Removal of sea buckthorn (*Hippophae rhamnoides* L.) berries by shaking

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Mann, D.D., Petkau, D.S., Crowe, T.G. and Schroeder, W.R. 2001. **Removal of sea buckthorn (*Hippophae rhamnoides* L.) berries by shaking**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada. **43**: 2.23 - 2.28. Mechanical harvesting equipment is being developed for sea buckthorn (*Hippophae rhamnoides* L.) berries. Tests were conducted using a branch shaker to determine whether berries of the 'Indian Summer' cultivar could be removed by shaking. Combinations of shaking frequency (7.7, 10.9, 14, 20, and 25 Hz) and shaking amplitude (13, 19, 25, and 32 mm) were tested at four harvest dates (September 28, 1999; October 13-14, 1999; November 2-3, 1999; and January 13-14, 2000). Berries removed by shaking were counted following two 15-s shaking episodes. Frequencies @14 Hz were ineffective at removing > 50% of the berries regardless of amplitude. At frequencies of both 20 and 25 Hz, the percentage of berries removed by shaking increased linearly with increasing amplitude. The combination of 25 Hz and 32 mm produced the best result during the November harvest date when 98% of the berries were removed within 15 s of shaking. During the January test, the branches were brittle and many broke when shaken at 25 Hz. The percentage of berries removed during two consecutive 15-s shaking episodes was not significantly greater than the percentage of berries removed during a single 15-s shaking episode (Student's t-test, ? = 0.05). **Keywords:** sea buckthorn, shaking, berry, harvesting.

Des équipements pour mécaniser la récolte des baies de l'argousier (*Hippophae rhamnoides* L.) sont en développement. Des tests ont été faits avec un secoueur de branches afin de déterminer si les baies du cultivar 'Indian Summer'pouvait être enlevées de cette façon. On a testé des combinaisons de fréquence (7.7, 10.9, 14, 20 et 25 Hz) et d'amplitude de secousse (13, 19, 25 et 32 mm) durant quatre périodes de récolte (28 septembre 1999; 13-14 octobre 1999; 2-3 novembre 1999; et 13-14 janvier 2000). Les baies qui étaient tombées après l'application de deux secousses de 15 s furent comptées. A des fréquences inférieures à 14 Hz, moins de 50% des baies tombèrent, quelle que soit l'amplitude. A des fréquences de 20 et 25 Hz, le pourcentage de baies enlevées en secouant la plante augmenta de façon linéaire avec l'amplitude. Les meilleurs résultats furent obtenus en novembre avec une combinaison de 25 Hz et 32 mm, lorsque 98% des baies furent enlevées après une secousse de 15 s. Durant les tests de janvier, les branches étaient cassantes et plusieurs brisèrent après avoir été secouées à 25 Hz. Le pourcentage de baies enlevées après deux secousses consécutives de 15 s n'était pas significativement différent du pourcentage enlevé après une seule secousse (test de Student, ?=0.05). **Mots clés**: argousier, secousse, baie, récolte.

INTRODUCTION

Sea buckthorn (*Hippophae rhamnoides* L.) is a deciduous shrub (usually 2 - 4 m in height) that produces orange or yellow berries (Fig. 1). Blahovec et al. (1995) measured berry masses ranging from 0.20 - 0.35 g and berry diameters ranging from 5 - 8 mm. The berries tend to be soft at the time of picking. This hardy shrub, native to Europe and Asia, has been used for centuries for its environmental, nutritional, and medicinal values (Li and Schroeder 1996). The interested reader is directed to Li and Schroeder (1996) for a detailed review of sea buckthorn. The Shelterbelt Centre of the Prairie Farm Rehabilitation Administration (PFRA) of Agriculture and Agri-Food Canada (Indian Head, SK) has been growing and distributing sea buckthorn seedlings for over 30 years for prairie conservation programs. The recent interest in sea buckthorn is due to the nutritional and medicinal value of the berries. For example, it has been shown that the oil from sea buckthorn berries inhibits platelet aggregation in humans (Johansson et al. 2000).

Fig. 1. A sea buckthorn shrub of the 'Indian Summer' cultivar (K30 years old) located at the PFRA shelterbelt Centre of Agriculture and Agri-Food Canada (Indian Head, SK), September 1999.

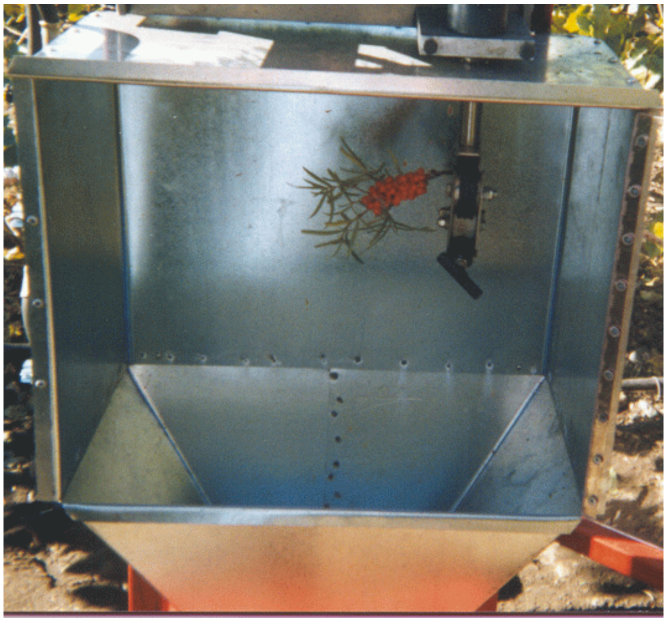

Fig. 2. Mechanism to shake the severed sea buckthorn branches in the vertical direction. As the berries became detached, they were collected in a plastic bag located at the bottom of the hopper.

Unfortunately, it is difficult to harvest the sea buckthorn berry because it does not readily form an abscission layer and the fruit is tightly clustered on two- or three-year old, thorn-covered branches (Li and Schroeder 1996). In Asia, harvesting is done manually or with the use of simple, hand-held tools. Manual harvesting, however, requires approximately 1500 h of human labour for every hectare of orchard (Gaetke and Triquart 1993). The costs associated with manual labour and the problems associated with recruitment and management of picking staff suggest that manual harvesting of sea buckthorn berries is not a viable option in North America.

Mechanical fruit harvesters can be classified as either direct harvesters or indirect harvesters (Olander 1995). A direct harvester relies on direct contact with the fruit, while an indirect harvester causes the fruit to be removed without physically touching it. Direct harvesters can be very effective at removing the fruit, but they usually damage either the fruit or other parts of the plant, or both. Robotic harvesters can reduce fruit damage, but they tend to be slow (Olander 1995). Indirect harvesting is usually accomplished by shaking a portion of the plant. Forces applied to either the trunk, branch, or foliage of the plant cause the fruit to be detached from the stem. Harvesters may also use a combination of direct and indirect techniques.

Attempts at harvesting sea buckthorn berries have typically experienced problems of fruit damage, bark damage, and low efficiency. The concepts that have been tried include tree shakers (Gaetke et al. 1991), vacuum suction units (Varlamov and Gabuniya 1990), quick freezing units (Wegert and Wolf 1990; Gaetke and Triquart 1993), and "whole branch harvesters" (Gaetke and Triquart 1992; Olander 1995). Although several concepts have been tried, shaking is a common theme. For example, quick freezing units were used to freeze the berries so that they would be easier to remove by shaking. The best results were observed when the entire branches were removed and frozen at -36˚C (Wolf and Wegert 1993). Following this treatment, the berries were removed by beating the branches. "Whole branch harvesters" have been developed based on the hypothesis that it is possible to expose every part of the branch to the same vibration if only a small portion of the branch is being shaken (Olander 1995). Thus, "whole branch harvesters" also rely on shaking for removal of the berries.

One disadvantage of "whole branch harvesters" is that a fruit crop can only be harvested on a biannual basis because sea buckthorn fruit is only produced on the previous years' growth of wood. There is incentive, therefore, to develop a harvester that will permit annual fruit harvest. Although a trunk shaker would allow the entire bush to be harvested at one time, trunk shakers are only effective for bushes that have one central trunk with short branches. Bushes with long, slender branches are more difficult to harvest by shaking the trunk because much of the energy is lost before it reaches the berries (Olander 1995). Bantle et al. (1996) showed that a foliage shaker is appropriate for some fruit crops native to Saskatchewan (i.e., saskatoon, choke cherry, and pin cherry) using vibration frequencies above 10.9 Hz and vibration amplitudes above 19 mm. The sea buckthorn shrub has somewhat similar structure to saskatoon, choke cherry, and pin cherry.

There have been some attempts at harvesting sea buckthorn berries by shaking, with mixed results. Stan et al. (1985) used a black currant harvester to test seven cultivars of sea buckthorn. Only one cultivar could be successfully harvested with a vibration frequency of 18.5 Hz and an amplitude of 25 mm. Gaetke et al. (1991) tested the sea buckthorn cultivar 'Hergo' at three different frequencies (20, 25, and 30 Hz) and three different amplitudes (13, 18, and 25 mm). At an amplitude of 25 mm, a frequency of 25 Hz was required for adequate removal. At smaller amplitudes, a frequency of 30 Hz was required. A Swedish prototype was tested with amplitudes of 40 and 55 mm at frequencies up to 25 Hz (Olander 1995). For some cultivars, the harvesting results were acceptable. In other cases, the berries burst, leaving the skins on the branch.

Although there is some evidence to suggest that sea buckthorn berries can be removed by shaking, there appears to be great variability among different cultivars. Research at the PFRA Shelterbelt Centre (Indian Head, SK) has identified 'Indian Summer' as the cultivar of choice for fruit production in western Canada based on harvest yield (unpublished data). The objective of this research, therefore, was to investigate the possibility of removing berries of the 'Indian Summer' sea buckthorn cultivar by shaking.

MATERIALS and METHODS

Design of branch shaker

The branch shaker was designed to shake short pieces of fruit-laden branches that were severed from the shrub (Fig. 2). The branch shaker consisted of a hydraulically-powered slider-crank mechanism, with a rubber-lined clamp attached to the slider (Fig. 3). The slider functioned as a reciprocating body with a mass of 3.4 kg. The amplitude of motion could be varied from

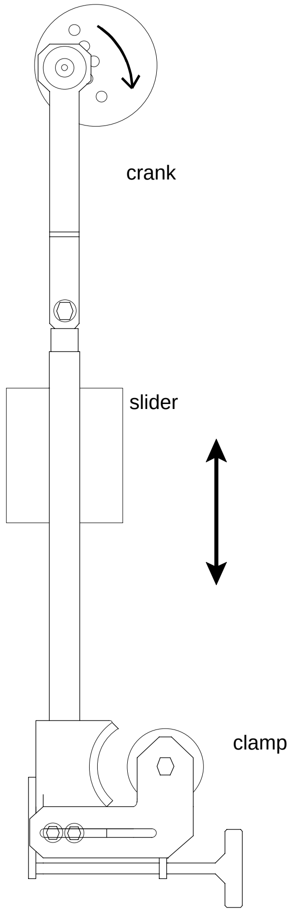

Fig. 3. Schematic diagram of the slider-crank mechanism used to shake the fruit-laden sea buckthorn branches. The severed branches were held with the clamp attached to the end of the slider

6.4 to 44.5 mm by changing the eccentricity of the crank. Hereafter, the term “amplitude” refers to the eccentricity of the crank. No attempt was made to measure the total travel at the clamp. A magnetic velocity pickup was installed on the rotating shaft to obtain accurate rotational speed readings. The mechanism was calibrated for operating speeds up to 35 Hz.

The entire shaking apparatus was oriented in the vertical direction, with the clamp inside an open-bottomed hopper (Fig. 2). The branches were shaken inside the hopper, and the berries were collected as they dropped through the opening at the bottom.

Experimental design

Initially, four amplitudes (13, 19, 25, and 32 mm) and four frequencies (7.7, 10.9, 14, and 20 Hz) were selected for testing, but a frequency of 25 Hz was later added due to poor results during the initial harvesting trials. This resulted in either 16 or 20 combinations of amplitude and frequency to be tested for each harvest date. A new branch was pruned from a shrub for each combination of amplitude and frequency tested. Replication was achieved by testing branches from four separate shrubs. Branches were randomly selected from the four shrubs, but an equal number were selected from the east and west sides. The entire testing procedure was repeated for four harvest dates (September 28, 1999; October 13-14, 1999; November 2-3, 1999; and January 13-14, 2000). All of the testing was conducted with the ‘Indian Summer’ sea buckthorn cultivar using approximately 25 year-old shrubs located at the PFRA Shelterbelt Centre in Indian Head, SK. ‘Indian Summer’ is a cultivar of sea buckthorn that originated from a hedge of clonally-propagated female plants at the PFRA Shelterbelt Centre (Li and Schroeder 1999). The shrubs used in this research were similar in appearance to those depicted in Fig. 1.

Experimental procedure

Once the appropriate frequency and amplitude were set, a severed branch was clamped into place. The end of the branch with the berries was left unconstrained so that it could vibrate freely. The severed branches ranged from approximately 125 to 300 mm in length. The severed branch was shaken at the prescribed amplitude and frequency for two periods, each 15 s in duration. All shaking was done outdoors under ambient conditions. After each of the two shaking periods, the berries removed by shaking were emptied from the collection hopper into a separate plastic bag. After being exposed to both shaking periods, the severed branch and any berries remaining on the branch were stored in a third plastic bag. After labelling, the bags containing the samples were frozen as quickly as possible to prevent moisture loss. The number of berries in each sample bag was counted in the laboratory. The percentage of berries removed was calculated based on the number of berries removed from each severed branch.

RESULTS

Percentage of berries removed during 15 s of shaking

The number of berries per branch ranged from 8 to 151, with an average of 53 (S.D. = 24). Table 1 presents the percentages of berries removed (mean and standard deviation of four replicates) when the severed branches were shaken for 15 s. At frequencies ≤ 14 Hz, it was not possible to remove more than 44% of the berries. In many cases, the percentage of berries removed was less than 10%. It was concluded, therefore, that frequencies ≤ 14 Hz are ineffective regardless of the shaking amplitude (within the range of 13 to 32 mm) or the date of harvest.

The results improved for all harvest dates when a shaking frequency of 20 Hz was used, however, harvesting in either September or October was still considered unacceptable because < 50% of the berries were removed (with one exception: 25 mm amplitude in September) (Table I). In November, amplitudes of both 25 and 32 mm removed more than 50% of the berries. The best result was observed in January when 84% of the berries were removed using a shaking amplitude of 32 mm. The percentage of berries removed by shaking increased linearly with increasing amplitude for both the November and January harvest dates (Fig. 4).

Although January appeared to be the best time to harvest sea buckthorn berries using a shaking frequency of 20 Hz, the same results were not obtained when a shaking frequency of 25 Hz was used (Fig. 4). For the November trial, the percentage of berries removed by shaking increased linearly with increasing

Table 1. Percentage (%) of sea buckthorn berries (mean and standard deviation based on four replicates) removed from a severed branch by shaking during a 15-s shaking episode.

Test Date	Amplitude (mm)	Frequency (Hz)				
		7.7	10.9	14	20	25
September	13	1 (1)	3 (5)	1 (2)	3 (4)	no data
	19	3 (3)	2 (2)	5 (11)	25 (40)	no data
	25	2 (2)	3 (2)	2 (2)	68 (31)	no data
	32	2 (1)	5 (6)	18 (18)	49 (41)	no data
October	13	1 (1)	3 (5)	2 (2)	0 (1)	no data
	19	3 (7)	1 (1)	20 (22)	17 (10)	no data
	25	3 (5)	4 (9)	6 (7)	39 (41)	no data
	32	1 (3)	7 (8)	17 (6)	29 (24)	no data
November	13	1 (3)	1 (1)	6 (5)	6 (9)	11 (4)
	19	0 (0)	2 (1)	7 (11)	14 (15)	33 (23)
	25	1 (2)	1 (3)	12 (18)	53 (34)	52 (22)
	32	3 (6)	1 (3)	44 (35)	55 (48)	98 (3)
January	13	3[a]	8 (11)	3 (3)	45 (36)	42 (33)
	19	2[a]	1 (1)	21 (27)	63 (32)	40 (43)
	25	0[a]	18 (20)	28 (40)	51 (38)	49 (57)
	32	0[a]	26 (35)	37 (37)	84 (15)	43 (51)

[a] Only 1 replicate was done.

amplitude (Fig. 4). At an amplitude of 32 mm, 98% of the berries were removed (Table 1). In January, however, the percentage of berries removed by shaking was constant at approximately 45% for all four amplitudes tested (Fig. 4). It is speculated that the branches were brittle due to the low ambient temperatures on the January harvest dates (daily maximum temperature was -15˚C; daily minimum temperature was -30˚C). When the brittle branches were shaken at a frequency of 25Hz, many of them broke during the first few cycles of the shaker before the berries could be removed from the branches.

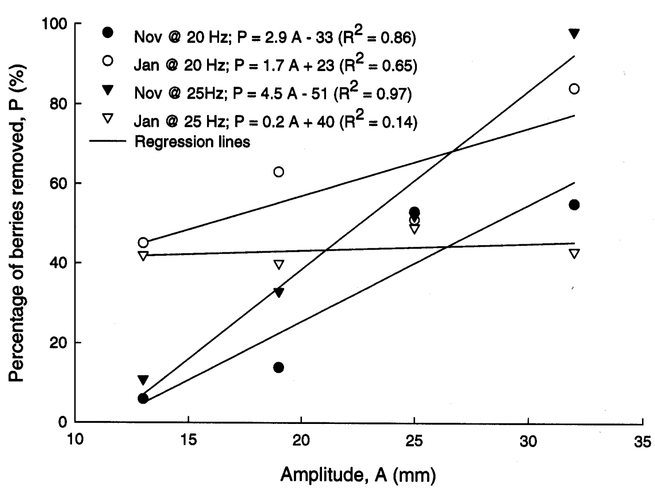

Fig. 4. Percentage of berries removed in both November and January when shaken for 15 s at 20 and 25 Hz using amplitudes of 13, 19, 25, and 32 mm.

Percentage of berries removed during 30 s of shaking

Table 2 presents the percentages of berries removed (mean and standard deviation of four replicates) when the original branches were shaken for an additional 15 s (i.e., the branches were exposed to 30 s of shaking). When compared with the results following 15 s of shaking, the same general trends were observed. Shaking frequencies ≤ 14 Hz were ineffective regardless of shaking amplitude or harvest date (Table 2). The results improved using a shaking frequency of 20 Hz, however, the best result was observed during the November harvest date using a shaking frequency of 25 Hz and a shaking amplitude of 32 mm. For this combination of factors, 99% of the berries were removed (Table 2).

There were no significant differences between the percentages of berries removed during shaking periods of 15 and 30 s at 25 Hz for any of the amplitudes tested in November (Student's t-test, α = 0.05). Consequently, there was no statistical evidence to warrant shaking beyond 15 s. In fact, there is limited evidence to suggest that the required shaking duration may be < 15 s. We visually observed that, for some trials, most of the berries were removed during the first few cycles of the shaker. Without data to confirm this observation, we recommend that further studies should be conducted to determine whether berry removal could be improved by subjecting the samples to several start-stop cycles of short duration.

DISCUSSION

The results presented in the previous section do not conclusively identify an optimum shaking frequency or shaking amplitude, however, there are several trends which emerge. First, shaking frequency has an obvious effect. At frequencies ≤ 14 Hz, very few berries are removed regardless of the shaking amplitude used or the harvest date. At frequencies ≥ 20 Hz, increasing numbers of berries are removed. Of the frequencies tested, 25 Hz produced the best results. It would be interesting to see whether this increasing trend continues for frequencies > 25 Hz.

The second trend which emerges is related to harvest date. During September and October, the results were generally poor. Despite exposure to light frost (i.e., the average minimum temperatures for the 3 days prior to testing were -1.3 and -3.0˚C for September and October, respectively), it is likely that the berries had not reached their optimum maturity. Although sea

Table 2. Percentage (%) of sea buckthorn berries (mean and standard deviation based on four replicates) removed from a severed branch by shaking during two consecutive 15-s shaking episodes.

Test Date	Amplitude (mm)	Frequency (Hz)				
		7.7	10.9	14	20	25
September	13	2 (2)	3 (5)	1 (2)	9 (7)	no data
	19	3 (4)	4 (6)	7 (11)	35 (40)	no data
	25	3 (2)	3 (2)	5 (5)	80 (27)	no data
	32	3 (3)	6 (7)	25 (25)	53 (43)	no data
October	13	1 (1)	5 (7)	2 (3)	6 (9)	no data
	19	4 (9)	3 (3)	26 (29)	32 (18)	no data
	25	3 (5)	10 (19)	11 (12)	79 (34)	no data
	32	3 (4)	13 (17)	42 (33)	46 (28)	no data
November	13	1 (3)	1 (1)	10 (9)	13 (22)	17 (6)
	19	0 (0)	3 (1)	7 (11)	29 (33)	48 (33)
	25	1 (2)	1 (3)	19 (29)	68 (36)	61 (30)
	32	6 (7)	7 (5)	58 (38)	61 (42)	99 (1)
January	13	3[a]	10 (11)	12 (13)	46 (34)	48 (39)
	19	2[a]	3 (6)	22 (28)	66 (33)	42 (42)
	25	0[a]	19 (19)	43 (38)	54 (39)	49 (57)
	32	0[a]	40 (29)	41 (39)	85 (15)	45 (52)

[a] Only 1 replicate was done.

buckthorn berries tend to remain attached to their branches into winter (Li and Schroeder 1996), Blahovec et al. (1995) observed that detachment force decreased as berry maturity increased. In January, the brittleness of the branches became a limiting factor at a frequency of 25 Hz. Overall, the best results were obtained in November when the branches were subjected to overnight lows of approximately -8˚C (note: the maximum daily temperature was approximately 10˚C).

A third trend is that the percentage of berries removed by shaking in November increased linearly with increasing amplitude for frequencies of both 20 and 25 Hz (Fig. 4). Increasing the frequency from 20 to 25 Hz increased the slope of the line. Consequently, the experimental evidence indicated that virtually all berries can be removed when shaken with a frequency of 25 Hz and an amplitude of 32 mm at the correct stage of maturity.

The final trend that was observed relates to the duration of shaking. There is no statistical evidence to suggest that shaking for 30 s is better than shaking for 15 s. In fact, it was visually observed during the experiments that many of the berries were removed during the first few cycles of the shaker. Consequently, shaking for even 15 s may not be necessary.

FUTURE WORK

The research described in this paper was the preliminary step towards the development of mechanical harvesting equipment for sea buckthorn berries. Shaking is often used to harvest berries, but it was unclear whether sea buckthorn berries of the cultivar ‘Indian Summer’ could be removed by shaking. Based on the trends observed during this laboratory-based study, development of a full-size shrub-shaking device is in progress.

CONCLUSIONS

Sea buckthorn berries of the ‘Indian Summer’ cultivar can be removed from branches by shaking, although a frequency of at least 20 Hz must be used to remove in excess of 50% of the berries. At frequencies of both 20 and 25 Hz, the percentage of berries removed increased linearly with increasing amplitude. Of the frequencies and amplitudes tested, the combination of 25 Hz and 32 mm produced the best result during the November harvest date when 98% of the berries were removed within 15 s of shaking. When the same combination of frequency and amplitude was tested in January, many of the branches broke before the berries could be removed. Harvesting in January is likely to cause substantial damage to the shrubs and, therefore, should not be attempted. Based on the experimental results, there was no statistical evidence to warrant shaking beyond 15 s.

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