ISSN: 0975-766X
CODEN: IJPTFI
Available Online through **Research Article**
www.ijptonline.com

INNOVATIONS IN POST-HARVEST HANDLING OF CORIANDER

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Received on 25-10-2016 *Accepted on 02-11-2016*

Abstract

Increase in production of essential oils is possible by means of improvement of post-harvest handling of raw coriander, the main essential-oil plant in Russian Federation. The proposed innovations are aimed at achievement of maximum yield in terms of essential and fatty oils at maximum retention of their quality. The subject matter of the research have been seeds of commercial batches of coriander, as well as those cultivated in laboratory plots. Measurements of content of essential oil and chromatographic analysis of its composition have been performed according to regular procedures. Thickness of seeds has been analyzed using a DCM-10 microscope, and optimum modes of step-by-step cleaning and fractionation of raw coriander have been performed using bench-scale separator. It is demonstrated that together with significant loss of essential oil storage of split seeds leads to increase in content of [para]-cymene in its composition. Essential oil made of freshly split seeds has increased content linalool, geraniol, geranyl acetate and minor amount of camphor and hydrocarbons. A series of innovations is proposed including the developed procedure of cleaning and fractionation into whole and split seeds, immediate handling of split seeds, storage of whole seeds according to various modes depending on their moisture weight portion. The developed procedure makes it possible to separate initial raw coriander into two fractions of whole and split seeds, to increase significantly efficiency of raw coriander cleaning from impurities, to reduce weight loss and to maintain quality of coriander essential and fatty oils upon production, to obtain essential oil with improved perfumer properties on the basis of split seeds.

Keywords: Coriander, split seeds, composition of essential oil, oxidation processes, fatty oil, cleaning from impurities, fractionation.

Introduction: Coriander is a grain essential-oil raw material, its seeds are used as spices either for production of essential and fatty oils [2]. The global acreage allotment for this culture is approximately 300-320 thousand hectares, the most part of it is located in Russian Federation, where the main purpose of raw coriander handling is production of essential and fatty oils [4]. In recent decades overall production and handling of coriander reduced considerably [16] thus, at present significant portion of demand of Russian Federation for essential oils and aroma materials, equaling to from 4000 t to 6000 t per year, is imported [1]. Thus, in 2012 the imported amount of essential oils and aroma materials in Russian Federation was US$620 million [1]. Domestic production of essential oils can be increased not only by increase in coriander acreage and increase in productivity of processing facilities but also by improvement of processing efficiency. The main stages of raw coriander processing are its post-harvest handling, distillation of essential oil by water steam and extraction of fatty oil from ester-free coriander [16]. The innovations of post-harvest coriander handling are aimed at achievement of the maximum yield of raw material in terms of targeted components: essential and fatty oils with maximum possible retention of their quality.

Main coriander species cultivated in Russian federation contain, on absolutely dry basis, 1.62-2.40% essential oil and up to 28.5% fatty oil [2]. The properties of current commercial raw coriander vary significantly from properties of raw material processed previously: coriander seeds are smaller in size, which can influence on technological modes of their cleaning, the main component of post-harvest handling. Herewith, the content of essential oil, the main and the most valuable component in current raw coriander, amounts from 1.16% to 2.02% [3].

The composition of coriander essential oil is comprised of about twenty representative components with weight portion in excess of 0.1% and numerous minor components [2, 5-7]. The most valuable component is linalool (3,7-dimethyl-1,6-octadien-3-ol), monoterpene monoatomic tertiary alcohol with lily-of-the-valley odor. According to Russian Standard GOST ISO 3516 the weight portion of linalool in the oil should be at least 65%. Pleasant odor is also peculiar to geraniol (rose odor) and geranyl acetate (bergamot), their content is in the range of several per cents (8).

In addition, coriander essential oil includes compounds the odor of which deteriorates perfumery properties of the product. First of all, it relates to camphor [2, 8, 9], its weight portion is limited by Russian Standard GOST ISO 3516 and should not be higher than 6%. Usual camphor content in oil varies from 4.0% to 4.5%. Another compounds, which impact negatively on the oil odor, are terpene hydrocarbons (also known as turpentinic fraction of coriander oil). Typical example of this wide group of compounds is α-Pinene, the main component of turpentine oil (at least 50.0%) [10] with known peculiar odor. The portion of α-Pinene in coriander oil is usually in the range from 6% to 8%. Another hydrocarbons with similar odor are also present in noticeable amounts: [gamma]-terpinene, camphene, limonene, myrcene, sabinene, as well as aromatic hydrocarbon [para]-cymene. It is known that [para]-cymene is included in biogenetic chain of mutual transformations with [gamma]-terpinene, the portion of which in the oil can reach 7%. [Para]-Cymene accompanies [gamma]-terpinene in numerous essential oils. Increase in content of [para]-cymene leads to corresponding decrease in content of [gamma]-terpinene [11]. Existence of [para]-cymene (more beneficial structure in terms of thermodynamics) in the oil can be related not only with biochemical processes in plant but also with oxidizing and isomerization transformations of terpenes, first of all: [gamma]-terpinene. The odor of [para]-cymene is unpleasant, similar to that of aromatic hydrocarbons, such as toluene abd xylene, and negatively impacts on quality of coriander oil. Under certain conditions all terpene hydrocarbons are readily oxidized, exposed to rearrangements and other transformations [12, 13]

Morphological structure of coriander seeds promotes their separated into two halves (the mericarps)[2, 5, 6]. Ripe seed separated are easily [14], hence, commercial raw material contains significant portion of split seeds –mericarps in glume and mericarps without glume [2, 5]. According to recent experimental data weight portion of split seeds in commercial raw material can reach 28% [3] Essential-oil receptacles are located inside seed on the surface of each mericarp, they are crescent shaped formations with thin porous shell containing essential oil [2, 6]. Upon seed separate the essential oil receptacles move to the surface if mericarps. Their walls are easily damaged upon contact with adjacent seeds, oil pores onto the surface and is evaporated [2, 5, 6]. The extent of losses depends on the portion of damaged, receptacles time, intensity of transfer of processed raw bulks, temperature and other conditions of coriander storage [14]. Intensive ventilation of split seeds with air accelerates evaporation of essential oil, but not the amount of its losses [20]

When a portion of oil is evaporated from split seeds the composition of remaining oil varies. This is related with different volatility of its constituents. Chemical transformations of oil components on developed surface of raw tissues cannot be excluded. The data in [2, 5,15] on variations of oil composition in broken seeds are limited and should be studied in more details. Herewith, it is unclear how composition of essential oil varies upon storage of split seeds and, respectively, influences this positively or negatively on the quality of essential oil from split seeds. Thus, the following tasks were being solved at the first stage of the researches:

- Comparative estimation of yield and analysis of composition of essential oil from whole and split seeds;
- Study of loss dynamics and variation of composition of essential oil from coriander split seeds in laboratory conditions.

Upon post-harvest handling of raw coriander separation of split seeds from whole ones (fractionation) and immediate processing of the split seeds is a disputable item. Some researchers [5, 27, 28] believe that by the time of delivery of raw coriander to processing facilities seed damage and respective loss of essential oil are terminated and separation of split seeds aiming at their immediate processing is unreasonable. Such point of view is based on the obtained data on the fact that instinctive ventilation and drying of split seeds do not lead to additional loss of essential oil but only accelerates its evaporation to the level characteristic to split seeds. Other researchers [14, 19, 29, 31] believe that separation of split seeds upon delivery to processing facilities and their immediate processing would promote elimination of additional loss of essential oil and facilitate improvement of working quality of raw coriander. This opinion is stipulated by the fact that essential oil from split seeds is lost upon long term storage due to its additional evaporation from porous structure of unopened essential oil receptacles upon seed damages [29, 14]. Growth of microflora on split seeds upon storage is more intensive than on whole seeds [31]. Storage (resting) of whole as-harvested dry coriander seeds with moisture weight portion up to 13% promotes completion of oil formation, which makes it possible to increase weight portion of essential oil [19]. Moreover, there are working procedures which can intensify this process, for instance, microwave heating of freshly harvested whole seeds [25]. For whole wet seeds with moisture weight portion higher than 13%, aiming at retention quality of essential and fatty oils upon storage, it is possible to apply convective drying [5] or treatment by propionic acid which also facilitates quality retention of fatty oil in coriander seed [30]. Despite the performed studies, which substantiate reasonability of separation of coriander split seeds, their immediate processing and, vice versa, storage of whole seeds, nowadays the conventional processing is applied when, aiming at production of essential and fatty oils, raw coriander is cleaned and split seeds are not separated but are stored together with whole ones, being processed later [16]. In cleaned raw coriander according to valid Russian Standard GOST 17081 weight portion of impurities should be not higher 2%, and that of split seeds not higher than 15%. While cleaning raw coriander from impurities classifying screens are used with sieving opening of 5 mm, where large impurity are screened, and cleaning sieves with openings of 1.5 mm, where small impurity are separated [24]. The process efficiency, estimated by extraction extent of impurities, is not high and equals according to various sources from 36% to 44% [21] or from 36% to 51% [16] depending on initial state of raw material, applied equipment and cleaning repetitions. Thus, when conventional cleaning procedure of raw coriander is applied, even at two-fold passing through separators the efficiency is low and split seeds are stored together with whole ones. Procedure of simultaneous cleaning of current raw coriander from impurities and fractionation into whole and split seeds is not developed yet. In this regard the second stage of the researches was devoted to development of procedure of cleaning and fractionation of raw coriander, which would permit to improve cleaning efficiency of raw coriander from impurities and to produce fractions of clean whole and split seeds for their subsequent separate processing.

The following tasks were being solved:

- selection of sieve for separation of current raw coriander, cleaned from large impurities into clean whole and split seeds with hard-to-remove and small impurities;
- determination of separation extent by the fraction of whole seeds on the selected sieve;
- determination of optimum parameters of cleaning and fractionation of commercial raw coriander on bench-scale separator.

Experimental

Subject matter and research procedures upon investigation into content and composition of essential oil of split seeds. Samples of five commercial batches of coriander seeds harvested in 2014 in Krasnodar krai and Rostov oblast as well as coriander cropped in 2014 and 2015 on laboratory plots were studied. Samples of two commercial batches were sieved into two fractions: whole seeds and split seeds, containing also split seeds of the hard-to-remove and small impurity and small whole coriander seeds with the size lower than 2 mm. Whole seeds of one commercial batch (sample 5) was separated into mericarps in laboratory for observation of variation dynamics of amount and composition of essential oil upon storage of the fraction of split seeds. Split seeds were stored in thin layer in air. Essential oil was distilled after disintegration of the material.

Variation in the course of ripening of coriander seeds were observed on samples from laboratory plots.

Weight portion of essential oil in raw samples was determined by steam distillation according to Russian Standard GOST 17082.5Mositure content in raw material was determined according to Russian Standard GOST 17082.2.

Experiments were performed on the same facility under the same conditions aiming at comparison of the obtained data. Chromatographic analysis of essential oils was performed according to Russian Standard GOST 14618.5, Russian Standard GOST ISO 7609, Russian Standard GOST ISO 11024-1. The analyses were aided by gas chromatographs with capillary polar and apolar columns. Weight portions were calculated by internal normalization.

Preliminary analysis of essential oils were performed using chromatic mass spectrograph aiming at identification of components. Laboratory experiments were performed three times upon experimental studies.

Statistic data processing was performed according to conventional procedures performing certain parallel measurements [22]. Arithmetic mean value (statistical expectation) of measured X_{mean} and root mean square deviation (S) were determined, then rough errors were detected using τ–criterion. When rough errors were detected, such values were discarded, calculations were repeated and the confidence interval of measured value was determined.

Subject matter and research procedures used upon development of cleaning and fractionation of raw coriander

At this stage a combined sample of commercial raw coriander supplied to the processing facility (OOO Fort, Ust-Labinsk) in 2014 was studied. Average sample was taken from commercial raw coriander [26] its fractional composition was determined. Then whole coriander seeds, half seeds and mericarps without glume were separated.

In order to select sieves for separation of commercial raw coriander into the fraction of whole seeds and the fraction of split seeds with hard-to-remove and small impurity, the values of thickness (diameter) of whole seeds, mericarps in glume and mericarps without glume (kernels) were preliminary determined as their main difference. Averaged sample of 100 pieces was taken from each fraction. Measurements were performed using a DCM-10 microscope.

The separation extent of whole seeds on the selected fractionation sieves was determined by means of the Laplace function:

$$F(z_i) = \frac{2}{2\pi}\int_{-\infty}^{z_i} \mathbf{e}^{\frac{-z^2}{2}}\mathbf{dz} \qquad (1)$$

where $z_i = \dfrac{\bar{X} - X_i}{S}$; X_i is the sieve opening size; $\bar{X}$ is the arithmetic mean size of whole seeds; *F* is the function; *S* is the root mean square deviation of the parameter.

The efficiency of sieve separation (fractionation) depends on numerous factors: sieve opening size, material and design of sieve, dimensions, form of sieve channel and procedure of sieve cleaning, kinematic mode of working unit [17, 23].Thus, optimum separation parameters of commercial raw coriander were determined on laboratory bench-scale separator with the following specifications: electrically driven basket, eccentric vibrator with variable amplitude, sieve working width 0.24 m, sieve length 0.7 m, surface area 0.168 m^2. The bench-scale separator provides possibilities to vary oscillation frequency, specific load, sieve inclination angle and feed rate of separated material.

Optimum separation parameters for cleaning of raw coriander from large impurities were determined using sieve with opening sizes of 5 mm [16], separation of whole seeds was performed with sieve opening sizes determined experimentally, the fraction of broken seeds from hard-to-remove impurities was cleaned in the sieve with opening size of 4 mm, and small impurities were separated on the sieve with the opening size of 1.5 mm. Four factors at two levels were studied: layer thickness of raw material, sieve inclination angle, osccilation amplitude, oscillation frequency. The procedure was performed using sieving of commercial raw coriander with moisture weight portion not higher than 12% upon rectilinear inclined oscillations of sieves. The coefficient of extraction of the fraction of split seeds, or fractionation efficiency*E*, (%), was used as the main response function (optimization parameter). The main optimization parameter *E*was determined as follows [17]:

$$E = \frac{A}{B} \cdot 100\% \qquad (2)$$

Where A is the weight of extracted fraction of split seeds; B is the weight of split seeds in initial mix which can be extracted by this separation procedure.

In order to determine rated separator yield the specific load was preset, kg/(h·cm), per 10 mm of sieve width [24].

Additional data were obtained by means of the index of sieve clogging. The sieve clogging index *K* is defined as the ratio of surface area of clogged sieve openings was F to total surface area of sieve opening F_0 using the equation:

$$K = \frac{F}{F_0} \cdot 100\% \qquad (3)$$

Where F is the surface area of clogged sieve openings, cm^2; F_0 is the total surface area of sieve openings, cm^2.

Optimum parameters were the values of the considered factors at which the fractionation efficiency was maximum and the sieve clogging was minimum.

Results

Composition and content of essential oil in broken seeds

Weight portions of essential oil in various samples of coriander seeds are summarized in Table 1.

Table 1. Weight portion of essential oil in coriander seeds of various batches and fractions.

Sample No.	Batches and fractions	Weight portion of essential oil,%
	Commercial batch 1:	
1	- fraction of whole seeds	1.55
1.1	- fraction of split seeds	0.45
	Commercial batch 2:	
2	- fraction of whole seeds	1.72
2.1	-fraction of split seeds	0.79

3	Commercial batch 3: - combined whole and split seeds	1.30
4	Commercial batch 4: - combined whole and split seeds	0.90
5	Commercial batch 5: - combined whole and split seeds	1.60
5.1 5.2 5.3 5.4 5.5	Broken seeds of batch 5 immediately after breakage, without disintegration Broken seeds of batch 5 after storage in air in: - 1 day - 3 days - 8 days - 17 days	0.98 0.99 0.23 0.20 0.19
6	Whole seeds of the year 2014 from laboratory plot	1.82

The contents of essential oil in commercial batches varied significantly – from 0.90% (sample 4) to 1.72% (sample 2). Herewith, in broken seed the weight portion of oil is by two-three times lower than in whole seeds (0.79% and 1.72% in batch 2; 0.45% and 1.55% in batch 1).

Oil is lost from split seeds mainly by evaporation from destroyed mericarps. Experimental data 5.1 demonstrate that from split seeds immediately after breakage without additional disintegration it is possible to extract more than one half of oil contained in whole seeds. This evidences damages of most essential-oil mericarps upon breakage.

The loss dynamics upon storage of split seeds is reflected in experiments 5.2, 5.3, 5.4, 5.5, Table 1. Intesice oil losses were observed in the first three days. Then the residual content of essential oil gradually stabilized at the level of about 11% of content in initial material. Lower losses in the factions of split seeds of commercial batches 1 and 2 are related, probably, with lower extent of damages of essential-oil mericarps, existence of small whole seeds in these fractions, as well as with different evaporation conditions of oil in dense bulk of raw material.

14 representative components with weight portion higher than 0.26% were identified in essential oil from coriander whole seeds by chromatic mass spectrometry. All identified components are specific to coriander essential oil from ripe seeds. The results of chromatographic analysis of the obtained samples of essential oil using gas chromatography on polar and apolar columns are summarized in Table 2.

Composition of all samples was peculiar to coriander oil. The oil from the considered fractions of split seeds, obtained from commercial raw material, slightly varied from the oil from whole seeds. Slight decrease in weight portion of terpene hydrocarbons can be mentioned together with simultaneous increase in the portion of [para]-cymene, as well as slight decrease in camphor content (Table 2, experiments 1, 1.1 and 2, 2.1).

Table 2. Chromatographic analysis of coriander essential oil.

Sample No.	Type of initial raw material	Weight portion of component in oil,%										[Para]-cymene/ [gamma]- Terpinene ratio
		[beta]-Pinene	Camphene	Myrcene	[para]-Cymene	Limonene	[gamma]-Terpinene	Linalool	Camphor	Geraniol	Geranyl acetate	
1	2	3	4	5	6	7	8	9	10	11	12	13
1	Fraction of whole seeds	7.55	1.20	1.30	0.60	2.70	5.10	65.50	4.35	2.10	3.90	0.118
1.1	Fraction of split seeds	6.20	0.90	1.10	0.70	2.40	5.25	68.00	4.00	2.00	4.00	0.133
2	Fraction of whole seeds	8.40	1.25	1.30	0.55	2.65	5.55	66.50	4.00	2.00	4.20	0.099
2.1	Fraction of split seeds	6.30	1.10	1.20	0.70	2.40	5.80	67.50	3.50	2.10	4.20	0.121
3	Combined whole and split seeds	7.30	1.10	1.30	0.50	2.70	5.70	67.20	4.10	2.20	4.40	0.090
4	Combined whole and split seeds	7.60	1.20	1.20	0.80	2.60	6.90	66.50	4.10	2.20	3.50	0.116
5	Combined whole and split seeds	6.30	1.0	1.0	0.60	2.30	5.40	68.40	4.10	1.80	4.10	0.111
5.1	Broken seeds of sample 5: - immediately after breakage without disintegration	3.80	0.60	0.80	0.50	1.90	4.20	73.60	4.10	2.00	5.00	0.190
	- afterstoragein:											
5.2	- one day	1.95	0.30	0.40	0.30	0.95	2.10	75.40	2.80	4.10	8.35	0.143
5.3	- three days	2.30	0.25	0.30	0.35	0.90	2.20	72.00	2.80	5.80	10.40	0.159
5.4	- eight days	2.50	0.50	0.60	0.60	1.40	3.30	72.70	3.30	4.00	7.05	0.181
5.5	-17 days	3.0	0.50	0.25	0.70	1.50	3.20	71.70	2.90	3.60	6.20	0.220
6	Seeds of the year 2014 from laboratory plot	7.60	1.40	1.30	2.20	2.90	4.50	66.20	4.60	2.00	3.90	0.489
7	Oil of sample 1 after four days of oxidation in air	4.50	0.80	1.10	0.90	2.35	4.30	72.0	4.60	2.20	4.10	0.209

Such trends were obvious upon laboratory studies of loss dynamics of oil from split seeds (experiments 5.1, 5.2, 5.3, 5.4, 5.5, Table 2). Already in several minutes after breakage intensive evaporation of oil was observed, which resulted in predominant loss of the most volatile compounds: hydrocarbons (boiling point from 155°C to 180°C), and the remaining oil was enriched in less volatile linalool, geraniol and geranyl acetate (boiling point 198°C, 230°C, and 245°C, respectively [12, 13; experiment 5.1).

This took place in the first three days of storage, when the oil loss amounted to 85.6%. Herewith, the weight portion of hydrocarbons in the oil retained in freshly split seeds decreased by 3–4 tines, whereas the portion of linalool, geraniol and geranyl acetate increased significantly.

Peculiar behavior of high boiling camphor should be mentioned (boiling point 209°C), its portion did not increase but decreased from 4.1% to 2.8%. Decrease in camphor weight portion together with increase in portion of linalool, geraniol and geranyl acetate could be attributed to lower sorption by seed tissues and ability of camphor to be readily distilled [12, 13].

Further storage of split seeds was characterized by minor losses of oil (from 86% to 90%) with predominant loss of semi-volatile components, their weight portion in retained oil approached 90%. This corresponds to total regularities of evaporation of organic solutions, when partial vapor pressure of single component is determined not only by its volatility but also by mole portion in the solution. Lower loss of [para]-cymene in comparison with other hydrocarbons is of peculiar concern. It weight portion in the first three days decreased by 42%, then it started to increase exceeding the initial value by 16% after 17 days of storage. This confirmed the assumption that [para]-cymene, being more beneficial in terms of thermodynamics, is formed upon storage as a consequence of oxidation of hydrocarbons, most probably of [gamma]-terpinene, by aor oxygen [12]. Increase in content of [para]-cymene resulted in respective decrease in content of [gamma]-terpinene, and the [para]-cymene/[gamma]-terpinene ratio constantly increased in time (Table 2, samples 5.2, 5.3, 5.4, 5.5). Formation of [para]-cymene upon oxidation of [gamma]-terpinene was observed also upon storage of oil sample in experiment 1 in thin layer, in sunlight, in unsealed container (Table 2, sample 7). After four days of storage the [para]-cymene/[gamma]-terpinene ratio increased by two times in comparison with that in initial oil. Studies upon development of fractionation procedure of whole and split seeds. Fractional composition of commercial raw material, preliminary cleaned from large impurities on sieve with opening size of 5 mm and used for further experiments, is summarized in Table 3.

It follows from Table 3 that the fraction of split seeds is comprised of mericarps in glume and essential-oil impurity, which in its turn is comprised if mericarps without glume (kernels), small unripe, smashed, blackened seeds. This fraction after cleaning can contain a portion of weeds of the same size as main components of the fraction of split seeds.

Table 3. Composition of commercial raw coriander.

Fraction	Weight portion of the fraction,%
Whole seeds	62.7
Whole seeds with the diameter less than 2 mm	4.6
Mericarps inglume	11.8
Impurities of this plant	10.4
Impurities, including	10.5
- of the same size as cleaned raw material and hard-to-remove	4.0
- small, passing through 1.5 mm sieve	6.5

Arithmetic mean value (L, mm) and root mean square deviation (S) were determined for the fraction of coriander whole seeds, as well as mericarps and mericarps without glume, which together form the fraction of split seeds. The obtained data are summarized in Table 4.

Table 4. Thickness of components of commercial coriander mix.

Components of commercial coriander mix					
whole seeds		half seeds		half seeds without glume	
L, mm	S	L, mm	S	L, mm	S
2.55±0.05	0.29	1.23±0.02	0.14	0.98	0.09

Thickness variation curves of coriander whole seeds, mericarps in glume and mericarps without glume (kernels) are illustrated in Fig. 1.

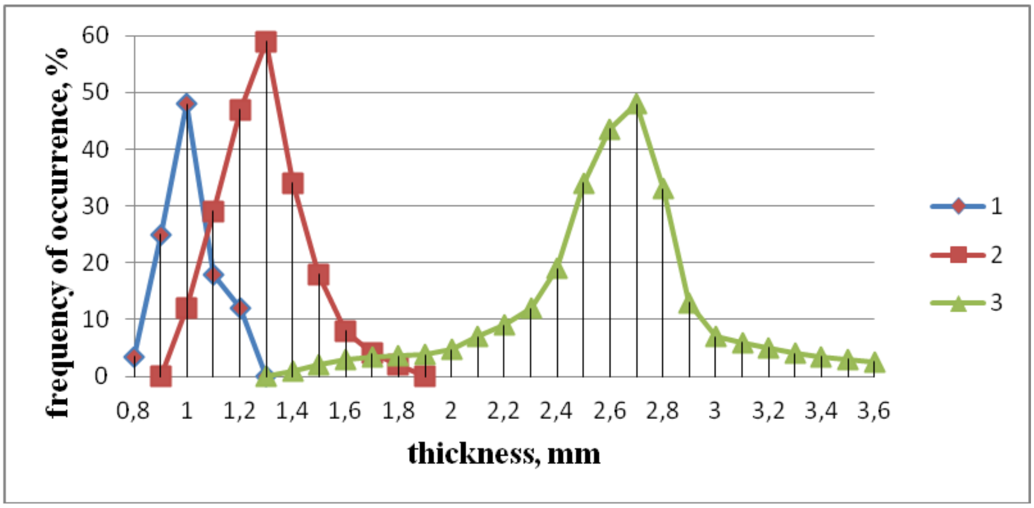

Fig. 1. 1 - Half seeds without glume; 2 - Half seeds in glume; 3 - Whole seeds.

As can be seen in Fig. 1, the considered thickness areas are overlapped. Herewith, the thickness of mericarps without glume (kernels) is not higher than 1.3 mm, and that of i mericarps n glume is not higher than 1.9 mm. The value 2.0 mm is peculiar only to whole coriander seeds.

The extent of separation of the mix into thickness fractions depends on sieve opening size selected in accordance with the sizes of separated components. It is also known that the fractions of raw seeds can be separated by thickness using sieves with rectangular openings [17]. Selection of sieves with rectangular openings demonstrated that whole seeds can be separated from split ones on sieves with rectangular openings 2 mm×20 mm. Then the coefficient of extraction of the fraction of whole seeds on selected sieve was calculated using normalized Laplace function with the following parameters of separation: X_i= 2.0 mm; $\bar{X}$ = 2.55 mm; S = 0,29.

Substituting these values into Eq. (1) we obtain z_i= 1.9. According to the table [18] for such value of z_i the extraction coefficient of the fraction of whole seeds is sufficiently high and for commercial coriander mix it equals to 0.9472. The obtained coefficient is slightly less than unity, which is stipulated by existence of unripe seeds with the size of less than 2 mm in the initial mix, nevertheless. the selected sieve can be efficiently applied for extraction of the fraction of whole seeds from commercial mix of raw coriander. Determination of optimum parameters of separation of commercial raw coriander demonstrated that at maximum extraction coefficient of the fraction of split seeds of 96.1% and sieve clogging of 9.1% the optimum parameters of the considered factors were as follows: oscillation frequency of sieve basket -- 400 vibrations per minute; oscillation amplitude of sieve basket -- 8 mm; sieve inclination angle -- 8°; raw material layer thickness -- 5 mm.

These optimum parameters of fractionation were used for obtaining of the fraction of whole seeds and the fraction of split seeds, their compositions are summarized in Table 5.

Table 5. Component composition of extracted coriander fractions.

Components of commercial raw material	Weight portion of components, wt %		
	in initial raw material	extracted fractions	
		whole seeds (weight portion 64.2%)	split seeds (weight portions 35.8%)
Whole seeds with diameter not less than 2 mm	62.7	97.6	-
Whole seeds with diameter less than 2 mm	4.6	-	12.9

Mericarps	11.8	1.5	30.3
Impurities of this plant	10.4	-	29.0
Impurities, including:	10.5	0.9	27.8
- hard-to-remove and of the same size as cleaned raw material	4.0	0.9	9.5
- passing through 1.5 mm	6.5	-	18.3

The fraction of whole seeds contains minor content of mericarps in glume (1.5%), which is 8.2% of that in initial raw material. Hence, the fractionation efficiency in terms of mericarps in glume is 91.8%.

Impurities content in the fraction of whole seeds is 0.9% or 5.5% of that in initial raw material. hence, the cleaning efficiency in terms of weeds is 94.5% .

High content of impuritiesin the fraction of broken seeds should be mentioned, it confirms reasonability of its further cleaning which can be performed on sieves with opening size of 1.5 mm according to common approach. Laboratory cleaning of the fraction of broken seeds on sieves with opening size of 4 mm and 1.5 mm demonstrated that total cleaning efficiency of the fraction of split seeds from impurities is 61.4%.

Discussion

Discussion of study of content and composition of essential oil from split seeds

It follows from the performed analytical and experimental studies of the first stage that separation of coriander from commercial mix and storage without split seeds would provide decrease in production losses of essential oil and limit undesired increase in [para]-cymene content in its composition, related with oxidizing processes upon storage of split seeds. Moreover, essential oil from the fraction of freshly split seeds can be considered as specific type of coriander oil with improved perfumeryproperties, which is related with increased content of components with flowery odor (linalool, geraniol, geranyl acetate) and low content of camphor and hydrocarbons. In this regard the oil from freshly split seeds is more valuable and can be applied for composition correction of coriander essential oil aiming at increase in linalool content and decrease in contents of hydrocarbons and camphor, as well as for extraction of valuable components: linalool and geraniol by means of vacuum rectification. The obtained data are an additional argument of substantiation of the necessity to fractionate raw coriander into whole and split seeds with their immediate processing. The most reasonable approach is to fractionate raw coriander into whole and split seeds immediately after supply of raw material to processing facility simultaneously with the initial procedure of post-harvest handling: cleaning from weeds.

Discussion of development of cleaning and fractionation procedure of raw coriander

On the basis of the performed studies we developed the innovative procedure of step-by-step cleaning of current raw coriander from impurities together with similar fractionation into whole and split seeds. The procedures is comprised of cleaning of raw coriander from large impurities and fractionation into cleanwhole coriander seeds and split seeds with hard-to-remove and small impurities at the first stage and subsequent cleaning of split seeds from impurities at the second stage. Current raw coriander can be cleaned from large impurities using sieve with opening size of 5 mm [16]; it was established experimentally that fractionation into whole and split seeds can be performed using sieve with rectangular opening 2 mm×20 mm; at the second stage cleaning from hard-to-remove impurities sieve with opening size of 4.0 mm was applied, and small impurities were separated on sieve with opening size of 1.5 mm [16].

The efficiency of fractionation into whole and broken seeds according to the developed procedures is 91.8%, and cleaning efficiency of raw coriander from impurities is significantly higher in comparison with conventional approaches and equals to 94.5% for whole seeds and 61.4% for split seeds. Optimum modes of cleaning and fractionation of commercial raw coriander are determined which provide the mentioned efficiency.

In order to implement the developed innovative procedure on commercial scale it is required to replace sieves in the existing separators and to redistribute flows of raw material instead of replacement of major equipment for post-harvest handling.

Conclusions

Therefore, on the basis of generalized results of the analytical and experimental studies the innovative procedure of post-harvest handling of raw coriander has been proposed, illustrated in Fig. 2.

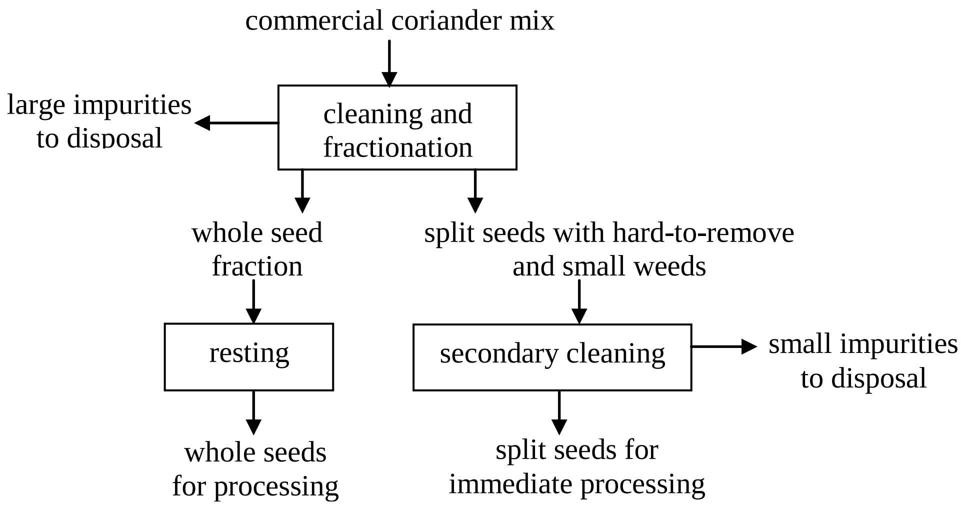

Fig. 2. Flowchart of post-harvest handling of raw coriander.

The flowchart is comprised of the following stages of post-harvest handling of commercial raw coriander:

- raw material supplied for handling is cleaned from large impurities to be disposed;

- thus cleaned raw material without large impurities is fractionated with obtaining of fraction of whole seeds and fraction of split seeds with hard-to-remove and small impurities

- the faction of whole seeds with moisture content of up to 13 wt% is transferred for resting and completion of oil formation, and that with moisture content in excess of 13 wt% can be stored up to handling after treatment by propionic acid;

- the fraction of split seeds is cleaned from hard-to-remove and small impurities and supplied to handling without intermediate storage.

Sieve sizes and modes of separation of commercial raw coriander are determined for the developed procedure.

The developed procedure in comparison with conventional one is characterized by the following advantages:

- it facilitates efficient separation of initial raw coriander into tow fractions: whole and split seeds with various working quality, thus creating backgrounds for optimization of their subsequent storage and handling;

- it improves efficiency of cleaning of raw coriander from impurities by from 36% to 51% in terms of total raw material: up to 91.8% for whole seeds and up to 61.4% for split seeds;

- it significantly reduces losses of coriander essential and fatty oils during production;

- it facilitates obtaining of essential oil with higher linalool/camphor and linalool/hydrocarbons ratio from split seeds.

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