). The means for temperature were used to plot the change in color values with fermentation time. The extracts were prepared in duplicate as described in the following section, except that the extracts were cooled to room temperature and filtered (Whatman No. 4 filter paper) before color measurements. The soluble solid content of the extracts was determined gravimetrically. An aliquot of the extract was evaporated on a steam bath and dried under vacuum at 70C for 16 h.

Sensory Evaluation

Expert panelists of the Rooibos Tea Board evaluated all samples according to the following standardized procedure used for grading commercially-produced rooibos tea: Extracts were prepared by pouring 600 mL hot (>95C) distilled water on 12 g tea (sieved fraction) in warmed 1000 mL glass beakers and steeping it for 2 min. The aroma was evaluated *ca.* 1 min after the water was poured on the leaves and stems. The taste and color were evaluated after the extract was poured through a tea strainer into a warmed beaker. The beaker was placed on a Perspex table, lighted from underneath with "day light" tube

lighting (2 × 40 W; 6100 K). The visual appearance of the rooibos leaves and stems was evaluated under similar tube lighting. Three-digit randomized numbers were used to identify samples, which were presented in random order. The overall grade awarded to the rooibos tea, i.e. Super, Choice or Standard, each with three subdivisions (+: slightly better than norm; 0: norm; -: slightly poorer than norm) and unacceptable was based on its aroma, taste and extract color. Super and Standard grade indicated the best and poorest rooibos tea quality, respectively.

Statistical Analysis

The ordinal data were analyzed using a General Linear Model (GLM) procedure (SAS 6.08 statistical software). Analysis of variance (Friedman) was then performed on the ranked data of Experiment I, while the data of Experiment II were subjected to logistic analysis using PC Plum (Randall 1989). In the latter case the mean sensory ratings for the different sensory parameters are presented in the figures as location values on the underlying logit scale. Student's t-LSD (least significance difference, P=0.05) was used to test for significant differences between treatment means. Two-way analysis of variance (Friedman) was performed on the ranked sensory ratings of tea dried under different conditions (Experiment III). Tukey's LSD (P=0.05) was used to compare the rank means.

RESULTS AND DISCUSSION

General Observations

Rooibos tea was harvested from a six-year-old plantation with a history of producing a Super grade quality product with traditional processing. This quality was therefore considered attainable with controlled processing of rooibos tea. Accessibility to plant material was a problem encountered in the execution of this study. The rooibos plantations are situated more than 240 km from the research facilities and plant material could therefore not be harvested daily. This was solved by bulk harvesting of rooibos tea and freezing of samples until used. Freezing was chosen to arrest and preserve enzymatic activity of polyphenol oxidase (Millin and Swaine 1981) in the cut rooibos leaves during storage. As soon as cutting of the plant material into small pieces took place, discoloration of the leaves occurred, but the stems remained a white-yellow color. Whole leaves that survived cutting discolored slightly in the period until frozen, but discolored rapidly upon thawing, indicating oxidation of polyphenolic substances. Sanderson (1968) found that low temperatures (-15C and -40C) were very effective to increase cell membrane permeability in tea flushes (*Camellia sinensis*) initiating polyphenol oxidation upon thawing.

Effect of Aeration During Fermentation on Tea Quality (Experiment I)

The overall grading of rooibos tea fermented in the FDU was significantly higher (P = 0.0043) than that of rooibos fermented in the glass containers as indicated in Table 1 by the rank means. This was attributed mainly to the better taste (P = 0.0005) obtained with rooibos that was adequately aerated during fermentation, since the aroma was not significantly (P = 0.0967) affected by aeration (Table 1). A sweet taste was absent from all samples of the poorly aerated rooibos tea. The taste remained astringent and "thin", while the aroma was excessively grassy, without the characteristic sweet, honey-like aroma of rooibos tea. The sweet taste and aroma were also, to a large extent, poorly developed in the aerated rooibos and the flavor was mainly watery and flat, but the grassy flavor was absent. Consequently the highest quality rating received by the poorly aerated rooibos was Standard (+) grade compared with Choice (+) grade of rooibos aerated during fermentation. Choice grade is awarded to rooibos with a slightly sweet to flat characteristic rooibos flavor. The astringent, "thin" taste and grassy aroma are associated with under-fermented rooibos tea. The extract color was not significantly affected by aeration (P = 0.8795). In both cases tea fermented for 8 and 16 h received the lowest quality rating, indicating optimum quality development during the 10 to 14 h fermentation period.

TABLE 1.
EFFECT OF AERATION DURING FERMENTATION ON THE QUALITY OF ROOIBOS TEA AS INDICATED BY RANK MEANS

Treatment[1]	Aroma	Taste	Extract colour	Overall quality
Aerated	6.27	7.00	5.57	6.80
Not aerated	4.73	4.00	5.43	4.20
LSD (P=0.05)	1.838	1.504	1.822	1.674
Level of significance (P)	0.0967	0.0005	0.8795	0.0043

[1] Aerated: Fermented in the fermentation and drying unit with an air velocity of 1.0 m/s

Not aereated: Fermented in closed glass containers

The development of poor taste could be, amongst other things, attributed to insufficient oxidation and polymerization of the rooibos polyphenols. Astringency depends on the molecular size of phenolic substances (Bate-Smith 1975). Highly polymerized polyphenols lose their ability to form a protein complex with resulting loss of astringency (Goldstein and Swain 1963). Inadequate degradation of flavor precursors such as carotenoids could also be detrimental to development of the characteristic rooibos tea aroma. Rooibos volatiles such as α-ionone, β-ionone, dihydroactinidiolide and damascenone (Habu *et al.* 1985), are formed with enzymatically induced (Sanderson *et al.* 1971; Reynolds *et al.* 1974) or autoxidative (Gloria *et al.* 1993) degradation of carotenoids. Both ionones have a floral to woody aroma, with α-ionone sweeter and less green than β-ionone (Arctander 1969).

The poorly aerated rooibos tea smelled excessively grassy since the sweet notes necessary to balance the aroma were absent. Freezing of rooibos tea prior to fermentation could be detrimental to flavor, which would therefore affect all samples. Cell damage due to freezing would enhance the enzymatic breakdown of lipids (Selvendran *et al.* 1978) and thus formation of degradation products such as *cis*-3-hexenal and *trans*-2-hexenal (Hatanaka and Harada 1973). A green or grassy aroma are associated with these hexenals (Hatanaka 1993).

Effect of Fermentation Time and Temperature on Rooibos Quality (Experiment II)

Fermentation time did not affect aroma significantly ($P = 0.2114$). However, optimum aroma tended to be reached progressively at an earlier stage during fermentation with increasing fermentation temperature (Fig. 1). Optimum aroma for the fermentation period tested was obtained after 8 h and 14 h fermentation at 40C and 34C, respectively. Most of the samples were rated Choice grade. The aroma changed noticeably from grassy to slightly sweet to flat during fermentation at 34, 36 and 38C, while the aroma of the tea fermented at 40C lost its slightly sweet note already after 8 to 10 h. This could be indicative of over-fermentation. This change in aroma is also evident during commercial processing of rooibos tea, which emphasizes the importance of fermentation period on rooibos tea aroma and quality.

The taste of the tea was significantly ($P = 0.0315$) affected by the fermentation time (Fig. 1). The taste of tea fermented at 40C did not change during fermentation from 8 to 14 h, but it remained flat. This is substantiated by the sensory data shown in Fig. 1. In the case of fermentation at 34, 36 and 38C the extracts lost their astringency and developed a slightly sweet taste with fermentation time to give an optimum taste after 10, 12 and 14 h at 38, 36 and 34C, respectively. Although the taste improved with fermentation time, it never developed the full-bodied rooibos tea taste. The tea remained to a large extent flat and watery.

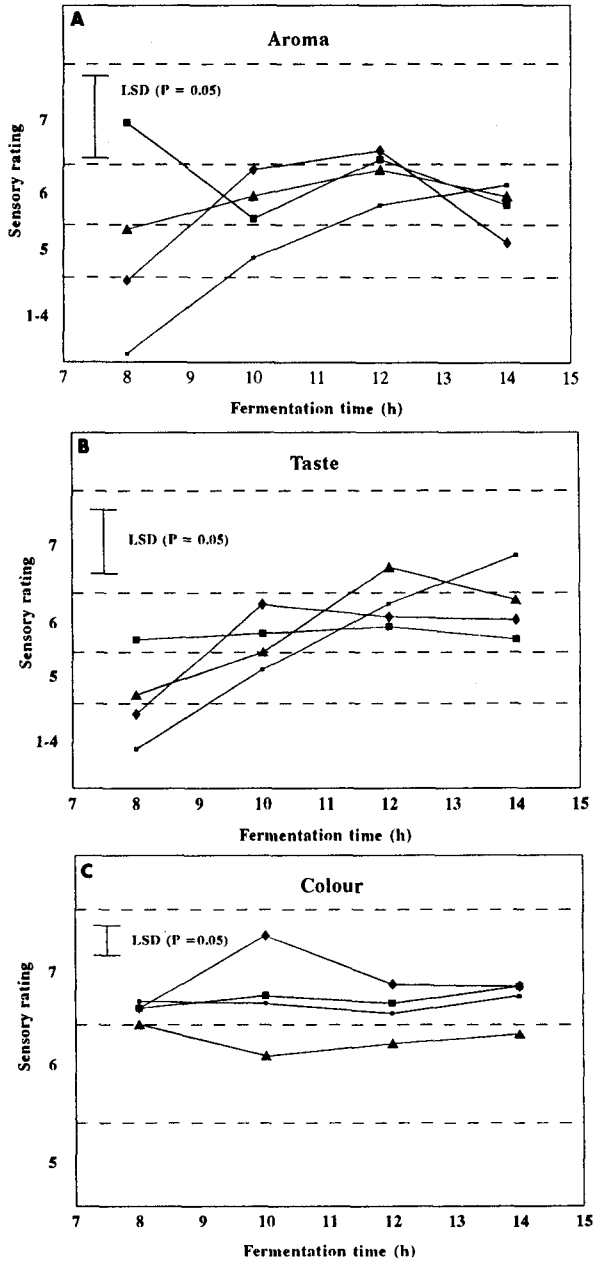

FIG. 1. CHANGE IN (A) AROMA, (B) TASTE AND (C) EXTRACT COLOR DURING FERMENTATION OF ROOIBOS TEA AT DIFFERENT FERMENTATION TEMPERATURES (■ 34C, ▲ 36C, ♦ 38C, ■ 40C) AS INDICATED BY SENSORY RATINGS
(1: Unacceptable, 2-4: Standard Grade; 5-7: Choice Grade)

Extract color was not significantly (P = 0.6827) affected by fermentation time (Fig. 1) according to the grading system used, but in some instances, it was noticed that extract color changed from clear yellow-orange after 8 h fermentation to a slightly turbid red-brown with an orange tint after 14 h fermentation. This indicated that active oxidation of rooibos polyphenols, initiated during bruising, still occurred at latter stages of the fermentation period. Polymeric proanthocyanidins (Marais 1995) present in rooibos tea extracts could be responsible for the turbidity.

The effect of fermentation time on the CIELAB color parameters and hue ($H°_{ab}$) is shown in Fig. 2 which indicates that the extract became darker (decreasing L* value) with more red (increasing a* value) and less yellow (decreasing b* value). This resulted in a decrease in $H°_{ab}$ observed as a shift from yellow-orange towards red-brown. Both L* and a* values agreed with their corresponding values obtained for commercially-produced rooibos tea, but the b* values were noticeably higher than that of commercially produced tea (Joubert 1995). The relatively high b* values obtained under experimental conditions could be the result of incomplete oxidation of polyphenols, which is substantiated by the under-fermented character of the tea. These color parameters, especially the L* value, are also affected by turbidity and the soluble solid content of the extract. The L* values decreased with increasing extract soluble solids (Joubert 1995). However, in this case the soluble solid content of the extracts decreased from 2.38 g/L to 1.98 g/L with increasing fermentation time and the decrease in L* values was therefore attributed to oxidation of polyphenols.

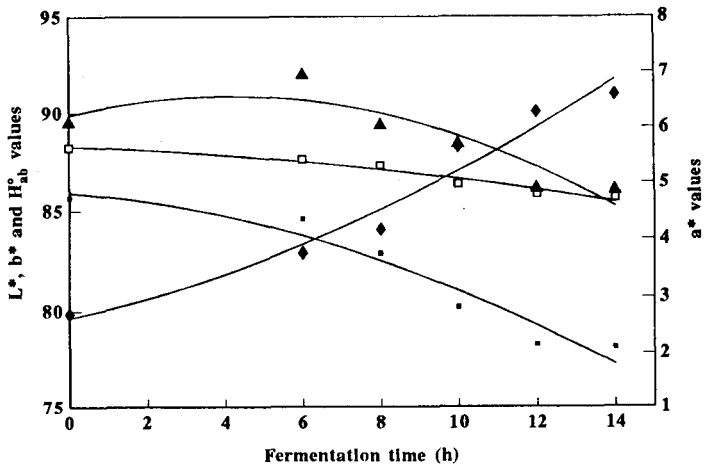

FIG. 2. EFFECT OF FERMENTATION TIME ON THE CIELAB COLOR PARAMETERS L* (■), a* (♦), b* (▲) AND HUE (□) OF ROOIBOS TEA EXTRACTS

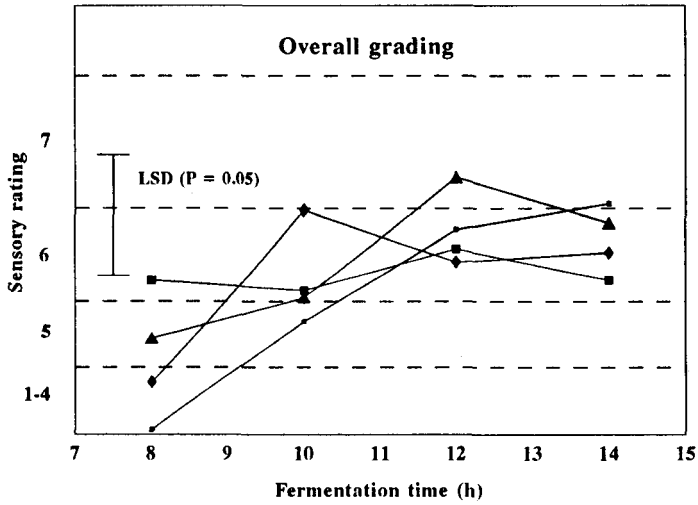

FIG. 3. CHANGE IN THE OVERALL QUALITY DURING FERMENTATION OF ROOIBOS TEA AT DIFFERENT FERMENTATION TEMPERATURES (■ 34C, ▲ 36C, ♦ 38C, ■ 40C) AS INDICATED BY SENSORY RATINGS (1: UNACCEPTABLE, 2-4: STANDARD GRADE, 5-7: CHOICE GRADE)

The significant effect of fermentation time on the overall quality of rooibos tea (P = 0.0414) was attributed to the effect of taste. Therefore, the overall quality improved with fermentation time as indicated in Fig. 3. Similar trends were obtained for overall quality (Fig. 3) than for taste (Fig. 1). After fermentation for 12 h at different temperatures all the tea was either awarded the norm or slightly better than the norm for Choice grade (Fig. 3).

From the results given in Table 2 it is evident that the effect of fermentation temperature on the taste and the overall quality of rooibos tea was inconclusive since no trends could be detected. Fermentation temperature also did not affect aroma significantly (P = 0.3907), but aroma tended to improve with increasing temperature (Table 2).

None of the samples developed the characteristic rooibos tea aroma and taste to such an extent that the tea could be rated as Super grade. Only samples at the optimum fermentation time, depending on the fermentation temperature, were rated Choice grade, in which case the grassy aroma and astringent taste were absent. However, in most samples the strong green, grassy note in the aroma and taste overpowered any sweet aroma and taste present to such an extent that it was detrimental to quality. This was largely attributed to the effect of freezing on rooibos tea as previously discussed, since production of Super

grade tea was possible if freshly comminuted tea was used (unpublished observations).

TABLE 2.
EFFECT OF TEA TEMPERATURE DURING FERMENTATION ON THE QUALITY OF ROOIBOS TEA AS INDICATED BY LOCATION MEANS

Temperature (°C)	Aroma	Taste	Overall quality
34	2.19	2.85	2.12
36	3.21	3.16	2.51
38	2.96	2.96	2.26
40	3.64	3.04	2.31
LSD (P=0.05)	1.632	1.246	1.277
Level of significance (P)	0.3907	0.9328	0.947

Effect of Drying Method on Rooibos Quality (Experiment III)

Deep layer drying as opposed to thin layer drying did not affect the quality of rooibos tea significantly (P = 0.781). The average rankings for deep bed drying and thin layer drying were 1.514 and 1.486, respectively, with a LSD value of 0.1985. Thin layer drying took longer than deep bed drying to reduce the moisture ratio of rooibos to less than 0.10 (wet basis). The shorter drying period with deep bed drying was possible, because a high air volume was forced through the bed as well as better contact was established between rooibos and air than in the case of thin layer drying. Fermentation, especially during the beginning of thin layer drying was therefore possible, but did not occur to such a degree that noticeable quality differences were obtained.

CONCLUSIONS

Processing of rooibos tea could be accomplished under controlled conditions of bruising, fermentation and drying, but freezing of the tea probably impaired tea quality, especially the aroma. Fermentation time affected rooibos tea taste

and the overall quality significantly. Only trends, which were not significant, were demonstrated for the effect of fermentation time and temperature on aroma. The effect of fermentation time and temperature on rooibos quality will be further investigated, using freshly comminuted tea to rule out the detrimental effect of freezing on quality. Deep bed drying as opposed to thin layer drying did not affect the overall quality significantly. This merited further investigation of drying methods for improved drying efficiency.

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